[1]Jeffrey T. Dellosa*,

[1]Ronieto N. Mendoza

[2]Robert Kerwin C. Billones,

[3]Yong Sheng

Current Trends, Advancements, and Challenges in Floating Solar Photovoltaic (FSPV) Systems for Off-Grid Applications: A Review

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Abstract: - Increasing energy demands and the pursuit of sustainable and clean energy sources have intensified interest in Floating Solar Photovoltaic (FSPV) systems, particularly for off-grid applications. FSPV technology presents a strategic alternative for countries with limited land but ample water bodies, contributing to energy diversification and conservation of arable land. This paper provides a comprehensive technological trends, advancements, and challenges in the deployment of FSPV systems, drawing from an array of highly regarded publications and extensive patent searches via the Derwent Innovation database and various publications. While large-scale FSPV deployments have been successfully integrated with existing hydroelectric power plants and grid systems, the application of FSPV technology for local community use remains underexplored. The paper identifies the lack of comprehensive literature on stand-alone FSPV systems that include battery charging capabilities and integrated monitoring and control systems to mitigate environmental risks. Moreover, the paper discusses the economic, regulatory, technical, cultural, and environmental barriers to FSPV deployment. It suggests that continuous research and development, backed by supportive policy frameworks, are crucial for overcoming these challenges. The aim is to pave the way for resilient, community-centric FSPV installations that can withstand extreme weather and cater to localized energy needs.

Keywords: component; floating solar photovoltaic system, floating solar technical, floating solar risks and challenges

1. INTRODUCTION

The global population increases pressure on energy requirements to support development and progress. With the rise in population, investments in power-producing plants also increase [1]. However, the increase in the establishment of power generating plants at the national level often opts for a stable and constant supply to the electricity grid. Most developing economies invest in coal-based power plants based on consistent supply to the grid compared to renewable energy sources [2]. However, these coal-based power plants often emit hazardous substances into the atmosphere and the environment [3].

Several studies have demonstrated using renewable energy to supplement energy requirements in the global economy [4-7]. Renewable energy, unlike fossil fuels, delivers clean energy to households with a minimal carbon footprint [4-7]. Homeowners or the community have several options available to them in terms of adopting renewable energy systems (RES). Micro-grid and stand-alone systems are two of the widely implemented RES, especially for more minor requirements [8-10]. Several studies have already been done on RES (environmental, financial & technical feasibility), making RES a viable option [11-12]. More importantly, several studies have shown that RES has reduced greenhouse gases (GHGs) in the atmosphere [13,14].

Renewable energy systems include systems that generate energy from environmental sources. Sources include the sun (solar), water (hydroelectric), heat derived from the grounds of the earth (geothermal), wind, plants (biomass), waves from the ocean, and even the temperature difference of the sea or the ocean [15].

Solar photovoltaic (PV) energy is a renewable source that captures available sunlight and converts it to electric power. Solar is widely used in developed and developing countries, as reported by various authors [16-17]. At least 402 Gigawatts of combined solar capacity for all countries worldwide as of the end of 2017 [18-19]. These

[1] Center for Renewable Energy, Automation, and Fabrication Technology (CRAFT), Caraga State University, Butuan City, Philippines

[2]Department of Manufacturing Engineering, De La Salle University, Manila, Philippines,

[3]Mechanical and Material Engineering, School of Engineering, University of Hull, United Kingdom

[1]jtdellosa@carsu.edu.ph, [1]rnmendoza@carsu.edu.ph, [2]robert.billones@dlsu.edu.ph [3]Y.Sheng@hull.ac.uk

massive solar power deployments in developed countries are also being translated as a solution to the problems encountered by those countries with no access to electricity, especially in rural areas.

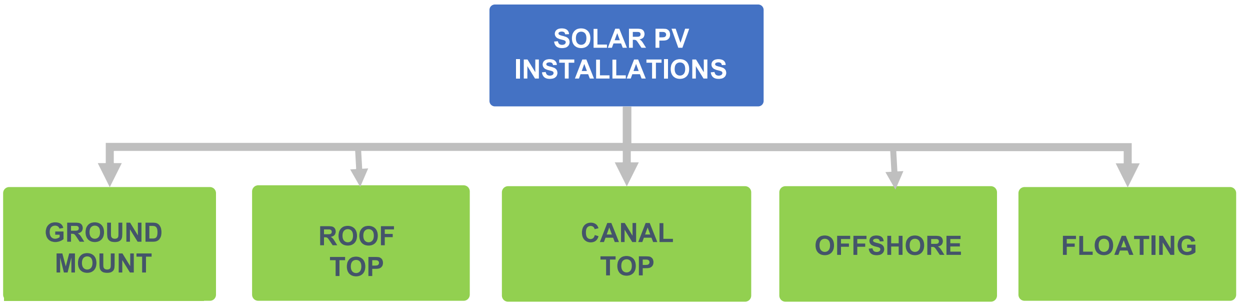

Figure 1. Classification of solar installations.

Figure 2. An off-grid floating solar photovoltaic (FSPV) system.

Solar PV installations come in five different forms or systems as shown in Figure 1 [20]: (1) ground-mounted systems; (2) rooftop systems; (3) offshore systems; (4) over-the-canal systems; and (5) floating solar PV as shown in Figure 2.

Utility-scale or large sizes of PV systems that act as power plants often adopt ground-mounted installations in Mega-Watt-peak (MWp) capacities [21]. Households or residential owners commonly select rooftop installations, which are also being adopted by small or medium size commercial buildings. Residential owners commonly connect from 1 kilo-Watt-peak (kWp) to below 20 kWp systems in size [22]. Commercial establishments may have greater capacities than those installed in residential or smaller businesses, like those in SM malls having more than 100 kWp in capacities [23]. Solar PVs can also be mounted over canals or irrigation systems, and installations can be in MWp capacities [24]. Offshore installations are commonly deployed in the open sea or the oceans, where they get a full view of the sun without shading and have higher efficiencies than most installations [20]. The installations made offshore are unprotected from difficult perils, such as high tidal waves [25].

The primary purpose of this survey is to determine the developments and advances in the available prior art, including the technical aspects of the FSPV, and to gain valuable insights into implementing a novel deployment of an off-grid FSPV system using electronic databases and the conduct of the patent search. The patent search activities are often missed when conducting a survey in which the determination of the novel aspects of technologies is identified. This study seeks to answer the following questions: What are the state-of-the-art global advancements in the FSPV system? What are the benefits and motivations for adopting FSPV systems? What materials and components are needed, and how can these components be set up to develop an FSPV system? What are the state-of-the-art off-grid or stand-alone FSPV systems, and what is the deployment of monitoring and control systems integrated into an FSPV?

The main objective of this paper was to conduct a descriptive analysis of the available prior art, including the technical aspects of the FSPV, to gain valuable insights about a novel deployment of a community-based, small-scale stand-alone or off-grid FSPV system in the intended location in Lake Mainit, Jabonga, Agusan del Norte.

2. METHODOLOGY

The descriptive analysis of the advancement of FSPV systems uses available online resources from various sources such as publicly available documents in highly reputable journals (i.e., Science Direct, Elsevier), conference proceedings databases, and those articles published which undergone the peer review process as provided in Figure 3.

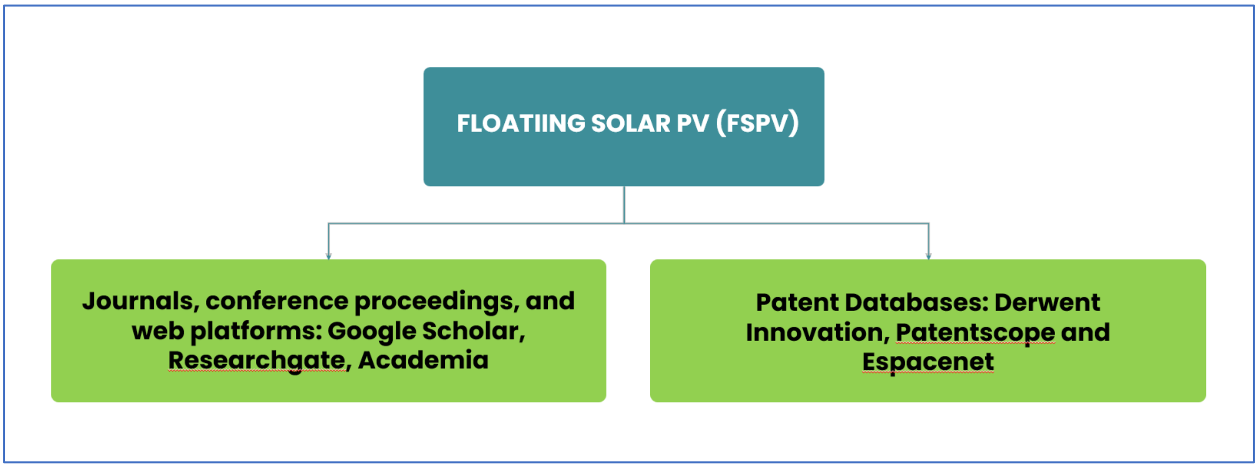

Figure 3. Coverage of the analysis of FSPV systems.

The unique part of this analysis is the addition of the patent databases as rich sources of state-of-the-art development of the FSPV. The patent search was conducted using Derwent Innovation, the commercial patent database available. It encompasses contents from non-commercial databases such as the Patentscope of the World Intellectual Property Organization (WIPO) and Espacenet of the European Patent Office (EPO).

A patent search is conducted to determine the state of the development of the FSPV as an alternative way to produce energy and determine the novel and inventive aspects of the FSPV systems' prior art. The patent search is crucial for designing around existing technologies that have already been covered in the prior art. This means that the proposed design of the FSPV system should have technical features not yet covered by those existing technologies already in the market or published in patent databases or other forms of literature. This article is divided into two parts: (1) introduction to renewable energy and solar photovoltaics; (2) floating solar photovoltaic systems (FSPV) as the energy source.

3. RESULTS AND DISCUSSIONS

The descriptive analysis covered the discussion on an FSPV system, its state-of-the-art at the global, regional, and national levels, and the benefits and motivations for adopting FSPV systems. Also included are the materials and components needed and how these components can be set up to develop an FSPV system. This section covers the status of the off-grid or stand-alone FSPV systems and the deployment of monitoring and control systems integrated into FSPV.

3.1 The Floating Solar Photovoltaic (FSPV) Systems

The solar industry is considering the Floating Solar Photovoltaic (FSPV) systems as a recent technological development gaining momentum in renewable energy [31-33]. FSPV is a solar PV type of installation wherein the solar panels are technically designed to float or hover on waterbodies [34], such as in hydroelectric reservoirs

[35], irrigation dams [36,37], including uninhibited mines [38-40]. The solar panels in the FSPV type of installation are typically mounted upon a pontoon-based floating structure anchored and moored to have a fixed location for the panels [41].

The primary motivation for the adoption of the FSPV systems is the complementation of hydroelectric dams, but more recently, it has something of greater importance in terms of preventing the potential conversion of productive agricultural lands to solar power plants [35,42]. Having the FSPV as an emerging technology, there are no commercial deployments yet, and most installations are being developed as demonstrator-type projects [43], including one in the Philippines [44].

3.2 Primary Benefits, Advantages, and Disadvantages of FSPV

The research and development activities of floating solar are gaining interest only in the last decade due to its benefits, besides providing clean energy. It was claimed by several reports that FSPV has several advantages over traditional land-based solar PV systems. These benefits are summarized and shown in Figure 3.

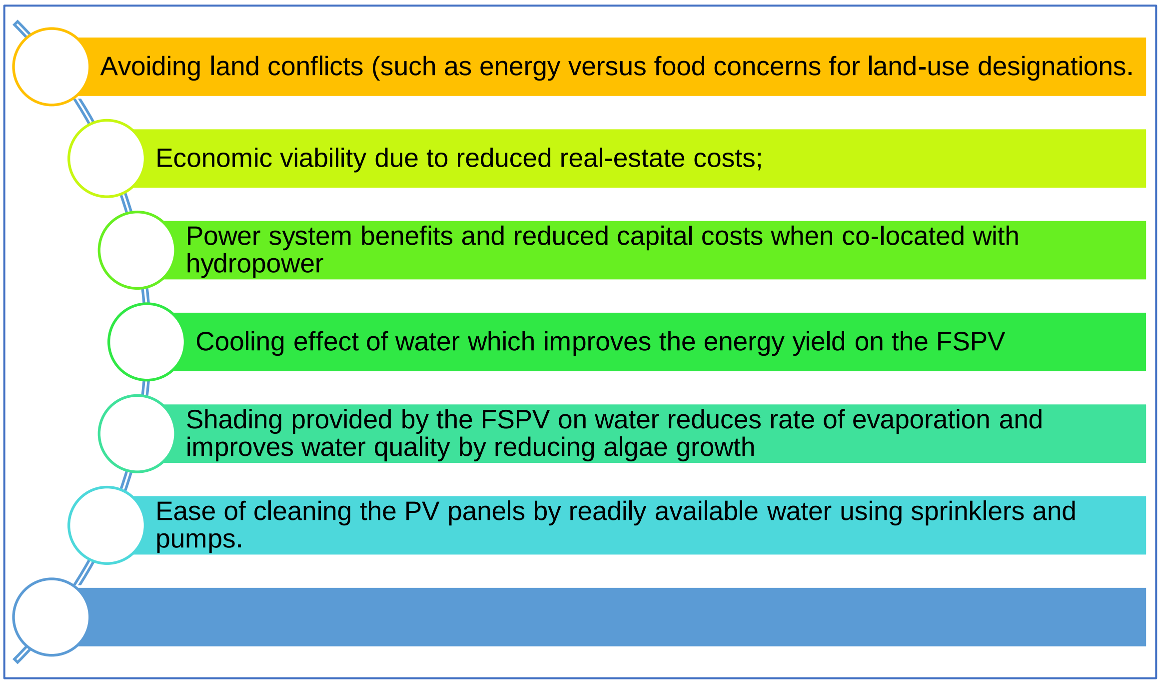

Figure 4. Summary of potential benefits of adopting the FSPV [45-47].

The first reason or benefit in Figure 4 is the avoidance of land-energy conflicts where agricultural lands are being converted to a solar power generating facility. This becomes a major issue in terms of priorities. However, in other countries or cities with too little land area but with water resources (i.e., Taiwan, Singapore, Hong Kong), the FSPV can be a great option. Other reasons highlighted in the figure are real-estate costs and technical or efficiency improvements [45-47]. With these value-adding benefits, large-scale FSPV systems were deployed across the globe.

Despite the attractiveness of the FSPV system, there are likewise disadvantages that it presents, among them are [20]:

- Vulnerable to strong winds, high tides, typhoons, and other adverse weather conditions like a tsunami if it is in the open sea;
- The metallic parts of the solar panels and other components are the potential to absorb corrosion;
- Fishing activities or transportation like boats can be affected by the presence of the floating solar, especially when it is large-scale deployments;
- Accumulation of clay can be a problem, especially for FSPV systems deployed in rivers or lakes;
- Aquatic animals or seaweeds below water can be affected by the non-availability of solar penetrations;

3.3 Large-Scale FSPV Systems

FSPV also came when the land was becoming scarce for the massive and industrial-scale deployment of solar PV farms; for example, Singapore is one of the countries with very limited land area and cannot afford to implement a ground-based solar PV farm [33]. Even in countries with bigger land resources, agricultural lands are converted to solar PV farms, reducing the capacity to produce agricultural products.

Table 1. Summarized Large-scale Floating Solar PV Installations in the world [20,50-52].

COUNTRY / LOCATION	Capacity	Name of Installer / Company
Vietnam - Gia Hoet 1 and Tam Bo irrigation lakes in the Chau Duc district commune of Quang Thanh.	70 MW [2 x 35MW]	Da Mi Hydropower Joint Stock Co
Singapore – Tengeh Reservoir	60 MW	Sembcorp Floating Solar Singapore
India – West Kallada	50 MW	NHPC Ltd.
Thailand – Ubon Ratchathani	58.5 MW	Sungrow
Vietnam -	47.5 MW	
India – Andhra Pradesh	25 MW	Bharat Heavy Electricals Limited (BHEL)
Australia – Jamestown	4 MW	Infratech Industries
Japan – Hyogo Prefecture	2.3 MW	Kyocera TCL solar
Hapcheon Dam	500 kW	K-Water
Italy – Bubano	500 kW	Bryo
Spain – Agost	300 kW	Celemin energy and Polytechnic University of Valencia
Philippines – Angat Dam	223 kW	Ocean Sun (Norway)
United Kingdom – Sheeplands Farm, Barkshire	200 kW	Ceil et terre
Italy – Petra Winery	200 kW	Tera Moretti Holding
USA, California – Napa Valley’s Far Niente Wineries [first FSPV in 2007]	175 kW	SPG Solar
France – Pommeraie-sur-sevre	100 kW	Osesol

Over the last few years, floating solar PV has gained interest and momentum, especially in highly developed countries such as the United States, China, Japan, Korea, and Singapore, in leading the deployment of large-scale FSPVs [20, 31, 48]. Table I shows the list of high-capacity FSPVs in the world. China leads all countries in FSPV deployment with a total of ~1.3 GW, followed by Taiwan with 300 MW, Japan with 260 MW, South Korea with 120 MW, Netherlands with 110 MW, and India with 92 MW total installed capacities [49]. All these large-scale installations are connected to the grid under different schemes depending on the country, i.e., commonly in Feed-In-Tarif (FIT) schemes.

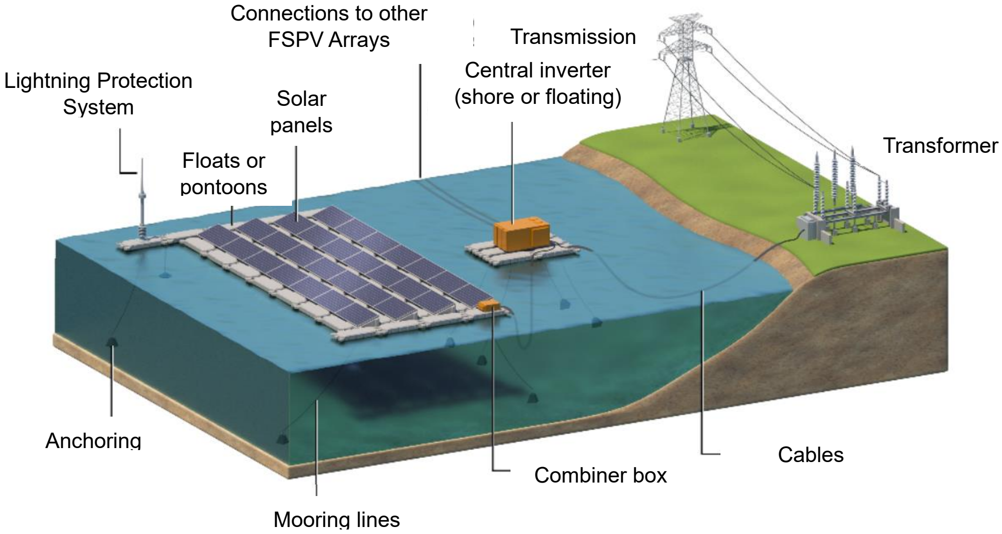

Figure 5. Schematic diagram of a typical grid-interconnected FSPV [58].

3.4 FSPV Systems in Southeast Asia

In Southeast Asia, Singapore launched 2021 their sixty (60) MW capacity deployed by Sembcorp Floating Solar Singapore, which is a grid-tied FSPV similar to what is shown in Figure 5. This is the second biggest capacity installed by an ASEAN member state and is close to the largest ground-based solar farm in the Philippines. The solar panels deployed would cover the size of 45 football fields. The floating solar plant was expected to generate 77,259,302 kWh of clean electricity annually to energize 16,000 households on average [34,50]. Thailand deployed its own 58.5 MW floating PV plant, already connected to the electricity grid. This is considered the first in Thailand and was launched only in September 2021. The floating PV plant was deployed in a hydropower plant reservoir and spanned 121 hectares in the northeast province of Ubon Ratchathani [53].

Vietnam integrated two 35 MW systems into the electricity grid for a combined generation capacity of 70 MW. These systems were deployed on the Gia Hoet 1 and Tam Bo irrigation lakes in Quang Thanh, district of Chau Duc in Vietnam [54]. On the other hand, Cambodia launched its 2.8 MW power plant on the reservoir of Chip Mong Insee Cement Corporation (CMIC) [55].

Most of these deployments and launching of floating PV in Southeast Asia are widely publicized in the media showing these countries' commitment to deploying renewable and clean energy systems. Presently, this material information is not yet reflected in journal articles. Other ASEAN countries developing large-scale floating PV include Laos, with 240 MW [56], and Indonesia, with 145 MW [57].

Unlike its neighbors, the Philippines have very limited activities on the FSPV. These large-scale floating PV plants have yet to see this type of engagement from developed countries on a massive scale here in the Philippines. So far, the only newsworthy FSPV deployment was the 220 kWp FSPV system installed in 2019 in Magat Dam for SN Aboitiz Power (SNAP) by Ocean Sun, a Norwegian company, as a test bed to complement the Magat hydroelectric power plant. This is a demonstrator-type project which is much the same as most of the other FSPVs in other countries [52]. But there are limited to no reports, documents, or journal articles from higher education institutions (HEIs) that can be found in highly regarded journals in Science Direct (Elsevier) or in conference proceedings that presented comprehensive findings on FSPV in a natural lake setting in Mindanao, or other parts in the country.

3.5 Barriers, Risks, and Challenges in FSPV Deployments

The National Renewable Energy Laboratory (NREL), the Federally-funded R&D center of the Department of Energy (DOE) in the United States, released a report entitled "Enabling FSPV Deployment: Review of Barriers to FSPV Deployment in Southeast Asia" as published in 2021 on the potential barriers to the FSPV deployments.

These concerns include the economic, environmental, cultural, technical, and regulatory barriers provided in Figure 5. Potential resolutions to these barriers are also summarized in Figure 5 [58],[49].

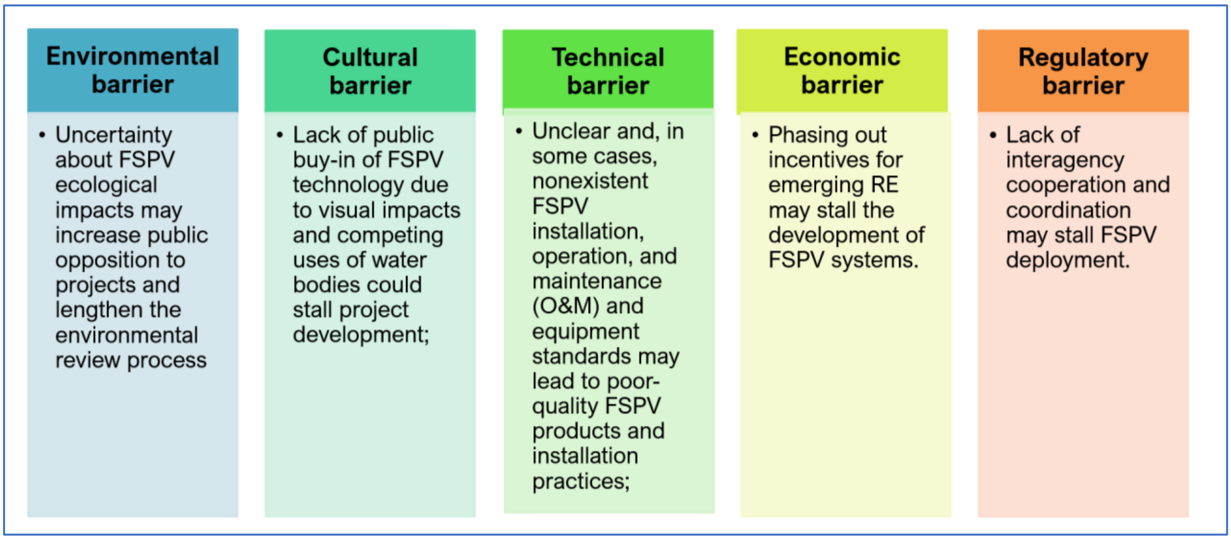

Figure 5. Summary of the identified barriers to the deployment and growth of the FSPV systems [49].

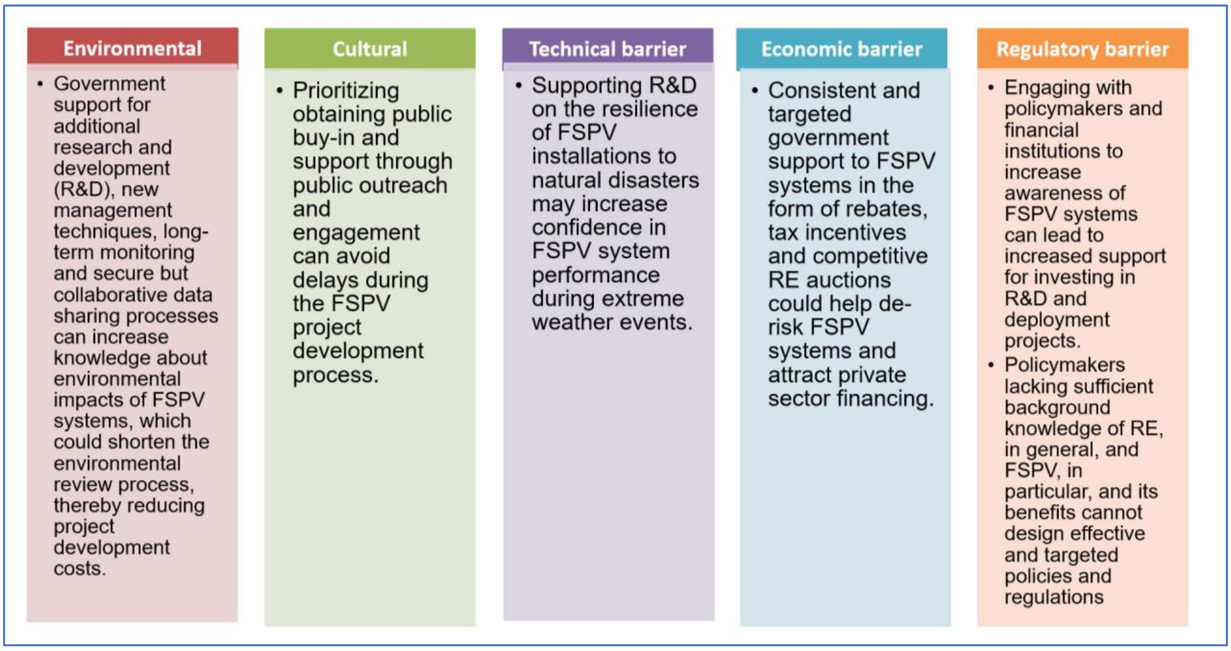

Figure 6. Summary and key points to potential solutions to barriers to the deployment and growth of the FSPV systems [49].

3.6 FSPV components and structural design

The FSPV system comprises the components (see Figure 7) like the land-based PV system, such as the photovoltaic modules (PV), inverters, cables, and connectors, except that these components are floated in water bodies using pontoons or floats and with mooring and anchoring devices to position the entire system in a specific location [62]. The pontoons and floats commonly carry solar PV arrays, combiner boxes, inverters, circuit protection systems, various sensors (temperature, wind speed, humidity), and batteries, among others, as deployed in rivers, lakes, or other types of water bodies. For this article, we pay special attention to pontoons or floats and the mooring and anchoring of the FSPV system. The PV modules, inverters, cables, and connectors were commonly used in various implementations.

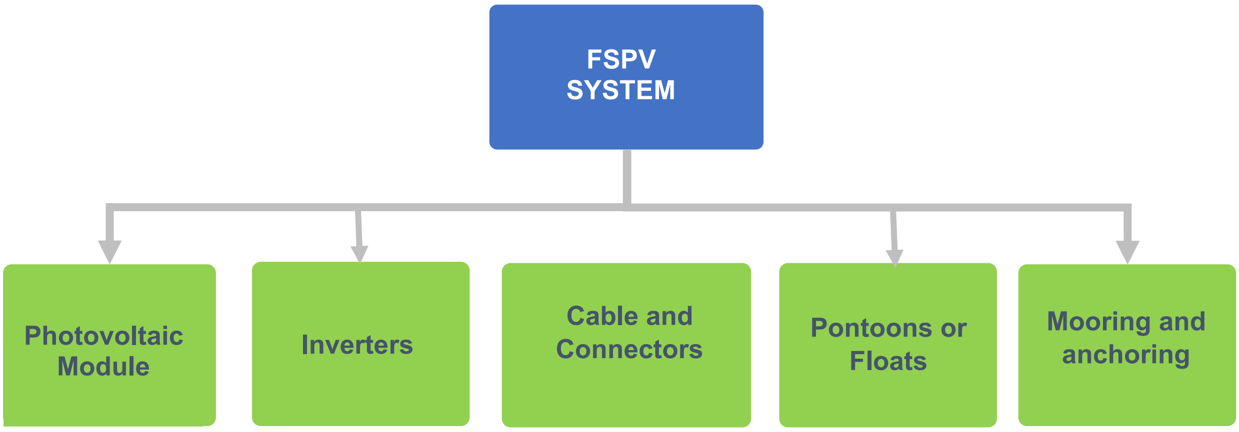

Figure 7. Components of the FSPV system.

3.6.1 Solar PV modules

Solar PV modules are the main components of any FSPV installation, just like in land-based deployments. The solar modules are primarily responsible for converting solar to electrical energy. In floating, residential, and other types of installations, an array or arrays of solar modules are deployed to generate a higher electric energy capacity, depending on the requirements. There are three major types of energy-generating solar PV modules: (1) monocrystalline; (2) polycrystalline; and (3) thin film [63]. The type of solar modules to use depends on the criteria set by designers in terms of cost, type of application, thermal efficiency, energy conversion efficiency, and even availability in the local market where the project might be located [64].

3.6.2 Power inverters

Power inverters convert generated direct electrical current (DC) electricity from a solar PV system to an alternating current (AC) form that can be used by an AC-based facility, such as households with equipment or appliances requiring an AC supply. The output of the solar modules or the solar array is generally fed to a combiner box before feeding the supply to the inverter. For an FSPV system, the inverter location can be decided based on how far the system is from the shore or the condition of the water bodies where the FSPV is deployed. Most FSPV systems deploy inverters on the pontoon or the floating platform if the system is installed in a location where it is farther from the shore. With a shorter distance, the FSPV inverter is preferable to be deployed on the shore [62,65].

3.6.3 Cables and connectors

The electrical output from the solar PV arrays in the FSPV system is carried through to the inverter and the electricity grid or the battery banks on the shore by cables and connectors. The cables are commonly set up to float to shore and be selected properly to avoid current leakage that might affect the surrounding area and may propose harm near the FSPV system. These cables and connectors should have high-temperature resistance and are waterproof (IP67) junctions meeting the minimum standards for safety [62,65]. Leakage current sensors should be deployed along the cable and the surrounding area of the FSPV system to detect any unwanted incidents.

3.6.4 Pontoons and floats

Pontoon is a type of device with sufficient buoyancy to float by itself. In contrast, floats are hollow devices with an effective buoyancy-to-self-weight ratio. Both devices allow the solar panels or modules to float over them and are typically designed to carry the weight of these modules. These devices are the most important element in the floating system providing structural support for the solar panels and walkway for easy access during maintenance [62, 65]. These floats and pontoons can also provide space for onsite installations of batteries, inverters, lightning protection systems, and monitoring devices, such as environmental sensors [62, 65].

The materials being used for the floating structure are (1) high-density polyethylene (HDPE); (2) medium-density polyethylene (MDPE); (3) ferro-cement; and (4) fiber-reinforced plastic (FRP). The selection criteria for which type of float is crucial in developing and implementing an FSPV system. Among these floating materials, HDPE comes out as the preferred material with favorable material characteristics concerning resistance to corrosion and ultraviolet (UV) rays and higher tensile strength compared to other types of floaters [59, 62].

Various installations are presently adopting various commercial and non-commercial floating modules and pontoons as seen in Figures 8-13.

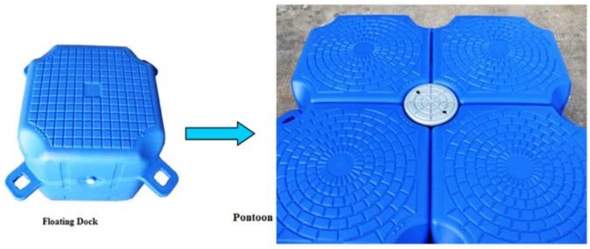

Figure 8. Pontoon structure [65].

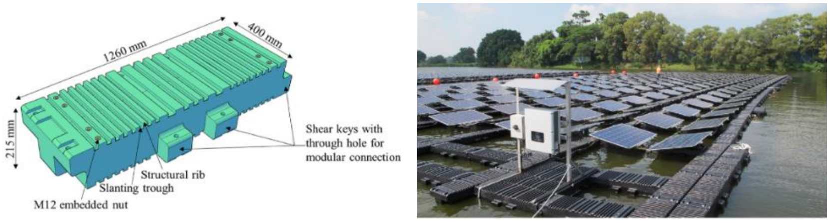

Figure 9. Isometric view of a floating module (left figure) and the actual floater (right figure) [66].

Figure 10. Floaters using the high-density polyethylene (HDPE) from Mibet Solar [67].

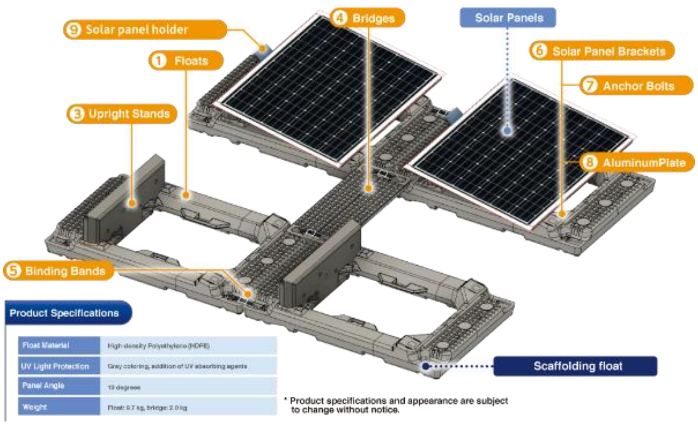

Figure 11. Floater design from Sumitumo Mitsui Contruction Corporation [68].

Figure 12. Floating structure from Kyocera for a 13.7 MW FSPV plant [69,70].

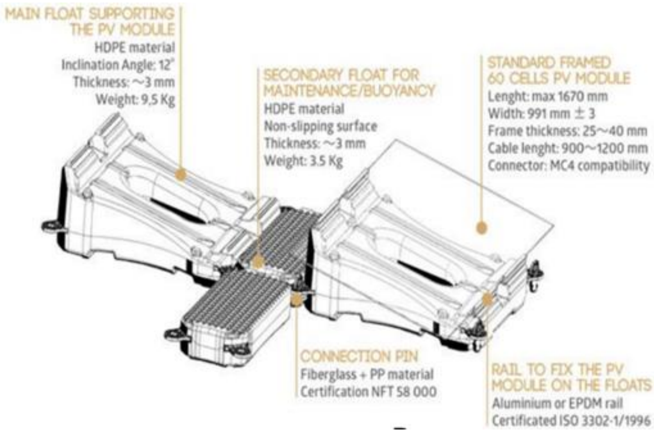

Figure 13. Floater design from Ciel&Terre [71].

3.6.5 Mooring and anchoring

Mooring and anchoring mechanisms are those permanent structures deployed to hold the FSPV system in the desired location to prevent the floating elements not to drift away [68]. Ropes such as nylon polyester and nautical are the commonly used mooring device held to bollards or posts on the shore, wherein these ropes are tied at the corners of the floating materials [62,65]. Mooring and anchoring must be set firmly so as not to depart from their intended position. However, this also presents challenges regarding when the water levels are constantly changing, especially with FSPV deployed in open waters.

Rosa-Clot and Tina (2020) proposed three FPSV mooring configurations, as shown in Figures 14-16. They are the catenary, taut, and hybrid configurations. These technical concepts were proposed for rivers and near-shore installations but can serve as a guide for future deployments onshore [72].

The catenary configuration came from the mooring lines' catenary shape. As shown in Figure 14, the mooring chain hangs in the catenary under self-weight. The mooring system uses the resistance of the line with the sea bed, which requires a large mooring footprint to operate on. Among the three configurations introduced, the catenary system is the simplest configuration. However, vertical loads are not suited for this type of installation [72].

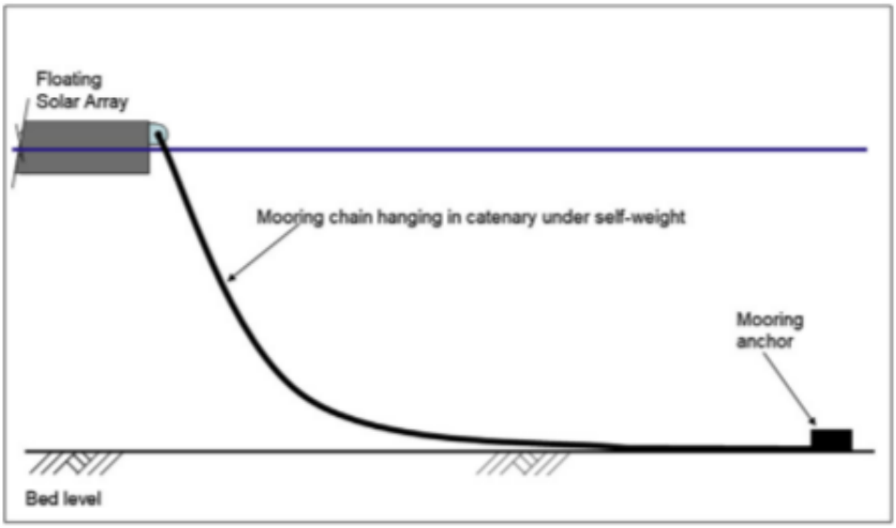

Figure 14. The catenary mooring configuration.

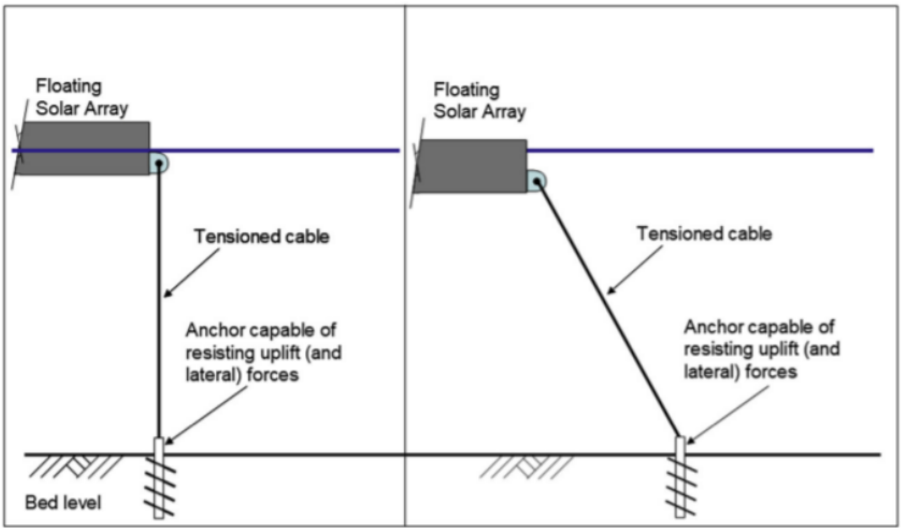

Figure 15. The taut mooring configuration.

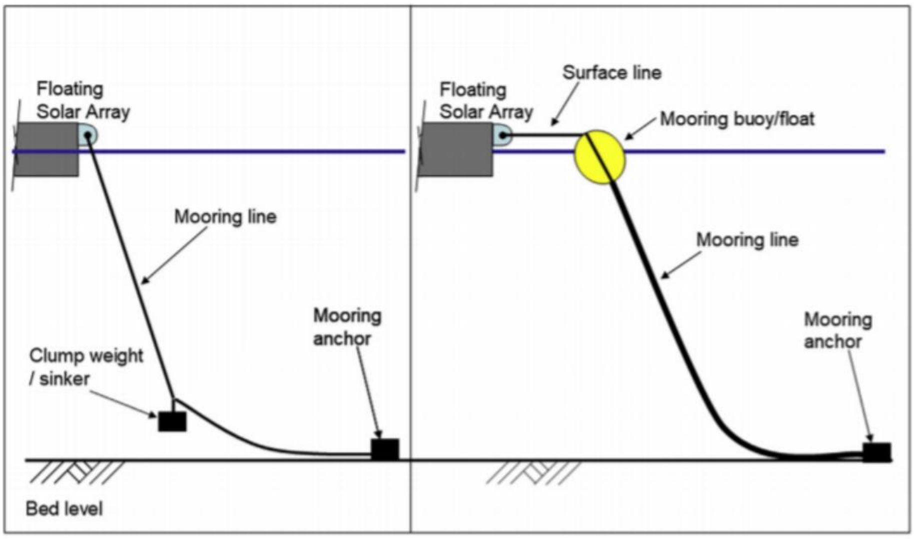

Figure 16. The hybrid mooring configuration.

In the taut configuration in Figure 9, the mooring lines are connected until they are fully stretched or taut, generating the returning forces from the line deformation instead of its weight, unlike the catenary type system. In this deployment type, the mooring lines can be stretched vertically and inclined but require a minimal footprint. It was noted that this type of system could not work with drag anchors as it needs the anchors to be embedded in the sea bed to provide load-bearing capacity in both horizontal and vertical directions [72].

The hybrid mooring system combines the catenary and taut principles. A weight or a buoy (or any kind of floater) is added in the lines with the FSPV and the anchors, as shown in Figure 16. This system can choose the catenary or taut mooring features. A clump weight or a sinker offers added support to the anchor to stand the load, making it probable to lessen the span of a line in catenary mooring. In contrast, taut delivers the stiffness to the lines essential with the water level variation. Whereas an analogous principle can be applied for buoys, the taut mooring offers stiffness to the line by adding buoyancy. In contrast, catenary mooring supports the anchor by dropping its loads with buoyancy [72].

3.7 Stand-alone or off-grid FSPV deployments with battery charging station for community use

Most of the FSPV deployments discussed were commonly deployed as grid-integrated systems. This section explores developed floating solar PV systems applied to provide energy or electrification for communities. The keywords "stand-alone floating solar" and "off-grid floating solar" were used to scan journals and publications through ScienceDirect (Elsevier), Google Scholar, Academia, and ResearchGate.

Jamroen (2021) investigated using a stand-alone floating solar to optimize the size of solar PV with a small-capacity battery energy storage system to energize an aquaculture aeration and monitoring system in a remote location in Thailand. This system was developed to raise dissolved oxygen as being used in aquaculture. The battery storage system deployed in this study was used to store the energy and power up the monitoring devices [73].

Table II. Publications Relating to Off-grid or stand-alone FSPV Systems [20,50-52]

JOURNAL / PLATFORM	**Keywords used**	**Number of relevant hits**
ScienceDirect (All journals within Elsevier)	Stand-alone floating solar	1
	Off-grid floating solar	0
Google Scholar	Stand-alone floating solar	1
	Off-grid floating solar	1
ResearchGate	Stand-alone floating solar	1
	Off-grid floating solar	1

Mandavi and Tawari (2022) conducted a comparative analysis of the off-grid and floating PV systems. The off-grid system in their study refers to solar PV deployed on the rooftop. They determined that the floating solar PV has higher efficiency than the solar installed on the rooftop due to the cooling effect of the water. The Maximum Power Point Tracking (MPPT) approach and MATLAB for the simulations were used in their study to achieve their objectives [74].

Hamid et al. conducted a feasibility study on an off-grid design of 4.4 kWp floating solar using the HOMER simulation software to simulate this system's economic, environmental, and technical potential. For this system size, the authors reported it would generate energy at 2.292 MWh/year. Solar irradiance was recorded to be between 4.28 to 5.70 kWh/sq.m. per day [75].

Only three relevant papers came out in reference to the search strings used. This would indicate that there are limited research and development activities in this area referring to floating solar PV used in stand-alone or off-grid installation to energize a community.

3.8 Community-based FSPV with environmental monitoring and control systems.

Based on the two comprehensive review articles published by Sahu, A. et al., and Kumar, M. et al. on FSPV systems, the monitoring, and control through the integration of environmental sensors were not covered, especially the deployments of AI or IoT applications with environmental sensors to control the FSPV system. The advantage of integrating monitoring and control systems is that FSPV operators can track the electrical or electronic behavior of the system or the environmental conditions where the system was deployed in real-time. Off-site operators can trigger or control the system's output even when they are not near when environmental stressors occur, such as strong winds and waves that might affect the FSPV system. With sensors and control systems deployed, the system can also autonomously configure the entire system's status.

The following keywords or search strings were used to determine the state-of-the-art of the FSPV systems with monitoring and control: floating solar, artificial intelligence (AI), internet of things (IoTs), monitoring, sensors, and control while using them in combinations (i.e., ("floating solar") and ("artificial intelligence")). Very limited relevant documents were found using these keywords under all journals in ScienceDirect and Google Scholar. One closest review article by El Hammoumi A. et al. (2022) was about integrating sensors for monitoring and solar tracking purposes used in land-based systems [76]. Soltani, S. R. K. et al. (2022) use artificial intelligence techniques to predict water loss through surface evaporation using a floating solar power plant on a wastewater pond. It was determined in this study that the evaporation of the pond will be reduced by up to 70% with the presence of floating solar. The Artificial Neural Network (ANN) method was used in this prediction, one of the more popular AI techniques. MATLAB was the software used to analyze the data collected [77]. Lee, A.K. et al. (2014) discussed using a 2.45 GHz Zigbee technology in a 100 kWp floating solar tracking system and developed a wireless mesh network with environmental monitoring system focusing on the amount of insolation, generated power, and solar tracking [78].

Jamroen (2021) developed an aeration and monitoring system for a pond using a small-scale floating solar at 450 Wp sizes and a battery storage 60 Ah capacity to power both systems studied. In that study, remote monitoring was developed to collect data on Dissolved Oxygen (DO), photovoltaic power, battery energy storage power, and temperature. The electronic monitoring system used the Arduino MEGA 2560 R3 and the narrowband internet-of-things (NB-IoT) to collect and transmit the data wirelessly through a cloud service [73].

The collected information was used to control the aeration system and whether or not to turn on the aerator to increase the dissolved oxygen in the pond.

3.9 Patent Search on FSPV and FSPV with monitoring and control systems

A patent search was conducted to help determine novel and inventive concepts about the FSPV and the FSPV system with monitoring and control systems. In some instances, inventive concepts were only applied for patent protection but were not published in journal articles.

Using the most comprehensive database, the Derwent Innovation, the following technologies were determined, all available as the prior art. The patent search results will also serve on how to design around the existing FSPV systems such that the proposed design will be novel and inventive. In the conduct of the patent search, the following keywords or search strings and the international patent classifications (IPCs) were used: solar energy, solar radiation, harvest*, convert*, absorption, stor*, battery charging station, wave sensors, integrated sensors, solar panel, photovoltaic, pv, renewable energy system, res, control system, monitoring system, artificial intelligence, ai wind speed, wave speed, floating, fspv.

Only two (2) documents were found to be relevant to this study, specifically on floating solar PV systems, as provided in the prior art search table (Table III). The first patent document (patent document number: CN216625623U and publication date: 2022-05-22) relates to the design of the floating structures or floater and is different from what was presented in the prior art or from those commercially available floaters.

Table 3. Summary of the Closes Prior Art or Relevant Documents Found after the Conduct of Patent Search.

Database	Search String Used	Number of Hits
Derwent Innovation	aic=(y02e006010 or h02s002000 or b63b20354453 or y02e001000);	448,080 documents
Derwent Innovation	ctb=(((solar adj (energy or radiation)) near5 harvest* or absorption or convert* or stor*));	751,067 documents
Derwent Innovation	ctb=(((solar adj (energy or radiation)) near5 harvest* or absorption or convert* or stor*)) and ctb=("battery charg*" adj station or facility or house);	438,059 documents
Derwent Innovation	ctb=(((solar adj (energy or radiation)) near5 harvest* or absorption or convert* or stor*)) and ctb=("battery charg*" adj station or facility or house) and aic=(y02e006010 or h02s002000 or b63b20354453 or y02e001000);	3,044 DPI
Derwent Innovation	ctb=(((solar adj (energy or radiation)) near5 harvest* or absorption or convert* or stor*)) and ctb=("battery charg*" adj station or facility or house) and ctb=(float* near5 ("solar panel" or fspv or photovoltaic or pv or "wave sensors" or "wind speed sensors")) and aic=(y02e006010 or h02s002000 or b63b20354453 or y02e001000);	22 DWPI
Derwent Innovation	ctb=(((solar adj (energy or radiation)) near5 harvest* or absorption or convert* or stor*)) and ctb=(float* near5 ("solar panel" or fspv or photovoltaic or PV));	1,728 DPI
Derwent Innovation	ctb=(((solar adj (energy or radiation)) near5 harvest* or absorption or convert* or stor*)) and ctb=(float* near5 ("solar panel" or fspv or photovoltaic or PV)) and ctb=(("renewable energy system" or res or "control system" or "monitoring system" or "artificial intelligence" or ai) and (wind or wave adj (speed)) and sensor);	16 WPI

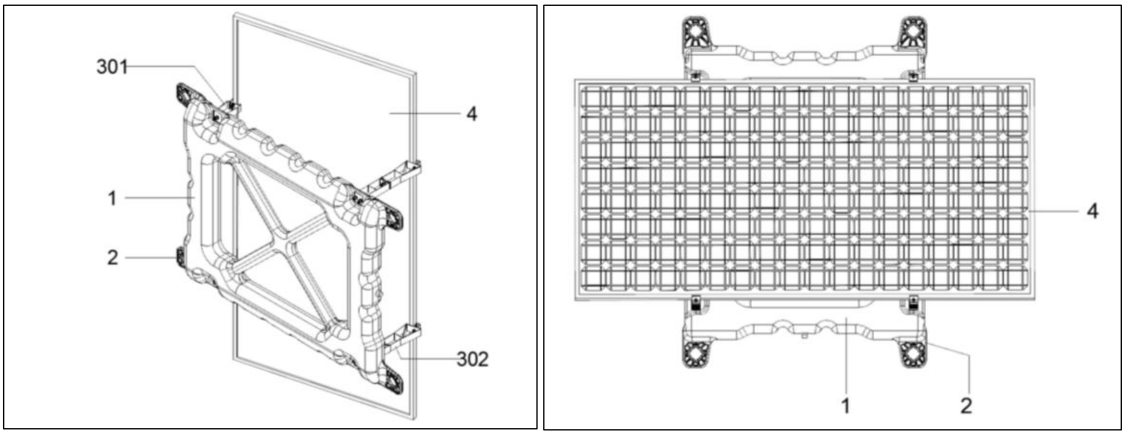

Figure 17 a and b. An FSPV floater comprising a floating body component, a bottom bracket, a solar photovoltaic bracket and a solar panel, four corners of the floating body component are provided with bottom brackets [79].

Figure 17 a and b are published patent-related design of a floater found through the WIPO's patent database. This floater design aims to solve the problems of corrosion of the floating body support to the aluminum alloy of the solar PV module and also seeks to solve the problem of the strength of the structure concerning low wind resistance and shock support compared to the present designs [79].

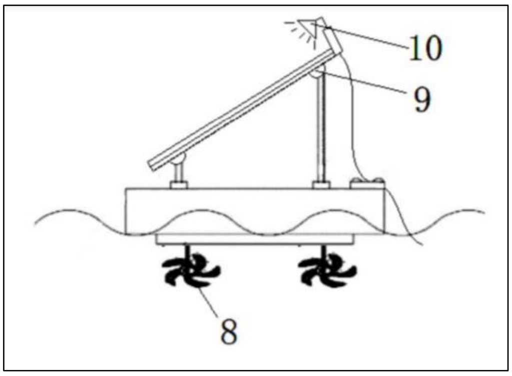

Figure 18. Representative drawing for patent document number two (CN215553998U)

Patent document number two (CN215553998U; Date of publication: 2022-01-18) is one close reference from which this study will take off from sensor integrations as shown in Figure 12. The following are the sensors and control devices integrated into this system: (1) GPS sensor; (2) raindrop sensor; (3) angle sensor; (4) azimuth angle control device; (5) temperature sensor; (6) wind speed sensor; and (7) cooling device sprayer. This utility model intends to improve the floating PV's automation [80].

In this section, a comprehensive patent search focused on floating solar photovoltaic (FSPV) systems, particularly targeting novel and inventive concepts was carried out. This search utilized the Derwent Innovation database, applying various keyword combinations and International Patent Classifications (IPCs) related to solar energy and renewable energy technologies. The aim was to identify prior art and guide the design of new, innovative FSPV systems that circumvent existing technologies. The search strings and IPCs covered a broad spectrum, including terms like solar energy, battery charging stations, wave sensors, and artificial intelligence, among others. Despite this wide net, only two patents were found to be significantly relevant. The first, patent CN216625623U, detailed a novel floating structure design for FSPV systems. This patent highlighted advancements in structural strength and corrosion resistance relative to existing commercial designs. The second, patent CN215553998U, described an FSPV system equipped with various sensors and control devices to enhance automation and operational efficiency.

Given the results of this patent search and the extensive prior art in the field, moving forward with designing a novel and inventive FSPV system will require carefully navigating these existing technologies. The search has not only highlighted relevant patents but also underscored the complexity of differentiating new designs in a saturated market.

4. CONCLUSION

This paper has thoroughly examined the advancements, challenges, and potential of Floating Solar Photovoltaic (FSPV) systems, particularly focusing on off-grid applications. The insights gained from the Derwent Innovation patent search highlight the significance of innovation and differentiation in the field, especially in a market dense with prior art. The evidence suggests that FSPV systems hold a promising future for renewable energy, offering a viable solution to land scarcity and enabling energy generation atop water bodies.

Despite the identified benefits, such as avoiding land-use conflicts and leveraging the cooling effects of water to improve efficiency, the research underscores the dearth of literature on community-based, stand-alone FSPV systems with integrated monitoring and control. This gap underscores an opportunity for further exploration and development in FSPV technology to support community use and enhance resilience to environmental risks.

Moreover, addressing the technical, economic, regulatory, and environmental barriers is paramount for the wider adoption of FSPV systems. Research and development, as advocated by entities like the US NREL, must continue to innovate and refine these systems, particularly to withstand extreme weather events and integrate seamlessly with existing energy infrastructures.

This study serves as a call to action for continued investment in R&D for FSPV systems. By pursuing advancements in design, sensor integration, and environmental monitoring, stakeholders can propel the FSPV field toward a more sustainable and efficient energy future, one that aligns with global renewable energy goals and the specific needs of local communities.

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