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Harnessing the promise of floating solar photovoltaics in sustainable energy revolution

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Editorial

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Abstract

Solar photovoltaic (PV) technology is one of the most widely used renewable energy sources, generating electricity without producing greenhouse gas emissions. Over the past few decades, PV technology has seen widespread adoption due to technological advancements and continuously reducing costs. Traditionally, PV panels are mounted on terrestrial installations, including rooftops, agricultural fields and utility-scale solar farms. Although terrestrial PV systems perform well and are relatively scalable, they are still facing problems with land use and environmental pollution. As a result of these constraints, floating solar photovoltaic (FPV) systems have come to the fore as a viable alternative. Aquatic systems, such as lakes, reservoirs and coastal areas, can effectively utilise their surface area for the deployment of solar energy panels. This will also help to reduce land cost and water evaporation and improve overall energy efficiency, among other advantages. FPVs also have the potential to diversify and fulfil energy requirements since they liberate property in populated regions for additional crop usage. Thus, the potential scalability of FPVs is also extremely relevant towards climate and energy security objectives. FPV is still a new concept requiring thorough feasibility and performance-degradation studies to improve its uptake.

Impact statement

To combat climate change and ensure energy security, the global community must transition to renewable energy sources. A transformative innovation in this transition is floating solar photovoltaic (FPV), an eco-friendly technology that enhances the utilisation of land and water resources while optimising solar energy production. FPV enhances energy production by using the cooling properties of water and mitigates land constraints by utilising underutilised aquatic environments, hence improving photovoltaic efficiency. Additionally, FPV systems safeguard aquatic ecosystems, reduce water evaporation and may be integrated with hydropower projects to enhance grid stability. Their adoption might significantly facilitate the decarbonisation process, particularly in regions with elevated energy demand or constrained land availability. The extensive use of FPV can catalyse economic growth by fostering technological advancements, creating green jobs and attracting investments in renewable energy infrastructure. To achieve its full potential, collaboration among governments, corporations and environmental stakeholders is essential, alongside investment in research and development and the endorsement of strategic policies. Harnessing the potential of FPVs is not only an innovative concept; it is crucial for propelling the global sustainable energy revolution and ensuring a future that is cleaner, more resilient and energy-secure.

Literature review

Traditional photovoltaic (PV) systems have been the subject of extensive studies and implementations around the world. These systems displace fossil fuel use by producing energy directly from sunlight by means of solar panels placed on the ground or rooftops. The twin forces of industrialisation and globalisation have given land scarcity and driven land values much higher. It is, hence, challenging to configure extensive ground-based solar facilities due to limited available land. As the demand for renewable energy increases, new techniques for PV generation are researched, and one such innovation is the floating solar photovoltaic (FPV) system.

FPV systems have several advantages over conventional ground-based PV systems. One major advantage is the conservation of land as FPVs can generate solar energy without occupying land. This land can be used for farming or human settlement (Benjamins et al., 2024). As FPV modules are floated on water, they operate with higher efficiency due to the cooling effect of water (Sukarso and Kim, 2020). Kjeldstad et al. (2021) showed that besides water temperature, wind speed can also contribute to reduce FPV panel temperature. FPV systems are also very efficient for water conservation as they lower evaporation by covering the water surface (Agrawal et al., 2022). Lytopoulos and Xydis (2025) found that covering just 5% of the artificial lakes of Greece will generate 2,245 GWh of energy, which will save 1.93 million tons of CO_2. Additionally, the integration of the FPV systems with hydropower units could guarantee more stable and efficient generation of energy, and it could create synergies between renewable sources (Lee et al., 2020). Recent advancements in FPV technology, particularly for mounting systems, anchoring technologies and hybrid energy systems, have also helped to enhance the position of FPVs in the global power matrix. Over the years, floating structures have evolved, consisting of various floater materials (e.g. concrete and metal) and designs intending to enhance the systems' stability under diverse water conditions (Oliveira-Pinto and Stokkermans, 2020). Dynamic anchoring techniques have been developed to keep the system stable because water levels can be variable. Moreover, hybrid systems of FPV with energy storage devices and hydropower plants are also being explored for reliable energy supply and efficient grid integration (Mishra et al., 2023). These developments help in improving the overall uptime and efficiency of FPV installations. FPV also plays a role in sustainable energy generation and outcomes for multiple environmental, social and economic challenges that are part of the sustainable development goals (SDGs).

SDG 7 (affordable and clean energy): FPVs enhance the share of renewable energy in the global energy mix by leveraging the opportunity of clean and sustainable means of power supply to the communities. FPVs can close the access gap with their use of water surfaces that are not in full use, and especially these places are remote (off-grid) and underserved in terms of electricity supply.

SDG 6 (clean water and sanitation): FPV systems help reduce the water evaporation from reservoirs and lakes that lead to the conservation of water in drought-hit areas. Preserving land is vital in arid and semi-arid regions, where water conservation is imperative.

SDG 13 (climate action): FPVs are a cleaner alternative to energy generation from fossil fuels, generating less greenhouse gas emissions. The adoption of these enablers will help the world alleviate climate change and progress as an economy to lower carbon emissions.

SDG 15 (life on land): FPVs utilise water surfaces as opposed to land areas, which has a remarkable positive sentiment on preserving terrestrial ecosystems by reducing the stress on such resources and therefore aiding biodiversity conservation.

Challenges of deploying FPV systems

Despite the merits, FPVs pose some serious challenges in terms of transmission and distribution integration, degradation and policy. These factors hinder the deployment and penetration of FPVs. Many FPV projects are located in aquatic locations not close to existing grid infrastructure. Doing so requires huge investment in underwater or subterranean cabling, which can be economically unfeasible. Many FPV installations are situated in remote areas, making energy losses during long-distance transmission a major concern (Huang et al., 2023). This is significant because it emphasises the necessity of grid planning which, with the support of smart grid technologies and energy storage systems, is key to minimising losses and keeping voltage levels stable.

Another drawback of FPV systems is the degradation that can significantly impact their performance and durability. Solar modules that are positioned in a high-humidity area and subject to prolonged moisture exposure, fluctuating temperatures and high humidity can suffer performance loss due to corrosion, delamination and potential-induced degradation (Luo et al., 2021). Floating structures also face degradation due to biofouling, fatigue of material and UV exposure, which can degrade the buoyancy and stability of the floating structure with time. Furthermore, anchoring and mooring systems are present in continuous and moving water, which lead to mechanical degradation, thus affecting the overall durability of the system (Hooper et al., 2021). Studies are exploring the use of new coatings, corrosion-resistant materials and enhanced encapsulation to help reduce degradation and enhance the durability of FPV systems.

The rapid deployment of FPVs is sometimes hindered by ambiguous legislative frameworks, especially regarding water rights, environmental impact assessments and grid connection processes. Policymakers should establish clear expectations to accelerate project approval and incentivise investment in transmission and distribution facilities. While it is difficult to integrate FPVs when hybridised with hydropower plants or other renewable resources, advanced energy management system is required for coordinating power generation between FPV systems, hydropower dams and traditional network systems, allowing optimised dispatching schedules and avoiding curtailment (Dellosa et al., 2024).

Increasing penetration of FPV systems

A multilevel approach is essential to unlock the full potential of FPVs. The growing penetration of FPVs in the generation mix calls for the grid to be upgraded and improved to the maximum extent by governing bodies and utilities. Key investment priorities should be strengthening the transmission network, building offshore and floating substations and enhancing flexibility and resilience through smart grid technologies. FPVs can be more reliable and make supply more stable when combined with battery and pumped hydro storage. FPV systems can also allow the creation of hybrid energy parks, integrating them with other renewable energy plants, like wind and tidal energy, thus improving overall efficiency and reducing the uncertainty of power generation.

It is also necessary to remove regulatory bottlenecks that obstruct timely approvals, clarify water-use rights and safeguard the facilitation of the private sector to FPV projects. To encourage private parties to invest in FPV projects, clear structures for power purchase agreements and transmission cost-sharing frameworks must be made ahead of time. Financial incentives, such as tax credits, low-interest loans and green bonds, can accelerate adoption.

Research related to advanced floating structures, high-efficiency PV modules, biofouling inhibition coatings and corrosion-proof materials will also contribute to improve the longevity and lifetime of floating photovoltaic systems. In addition, the synergistic energy management system for hybrid floating solar and hydropower projects will enable easier and smoother integration of grid connectivity and grid stabilisation. Also, close collaboration among governments, R&D institutions and FPV industry players will be key to supporting innovation and scaling the technology. All these things will help in the penetration and growth of FPVs for clean and sustainable energy generation.

Way forward

FPV is emerging as a viable alternative to PV systems for clean and green energy generation due to its immense advantages. The FPV systems operate nearly with 8%–10% higher efficiency than similar land-based PV systems. This is due to the water-based cooling of FPV systems; it is found that FPV systems are cooler by 5–10°C depending on the location and weather parameters. FPV systems also help in water conservation by reducing evaporation. Research has shown that FPV systems can reduce evaporation by 42%, depending on the water coverage ratio (Farrar et al., 2022). Nonetheless, its success hinges on surmounting significant hurdles in transmission, distribution and regulatory conformity. Facilitating collaboration among policymakers, industry executives and researchers can lead to the more effective integration of FPVs into national grids, hence improving energy resilience and sustainability. Through deliberate investments in grid upgrading, hybrid energy systems and favourable legislation, FPVs possess the capacity to revolutionise the global energy environment. Following the aims of SDGs, the implementation of FPVs will be essential for achieving a cleaner, more dependable and more equitable energy future for everyone.

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