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Review

Overview of Possibilities of Solar Floating Photovoltaic Systems in the OffShore Industry

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Abstract: The demand for energy has rapidly grown around the world. Solar floating photovoltaic (FPV) systems are an efficient solution to solve the issues from nonrenewable energy sources, such as reduction of CO_2 emission, limitation of global warming, environmentally friendly, a great innovation in sustainable aquaculture, and a new ecofriendly technique, along with reducing production costs, especially regarding the scarcity of habitable land. A large number of installation projects using FPV technology have been operated in water bodies such as lakes and dams/reservoirs. However, deployment of FPV offshore is still limited because of the existing characteristics of marine/sea environments that are different from onshore, such as wind loads and wave loads. Despite these difficulties, there are several projects that have been installed in some countries and gained many significant achievements. It opened possibilities to apply FPV systems offshore worldwide. In this review, we present a brief overview of FPV systems both onshore and offshore, analyze advantages and disadvantages of offshore FPV systems, and provide an overview of their future.

Keywords: solar energy; renewable energy; aquaculture; future; potential

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1. Introduction

The growth of energy consumption, lack of habitable land, and environmental issues have increased the increased deployment of renewable energy sources in offshore areas [1]. To date, the main forms of marine renewable energy have been researched intensively, which helped to develop offshore energy technologies. They are energy sources from wind, waves, and tides [2]. Moreover, it is estimated that about 70% of the global primary energy supply for oceans comes from radiation from the sun [3].

Considering wind energy, the first offshore farms were conducted, supplied, and connected to the grid in the 1990s. It has been developed with notable growth in the last decade in many countries worldwide, but particularly in Europe [4]. For wave and tidal energy, tides and ocean waves are generated by gravity from the sun, earth, and moon. Waves are a source of low free frequency energy; however, the energy related to tidal oscillation masses is useful for generating electricity [5].

In addition, solar energy is an alternative energy source that has been infrequently explored in the marine environment [5]. To explore this energy source, solar floating photovoltaic (FPV) systems in seas and oceans have been considered as a novel solution for renewable energy production without the necessity for water and land resources [6]. There are many advantages to installing FPV system over water bodies, including the saving of land, natural cooling of water bodies due to enhanced PV performance, a lower number of fewer obstacles that cause shadow loss, and a lower quantity of dust. Moreover, an estimated 50% of the total world population live within 100 km of the coast, which provides a good chance to providing electricity to these regions [7,8]. Furthermore, these energy sources can also supply energy for offshore platforms, such as ships and tourism [8,9]. The United States and Japan are the first two countries to install FPV. The first commercialized FPV plant was deployed by SPG Solar in July 2007 in a reservoir in the Far Niente Farm, Napa Valley, California, USA. The goal of this system is to prevent evaporation from the reservoir [10,11]. The National Institute of Advanced Industrial Science and Technology, Aichi, Japan, installed FPV systems in 2007, making it the first test of a scheme for a 20 kW FPV [12], followed by other countries, including France, Italy, South Korea, Spain, and the United States [13].

Generally, many FPV systems that have been deployed gave an overview concerning several FPV projects worldwide from 2007 to 2013, such as Trapani and Santa Fé [14]. For instance, in 2009, the largest project was conducted in Italy with 500 kW, based on the collaboration of four local companies. Other projects included a 24 kW project in Spain, a 20 kW project in Italy [15], and a 30 kW and 100 kW FPV array in France and Vendeé, respectively, along with a 500 kWp installation at Hapcheon Dam, South Korea, in 2012. Most countries have deployed FPV systems onshore, with a small number deployed offshore [13].

Currently, the largest FPV market is in China, followed by Australia, Brazil, Canada, France, India, Indonesia, Israel, Italy, Malaysia, Maldives, the Netherlands, Norway, Panama, Portugal, Singapore, Spain, Sweden, Sri Lanka, Switzerland, Thailand, Tunisia, Turkey, the United Kingdom, and Vietnam, and others. Projects are under consideration or development in Afghanistan, Azerbaijan, Colombia, Ghana, the Kyrgyz Republic, Myanmar, and Pakistan, and others. For example, FPV with tens or even hundreds of megawatts of capacity have been deployed in China, while more will be deployed in India and in Southeast Asia. In 2016 and 2018, the first FPV with more than 10 MWp of capacity was operated. Moreover, worldwide, the first of larger FPV plants reached more than 100 MWp with the largest at 150 MWp [13].

In addition, the latest review concerning floating photovoltaic technology (FPVT) was investigated by Yousuf et al. [16]. FPVT is increasing with several setup project designs, including conventional land-based and ground-mounted solar, roof-top solar, canal-top solar systems, offshore solar PV systems, and reservoir/lake-based floating solar systems. Power with floating technology was installed worldwide by 2020 [15]. The renewable energy sources such as hydropower, wind power and solar PV cover 46.5%, 23.9%, and 23.8% of the total installed power sources, respectively, in 2020. The most perceptible observation is the significant and rapid increase in FPVT installations, which have reached the accumulation of wind power in less than 10 years. PV technology with the FPVT systems is predicted to increase 7.38% to 485.4 GW, more than today's installed power and installation of hydropower, which is predicted to decrease by 9.28% of currently installed power worldwide [16]. That is the reason FPV systems have become a recent investment interest [8].

There are a few implementations of FPV technology in marine environments. However, almost all of its applications are in freshwater, such as lakes, ponds, and dams and reservoirs worldwide [6]. In marine environments, FPV systems may be more economical than wind farms [17]. FPV systems have not yet been completed, therefore there is much work that remains to be completed in marine environments [18]. China and the Netherlands are the first countries that set up FPV systems in offshore areas [19]. There extensive research and many reports and reviews concerning FPV in offshore areas, which is one of the renewable energy sources to become a prevalent and potential target for a green and clean energy solution, such as environmental impacts of marine floating solar [20,21], applications of FPV in marine areas [9], and FPVT used offshore [15,16,22,23].

In this review, we evaluate the possibilities of FPV systems in offshore areas through previous research and reviews. This review is presented briefly as FPV systems are installed both onshore and offshore to generate electricity supply for houses, factory industries, agriculture, and aquaculture (Figure 1). The strategy of this review follows: the first part examines the status of implementing FPV onshore; the second part gives an overview of the status of using FPV offshore; the third part evaluates the advantages and disadvantages of FPV systems deployed offshore; and the last part covers conclusions and trends of offshore FPV systems.

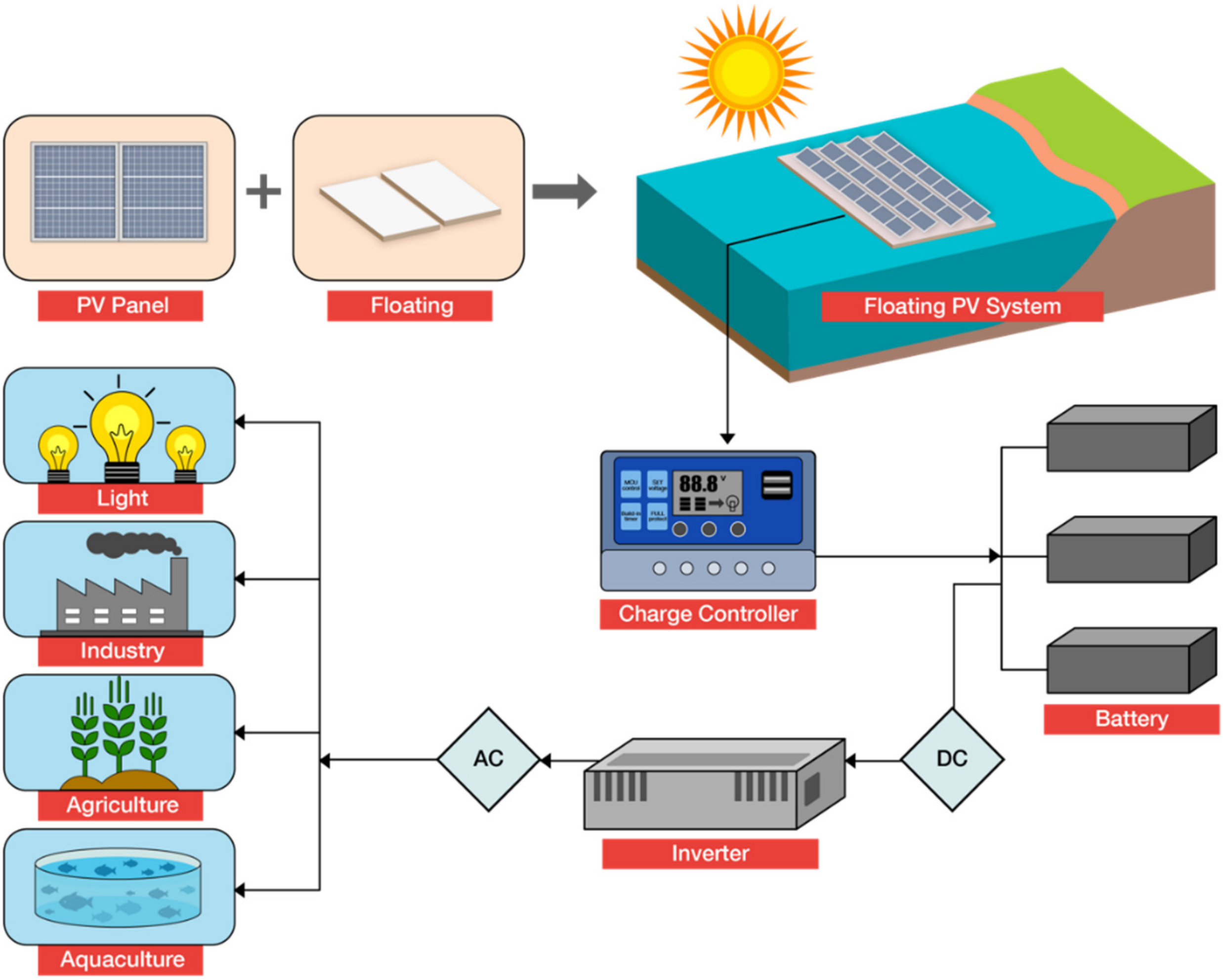

Figure 1. Diagram of a typical FPV system described in this review.

2. Survey of Literature

2.1. The Status of FPV Implementation Onshore

Basically, FPV systems are similar to land-based PV systems. This installation opens a new opportunity to increase power generation capacity; moreover, it is a system suitable for application in countries with large populations and have not enough land resources for PV installation [13], for instance in sub-Sahara and parts of developing Asia. A generic FPV plant can be summarized by the following elements [24,25]: the float; the PV modules and their supporting systems, which support modules weight and transmit forces for the float; and the electrical equipment. The major compositions of an FPV system include a floating structure, a mooring line, anchoring, PV module, inverter, and electrical [26], all of which are shown in Figure 2.

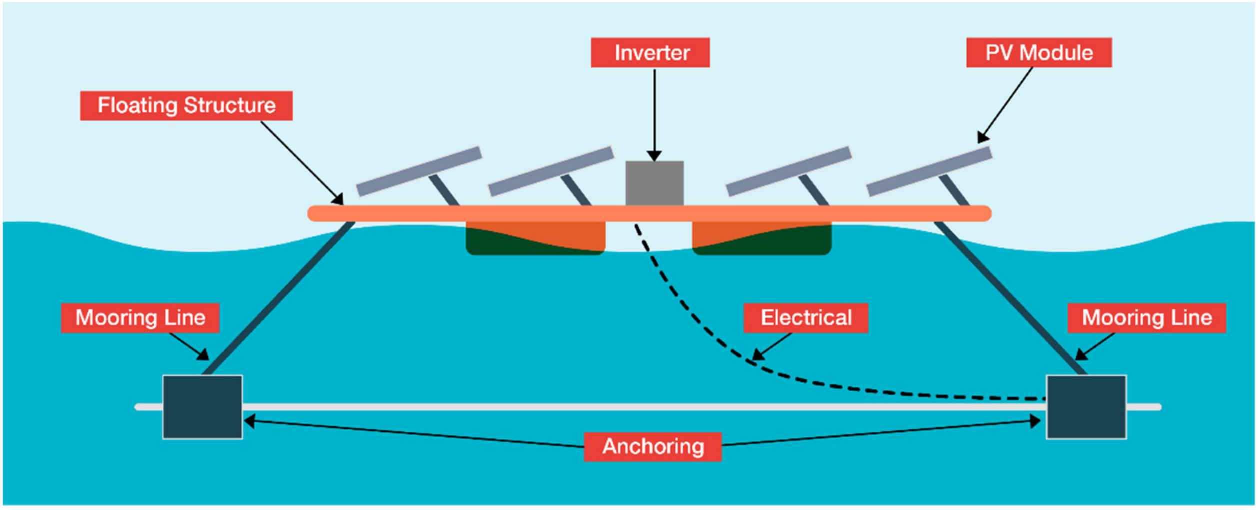

Figure 2. The main components of an FPV system.

Worldwide, there are many studies that have investigated ways to build and install FPV systems on water bodies. Clear information is presented in several recent reviews [16,26,27]. As the report belongs to the World Bank, the latest FPV global market shows that the demand of this energy has increased dramatically since 2007. A brief description of different energy projects and situations in various countries follows [13]:

For Asian countries, two planned projects were installed on a lake in Bangladesh in 2019, one with 50 MW, which were supported by the Asian Development Bank [28]. In Cambodia at the end of 2018 and early 2019, 2.8 MWp and 400 MW of FPV systems were deployed on a pond and a hydropower dam, respectively [29]. In Vietnam, Vasari Energy, a California-based green technology company, deployed 2 FPV projects, each with a 40–50 MWp capacity [30]. A 47.5 MWp FPV project was completed in 2018 on the reservoir of a hydropower plant in Binh Thuan province, with financial support from the Asian Development Bank [31].

In Indonesia, Masdar Clean Energy signed a 200 MWp project covering 225 hectares of reservoir in West Java province [32]. An evaluation indicates that Indonesia has significant FPV potential with 60 reservoirs that could host FPV systems.

Japan has the longest deployed MW-scale FPV installations. The first 20 kWp FPV project was achieved in 2007. The world's second largest project, generating 13.7 MWp, was deployed in a retention dam in 2017 [33]. With its many lakes, dams, and reservoirs, Japan also has the potential of becoming a prime FPV system country in Asia [34].

Lao People's Democratic Republic had plans by a Japanese company to build a 14 MWp FPV system project on ponds in 2018 [35]. Meanwhile, in Malaysia, a 270 kWp of the largest FPV project was installed on a reservoir of drinking water by Cypark Renewable Energy in 2016 [36,37]. It is also a suitable country for FPV installation with 78 lakes [38].

In Singapore, a 1 MWp of FPV was deployed on a reservoir in 2016 by a collaboration of PUB, Singapore National Water Agency, and Singapore Economic Development Board (EDB). In 2017, 50 MWp and 6.7 MWp of FPV systems were surveyed to be installed on Tengeh and Upper Peirce reservoirs, respectively. Singapore is considered to have one of the greatest potential FPV systems in the world, with hundreds of megawatt-peak generated over the coming years [39].

In Republic of Korea, a 0.465 MWp is a notable FPV project, which was developed by Solkiss in 2014 [40]. Another project of 18.7 MWp, the world's largest FPV project outside China, was installed in Gunsan, Republic of Korea, in 2018 [41]; 1 GWp is the planned capacity of FPV systems on reservoirs by K-Water Corporation by 2022. The Korean Rural Community Corporation had plans to set up 280 MWp of FPV system capacity over three sites by 2019 [42]. In 2018, a decision was made to install a 102.5 MW FPV system on Sihwa Lake in Ansan by 2020 by Korea Western Power Company [43].

In Taiwan and China, the water surface of eight lakes was installed with FPV systems by Taiwan Power Co. and Taiwan Water Company [34]. A 20 MWp FPV project was also deployed on an irrigation pond by New Green Power and J and V Holding [44]. In Thailand, SPCG, a Thai solar company, plans to collaborate with InterAct, a Japanese company, to apply an FPV system to power shrimp farms [45]. The Electricity Generating Authority of Thailand (EGAT) collaborated with SPCG to study and develop a mooring system for an FPV plant, which is deployed on reservoirs/dams [46]. A 979 kWp capacity FPV system was installed by SCG Chemicals in Thailand [47] and is situated on an industrial pond. In China, Anhui province is the site for the country's largest FPV project on a lake. A further 400 MW was tendered in Shangdong province. The total installed capacity was more than 950 MWp in 2018 [34]. In India, 2 MWp and 3 MWp FPV systems were installed on Mudasarlova and Meghadrigedda reservoirs in 2016 and 2017, respectively [48]. Another 15 MWp FPV system was set up on Meghadrigedda reservoir in 2018 [49].

In European countries, an FPV project was deployed by the largest Albanian producer, Korporata Elektroenergjitike Shqiptare (KESH), which is planning to further develop a 12.9 MW FPV system [50]. The first 998 kWp FPV system was installed in early 2018 in Belgium [51]. In France, a 17 MWp project was installed by Akuo Energy in 2019. It is situated on a lake [52]. Currently, other large scale FPV projects are being developed in the Hautes Alpes and Bouches-du-Rhône regions. In Italy, the 343 kWp FPV project is the largest system to date, which was located on an irrigation pond by Ciel and Terre International [53]. In the Netherlands, a 2 GWp FPV system will be deployed by a consortium of 40 companies by 2023. There was a 1.85 MWp FPV system built on a local reservoir in 2018 [54]. In the United Kingdom, several 100–200 kW FPV power plants were also built on farm irrigation reservoirs. The first project with 6.36 MWp of capacity was installed on the reservoir in 2016. [55]. The second largest FPV project is located on Godley Reservoir in Hyde with 2.99 MWp capacity [56]. In Portugal, the first 220 kWp FPV project was built on a hydropower dam reservoir in 2016.

Seychelles is one of the first countries that installed an FPV system. In 2018, a 4 MW FPV utility-scale system was the first in Africa [57]. It is supported by the African Legal Support Facility of the African Development Bank and the Clinton Foundation.

For Colombia, Empresas Públicas de Medellín (EPM), the local energy and telecommunications utility of Medellín, in 2018 successfully installed a 99 kWp FPV system on the water reservoir of Peñol-Guatapé [55,58]. In the United States, the world's first FPV system, 175 kWp, was set up on an irrigation pond in Napa Valley, California, and operating since 2008 [59]. Another FPV system project with 31.5 kW was built on a storm water storage reservoir in 2017. A 252 kWp project was installed on a waste water treatment pond in Kelseyville, California, in 2018 [60]. Images of some installed FPV systems are shown in Figure 3, representing several countries around the world—Brazil, Japan, Singapore, China, Korea, the United States, the United Kingdom, the Netherlands, and Panama [13].

Generally, it is still a relatively immature field to apply in many countries. Acharya and Devraj [61] reported that the global installations of FPV remain low, and are mainly in developed countries with high energy production such as the UK, Japan, Korea, and particularly China. In addition, due to the development of FPV technology, energy production has increased within the three years from 2016 to 2018. The total installed capacity in 2018 was estimated at 1314 MWp, which was expected to reach 4600 MWp by 2020 (Figure 4) [61].

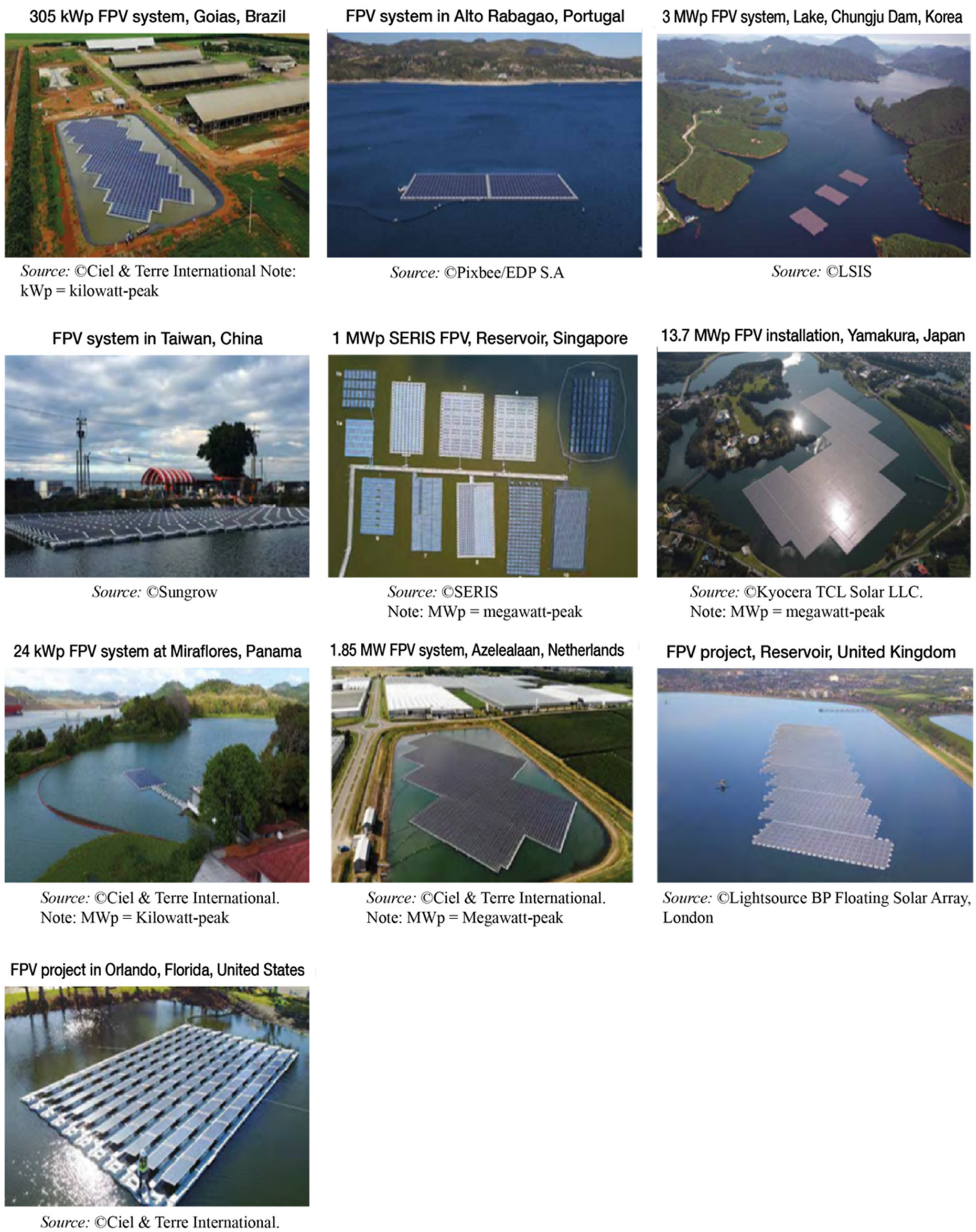

Figure 3. Examples of installed FPV systems worldwide.

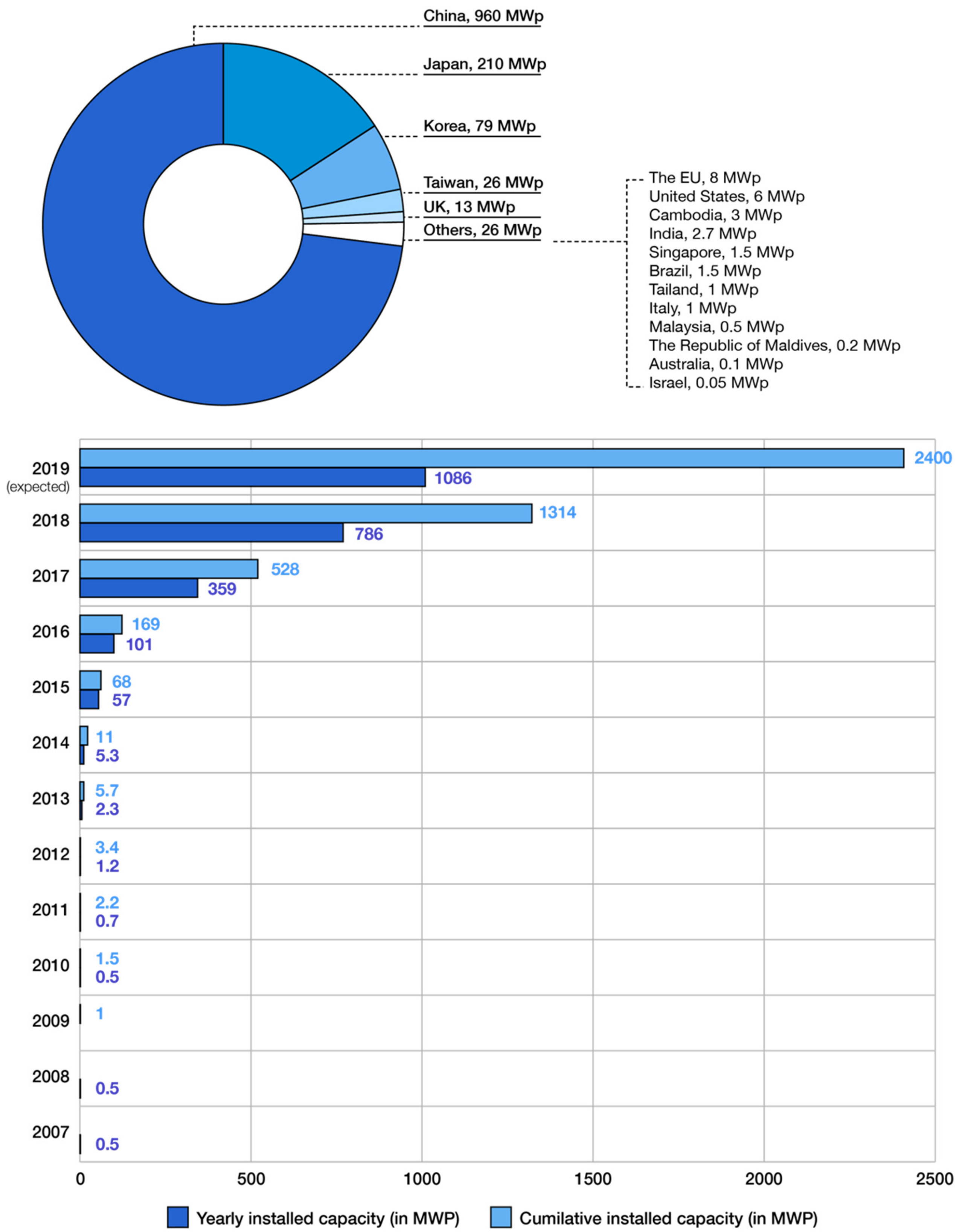

Figure 4. Global installations of floating solar PV.

2.2. Overview of the Status of Using FPV Offshore

The ocean receives much solar energy. Due to the scarcity of land, offshore is a suitable environment that receives more sunlight during the day and is a great opportunity for FPV systems. Cadmium chloride is the main component of photovoltaic solar cells that is very poisonous and costly; therefore, it will affect the production progression and the cost of solar cells. Seawater contains magnesium chloride, which can replace cadmium chloride, which is an extremely poisonous and expensive material used in PV modules [16].

Simulation tests show that the efficiency of marine photovoltaic systems can reach 13% compared to land-based systems, because the temperature at sea is lower than on land, or natural cooling [62]. There are many studies to complete and apply FPV systems offshore in countries around the world. Trapani et al. [17] deployed PV systems in an offshore environment. They conducted six experiments in lakes and reservoirs. The results showed that the offshore FPV system is more economically and technically efficient when using thin film PV at different latitudes from 45° N and 45° S than conventional marine renewable energy technologies (Figure 5) [17]. In addition, the system can reduce collisions, which is one of the important factors to be known for development of offshore infrastructure.

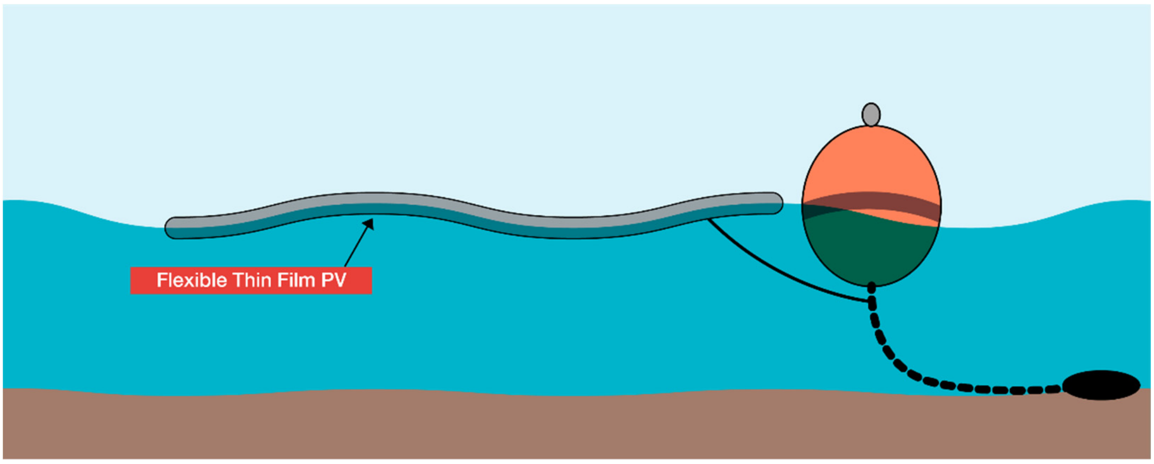

Figure 5. Schematic of the flexible floating PV concept.

The dynamic model is a basic model used to generate the aeration collector platform, consisting of a parabolic trough collector and a pneumatic prestressed solar concentrator (Figure 6) [63]. The results of the experiment suggest that offshore floating solar power plants can generate and provide electricity for European regions. The floating stability of the platform presented is confirmed both on the dial and the periphery, and the performance impact offshore is small.

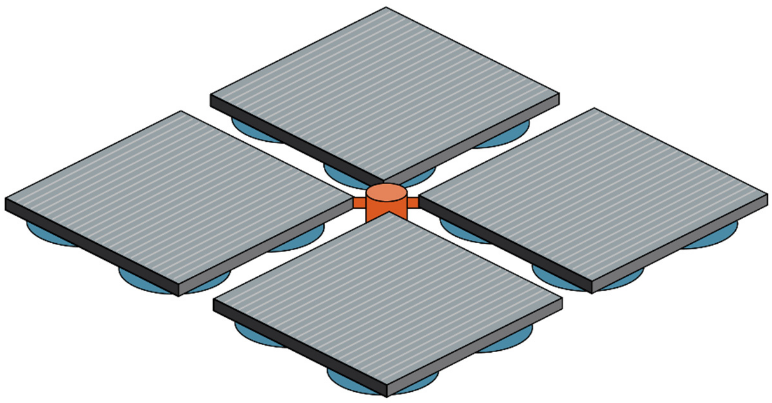

Figure 6. Conceptual design with four solar fields.

Trapani and Millar [64] installed a PV system on the sea surface surrounding the Maltese islands. This report showed that PV integration by using PV α Si technology can help reduce the total cost of electricity generation throughout the system. Three hundred twenty megawatts of energy capacity with thin film PV can be obtained with the maximum cost-benefit. Figure 7 shows the solar radiation for all months with yield (α-Si and poly crystalline), which assumes miscellaneous losses of 10% from total electricity generation and depicts an efficiency of 7% and 14% for thin film arrays and crystalline arrays, respectively [65].

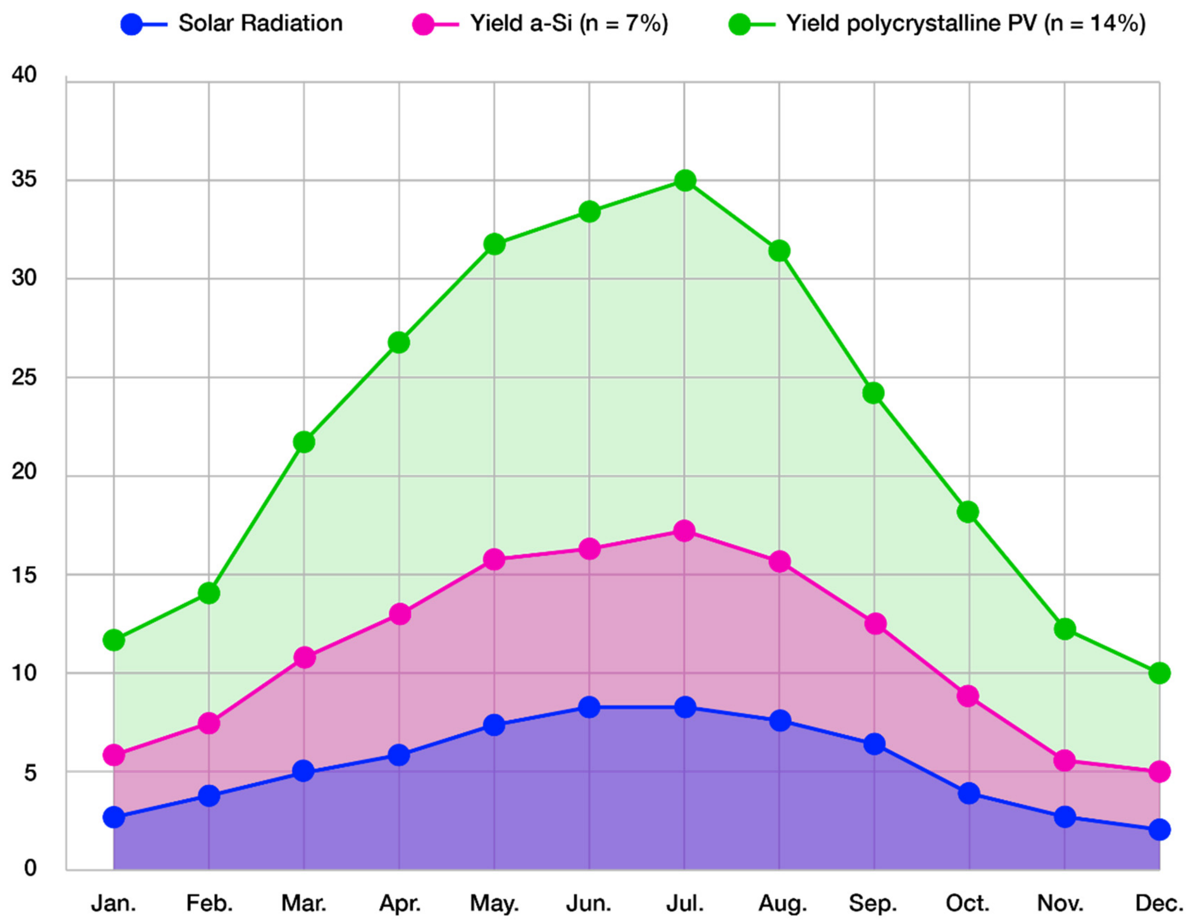

Figure 7. Malta solar and technical PV (horizontally oriented panels) resource averages.

Lee et al. [66] proposes an improved model of the photovoltaic system, which is the optimal model for offshore plant installations. The angles between the photovoltaic panels are studied and how they produce a difference in the intensity of the radiation. They evaluated how the output characteristics of the photovoltaic system changed with differences in radiation intensity, which varies depending on the altitude of the sun. For the SPM system, four directions of the installed solar panels receive sunlight by rotation (Figure 8).

Liu et al. [67] compared traditional terrestrial photovoltaic (PV) systems with each other and with an FPV system. The result showed that floating PV systems provide several advantages, such as saving land and water resources, and, in particular, generate more electricity. In the 3D model of a polysilicon PV module, there are five layers, including glass, EVA, polysilicon solar cells, EVA, and TPT back sheet. Moreover, the PV cell contains a 156 × 156 mm dimension and heat transfer direction, which is shown in Figure 9 [67].

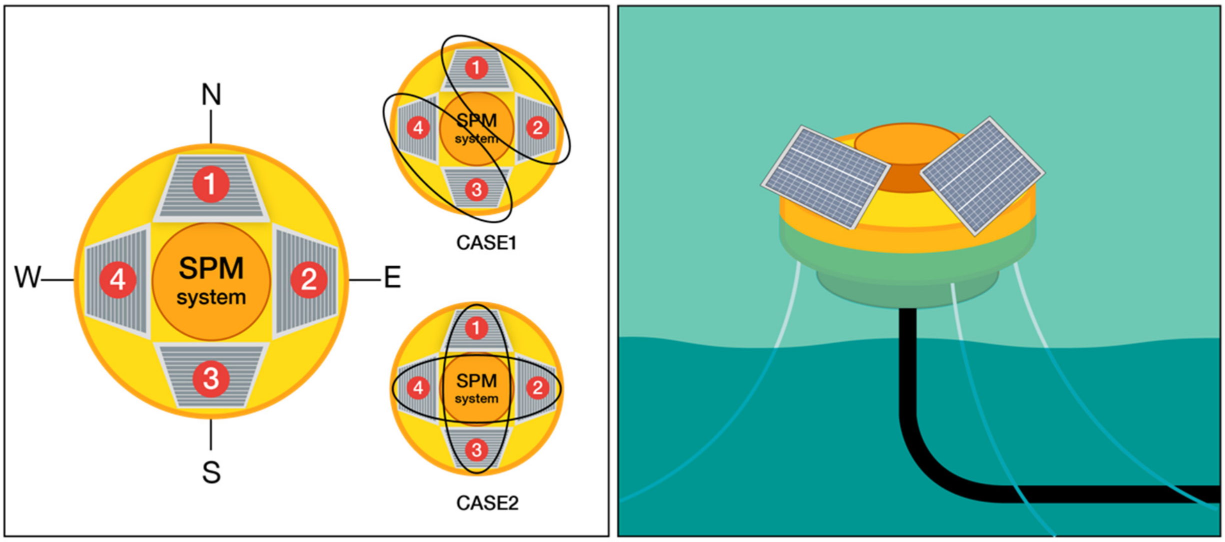

Figure 8. SPM (single point mooring) model with 4 panels (**left**) and SPM system (**right**).

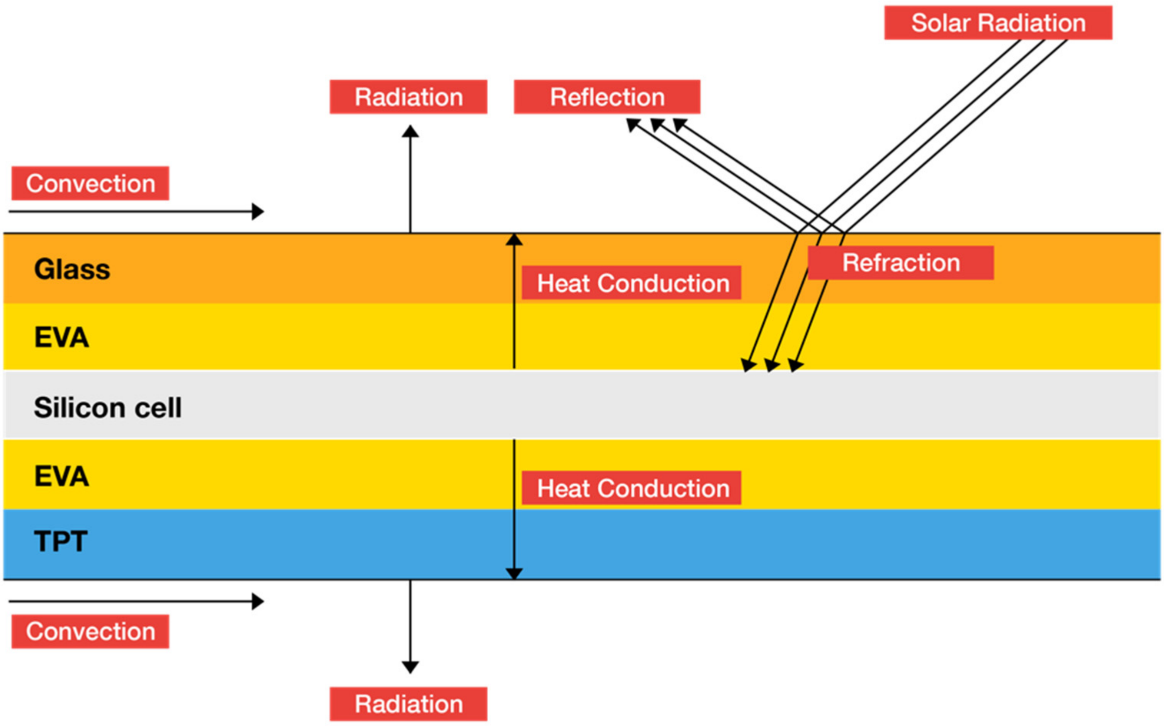

Figure 9. Sketch of the internal structure and heat transfer form of PV cells.

According to, Rosa-Clot et al. [68] suggested the possibility of integrating PV plants with existing basins installed for wastewater treatment. The compact FPVS is installed with optimal row spacing for economic efficiency and technical ease. Figure 9 shows two different solutions for Bolivar wastewater. In Figure 9, on the left, there are 53 floating platforms, one track shaft 800 kWp each, and the diameter of one pedestal is 100 m. An alternative to directional fixed platforms is shown on the right in Figure 10. The capacity of this FPV plant is 42.4 MWp.

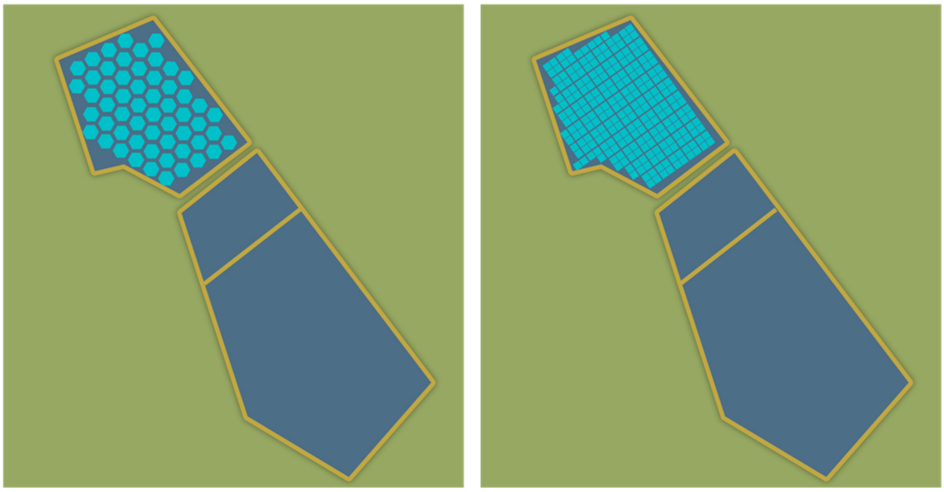

Figure 10. A schematic drawing of two different solutions for Bolivar wastewater basins.

Wu et al. [19] conducted a risk evaluation on offshore FPV projects in China based on the fuzzy framework. They identified 16 risk factors that affect these projects, which are divided into four groups, including microeconomic, technical, environmental, and management risks (Figure 11).

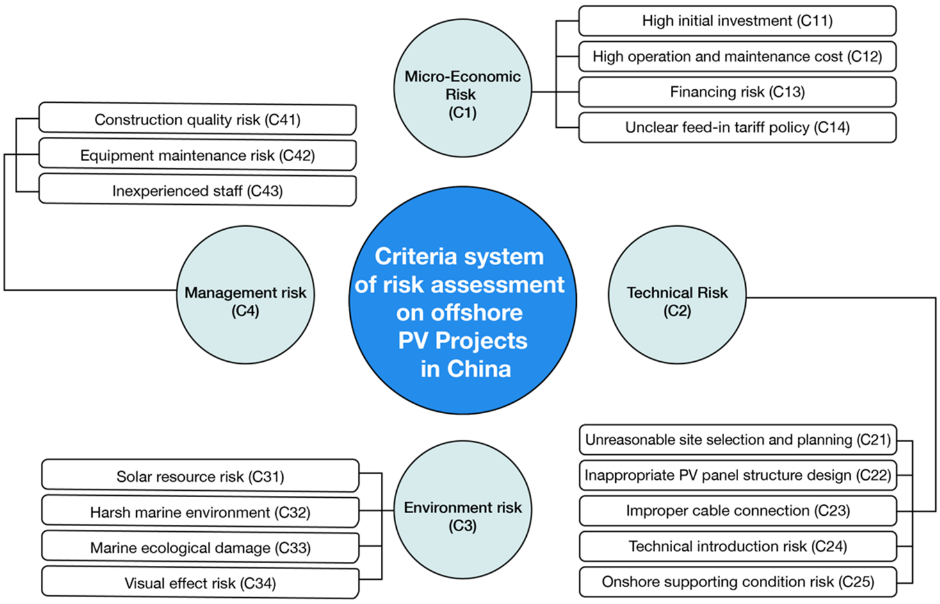

Figure 11. Index system of risk assessment on offshore PV projects in China.

Research was conducted by Golroodbari and van Sark [62] to model, stimulate, and compare between the displays of PV/FPV systems for inland and offshore, respectively. There are three main factors used as hints for comparison: attenuation of sea waves, irradiation, and temperature. They used a wave spectrum to model sea waves in the frequency domain to calculate irradiation on a tilted surface for floating systems, based on the angle which is affected by the sea waves, due to heat transfer theory and the natural cooling system for both land-based PV and FPV systems to determine temperature. The results showed that 12.96% of electricity energy annual for offshore is higher than for inland. Both system models are shown as a flowchart in Figure 12. The 14 numbered boxes represent a process, function, or documented data.

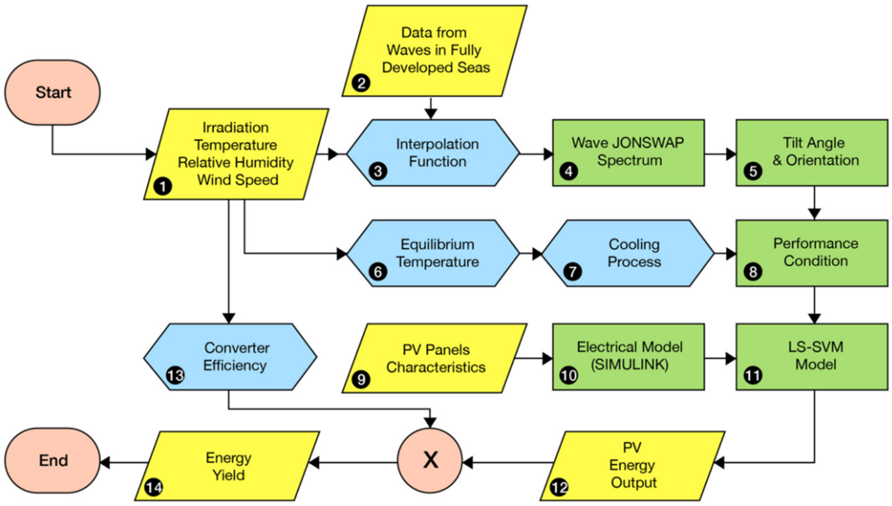

Figure 12. Model flowchart. JONSWAP (Joint North Sea Wave Project); LS-SVM (Least Square Support Vector Machine); PV (PhotoVoltaic).

Lin and Liu [69] presented a new concept for converting decommissioned FPSOs as a platform for FPV plants. The study designed a PV system to power offshore platforms. To evaluate the effect of the tilt angle on energy output, the authors used a frequency-domain hydrodynamic analysis of the FPSO. To investigate the total radiation on a divided collector, two case studies are shown in Figure 13a,b. Figure 13b shows the solar radiation striking a collector and tilt angle modeled to receive solar radiation efficiently. Compared with pitch motion, the result showed that roll motion has a strong effect on the total radiation on a collector [69].

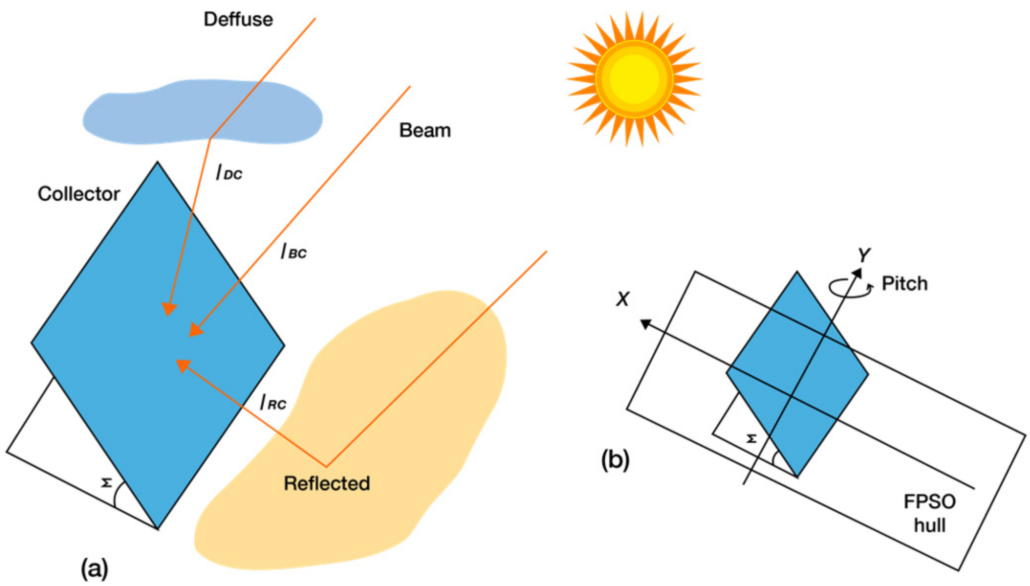

Figure 13. Solar radiation strikes a collector at a tilt angle (**a**). Location and orientation of the PV panel, effects of pitch motion; top view for case study 1 (**b**). Location and orientation of the PV panel, effects of roll motion; top view for case study 2.

Kim et al. [70] examined an FPV power generation system, which is a structure composed of high-durability steel. It was designed with excellent corrosion resistance and durability for building and installing 500 kW of FPV power generation capacity. A solar module, structure, and buoy comprise the photovoltaic power generation unit structure (Figure 14a,b). The installation of the study is set up as a model, as shown in Figure 14c,d, including the frame and photovoltaic module, respectively. Figure 14e–j shows the process to install the FPV system. The result showed that the energy production of the system studied was much more than the PV systems on land [70].

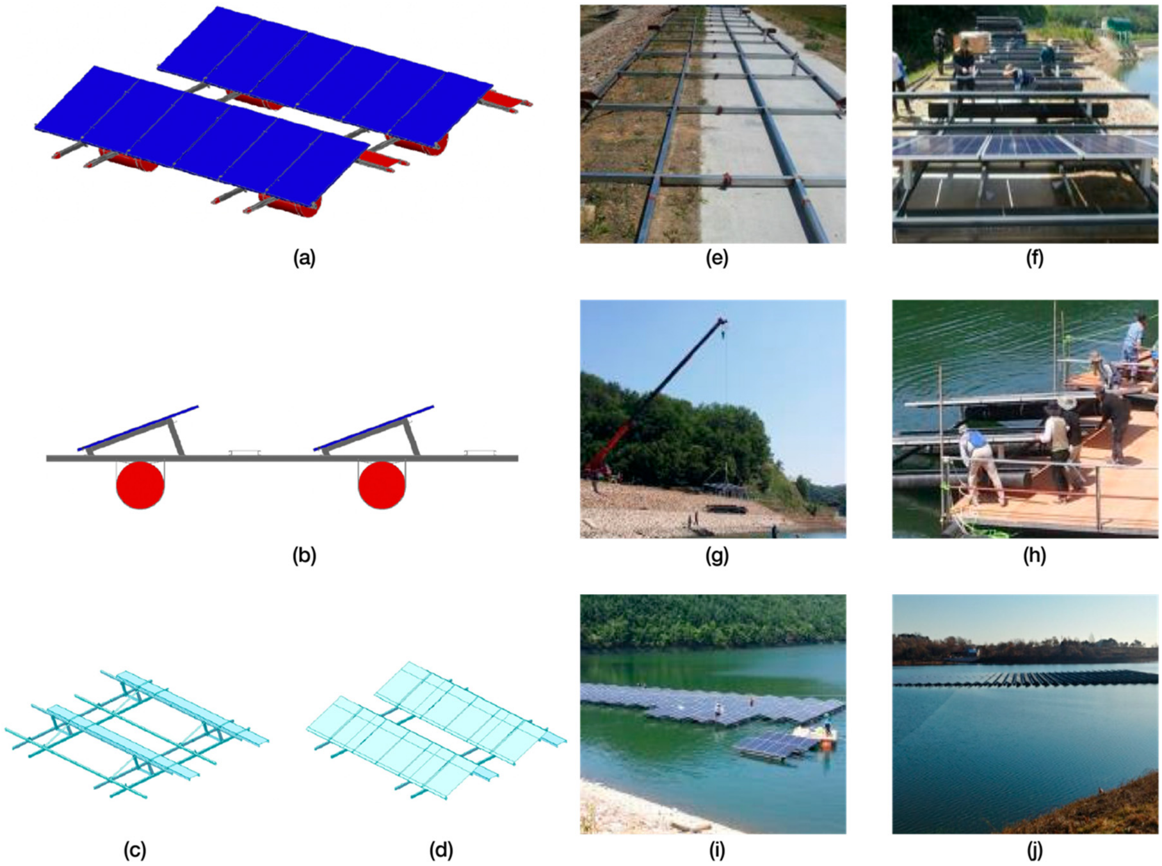

Figure 14. Floating photovoltaic system: (**a**) unit module, (**b**) side view, (**c**) frame, (**d**) photovoltaic, (**e**) basic frame assembly, (**f**) photovoltaic module installation, (**g**) lifting, (**h**) launching, (**i**) assembly on water surface, and (**j**) completion.

Currently, there are many governmental and private companies and consortiums that have invested in FPV systems or have strongly considered investing. The Norwegian consultancy DNV GL experts recognize offshore PV can combine an installation with wind turbines to improve the power generation production. The DNV GL on behalf of the Netherlands Ministry of Economic Affairs and Climate studied and found that the North Sea may host approximately 100 and 500 MW of floating solar capacity by 2030 and 2035, respectively [71]. Norway is one country that has successfully tested two offshore floating PV systems, due to their hydroelastic membrane concept [72].

In Taiwan, a 181 MWp FPV offshore project is the largest facility to be conducted by Chenya Energy, and they have a plan to further expand this system on the west coast of Taiwan. Their project will help provide up to 20% of electricity capacity from renewable sources by 2025 [72]. In Singapore, a 5 MW FPV system was deployed offshore successfully. This achievement creates an optimistic future for more FPV system installations in these regions that have scarce land area [73]. To maximize the solar PV potential for cleaner and sustainable energy, reduce the dependence on fossil-fuel-based sources of energy, and reduce energy costs in Seychelles, a 3.5–4 MW FPV project in a saltwater lagoon on the main island of Mahe was developed by the Seychelles Energy Commission instead of Seychelles government. It is the first FPV project installed in seawater in Africa [74].

Karpouzoglou et al. [75] is the first study to examine potential effects of FPV systems on the ecosystem, including hydrodynamics and fishery exploitation in a coastal area, and to identify its actual field application of FPV in an offshore environment. Based on a water column physical-biogeochemical model, including a general ocean turbulence model, the European regional seas ecosystem model-biogeochemical flux model is used to analyze related ecological parameters. The result showed primary production depends strongly on the coverage density by floating platforms because of the light deficit at three sampled positions: Oyster Grounds (OG), West Gabbard (WG), and Noordwijk-10 (NW) (Figure 15a). The primary production changed less than 10% when the coverage of PV/FPV panels model was up to 20% (Figure 15b) [75].

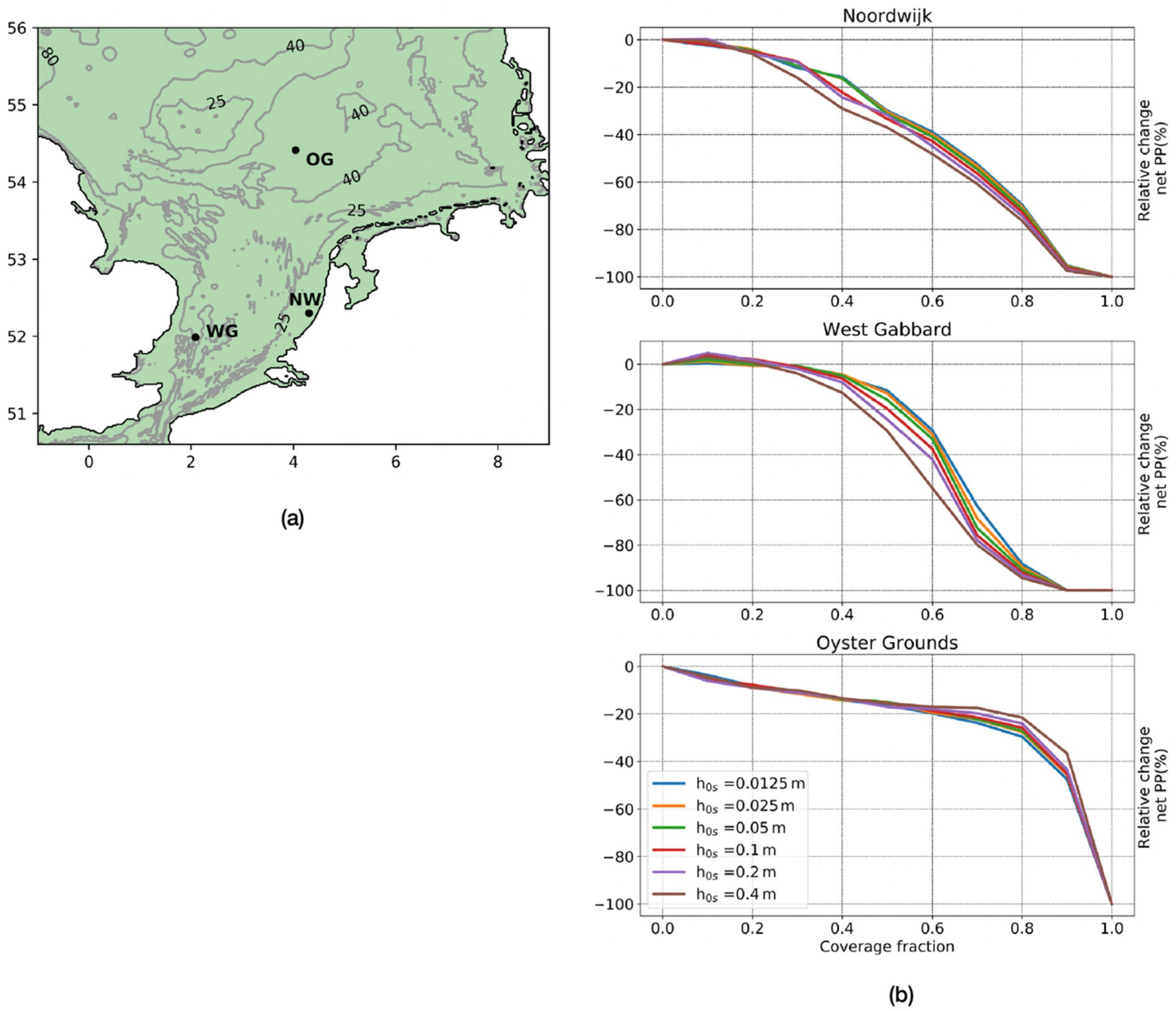

Figure 15. (**a**) Oyster Grounds (OG), West Gabbard (WG), and Noordwijk-10 (NW) sampling stations. (**b**) Relative change against the reference of net primary production with coverage for the three locations of the experiment and different values of roughness height of the platforms.

Su et al. [76] proposed a study to examine the wind loads on a standalone solar panel in a marine environment throughout a wave cycle. A change in deviation of the angle tilt, 20° and 40°, corresponds to variation of wave angle (0–180°). Figure 16 shows a schematic drawing for a tilting panel on a pontoon. The initial angle between the tilting panel and the pontoon, 20° and 40°, is α. A numerical simulation determines the effect of β (= 0–180° in increments of 45°) and γ (= 0–180° in increments of 45°) on wind loads on a standalone tilting panel, which is critical for a system in a harsh marine environment. The results show how the wave angle influences the motion of the pontoon. As the deviation in tilt angle increases, the value of surface pressure on the lower surface increases and the variation in roll angle has an opposite trend.

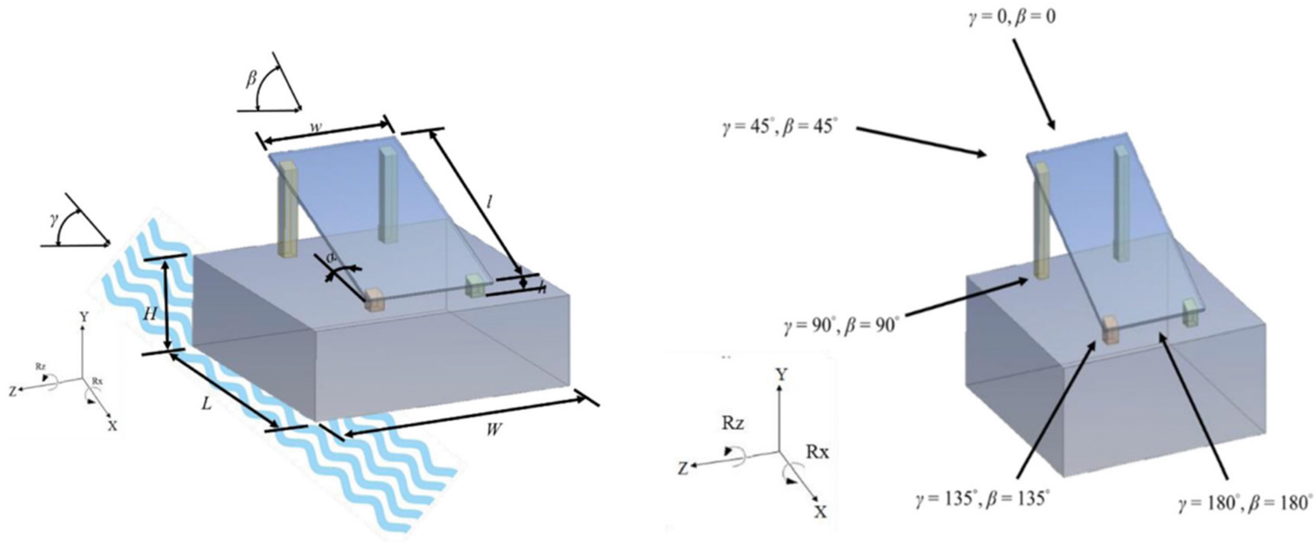

Figure 16. A schematic drawing of a tilting panel on a pontoon.

Ikhennicheu et al. [77] showed several recent ways applied by the industry to design moorings and to identify outstanding areas where further research is necessary before continuing development of industrial projects. Three locations were identified: a small lake (2.5 MWp island) at a solar farm in Murcia, Chile; a large lake (7.5 MWp island) at a floating solar farm in Huancheng Jinning, China; and offshore (2.5 MWp island) at an FPV plant in the Dutch Northern Sea (Figure 17). Wind, waves, and flow currents are colinear with FPV at the offshore site. Figure 16 shows the different angles of FPV in the offshore. There are several load factors considered, such as wind, current, and wave drift. The results showed that wind loads dominated all cases; however, wave drift loads contributed to the total power generation (approximately 50%).

There is an excellent way to explore the green energy in offshore that is a combination of sun (PV/FPV system) and wind turbines. This combination can generate much energy, with five times more compared to the same part of the sea, and it also generates more stable and continuous power generation due to stronger winds in winter and more sun in summer. Moreover, the system also has many advantages for the sea environment, for example, providing the floating installations that serve as protected habitats for fish and a sea platform for attachment of mussels and seaweed.

López et al. [78] explored the potential for a combined offshore wind and FPV system in the coast of Asturias, North Spain. The study shows the way to arrange the PV panels in offshore between the wind turbines to obtain the maximum power generation and to prevent the effect of PV panels and wind turbines on generation of electricity (Figure 18). The results show that energy production per unit of surface area of offshore and solar farm increased by ten and seven times, respectively. This is an excellent model to expand worldwide.

Figure 17. The FPV systems described in this study.

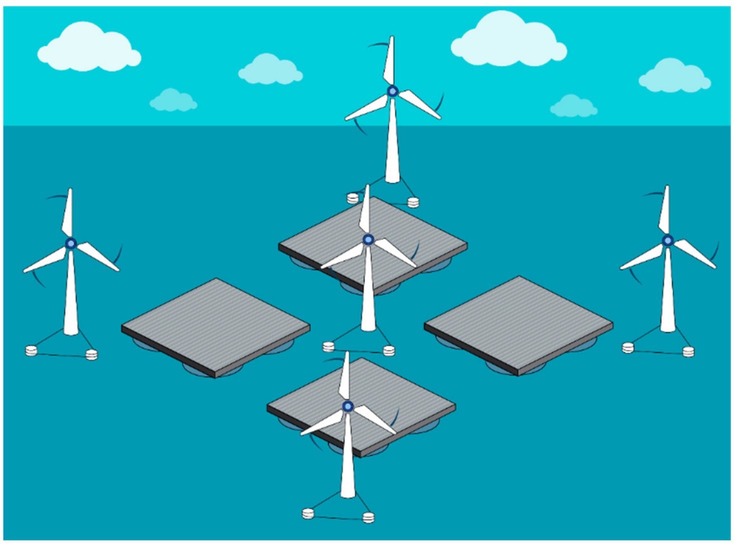

Figure 18. Combined floating wind and solar energy farm: general view.

2.3. Advantages and Disadvantages of the FPV Offshore

2.3.1. Advantages

Rosa-Clot et al. [68] showed that FPV systems that are deployed on the water surface, such as ponds, lakes, dam impoundments, or reservoirs, have been given increasing attention about using this system offshore because of its benefits realized by many countries worldwide. It has already been deployed in several countries during the last decade, including Japan, South Korea, and the USA. According to Esteves Galdino and Almeida Olivieri [79], advantages gathered from many studies include: reducing evaporation of surface water, which helps to conserve the amount of water, especially in dam impoundments, ponds, reservoirs; reducing the formation of waves, which could reduce the erosion of reservoir banks; minimizing the use of land; decreasing the reflectivity of the water increases the incidence of radiation on the PV array, which enhances its energy generation; and increasing the efficiency of FPV system with the evaporative cooling of PV modules and cables.

Furthermore, as the cost of PV panels decreases, the cost of PV installation also declines. The total cost of installation for solar panels will be strongly lower in the next three decades, estimated to be USD 340 to USD 834/kW and USD 165 to 481/kW on average by 2030 and 2050, respectively, compared to the average of USD 1210/kW in 2018. This results in a trend to develop FPV systems throughout the world (Figure 19) [80].

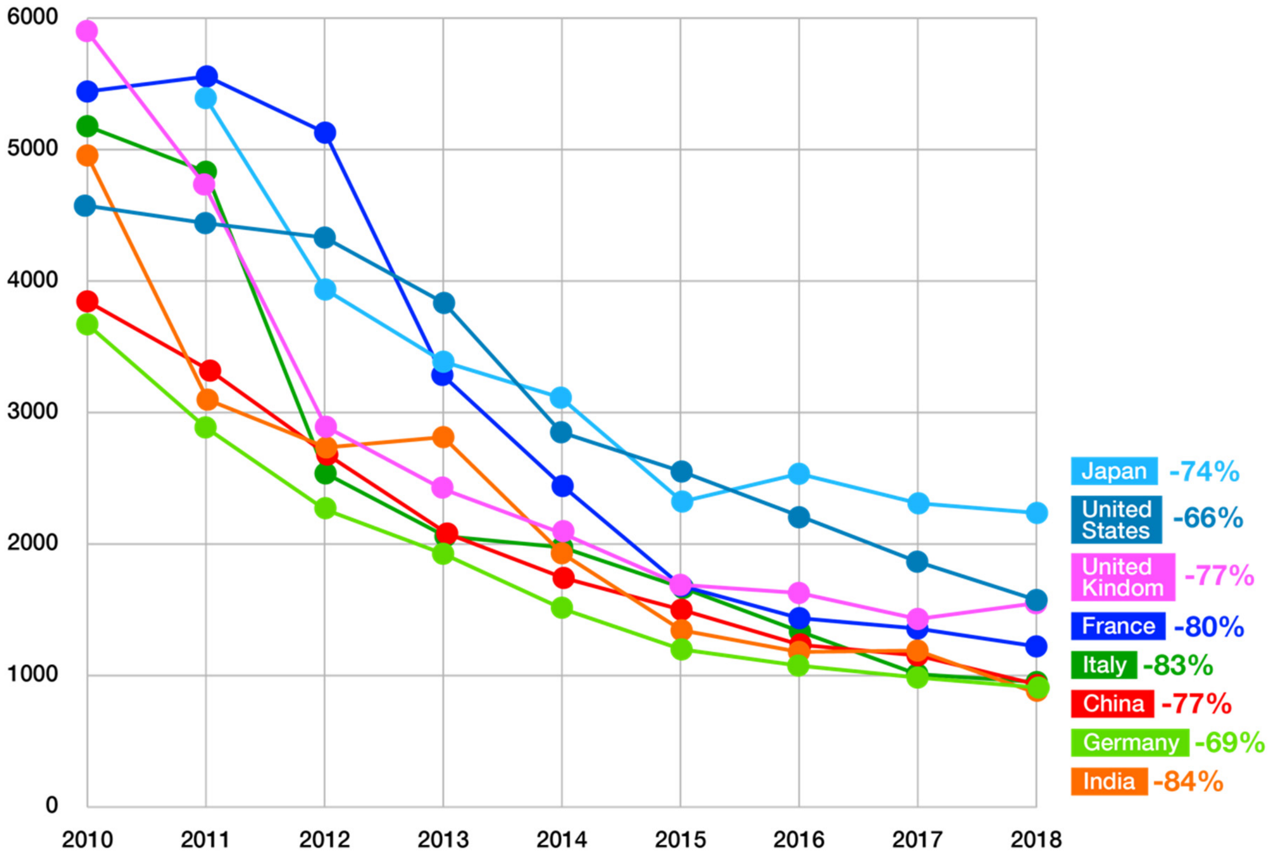

Figure 19. Total installed cost of utility-scale solar PV for selected countries, 2010–2018.

To obtain these results, feed-in tariffs (FITs) are one of the effective solutions to increase energy production in many countries. In reality, half of the PV installations worldwide are a result of FITs [81]. FITs are from governments with many policies to support the development of FPV installations. Each country has suitable FITs to increase their energy production to satisfy the society's energy demand and to protect the environment, including financial incentives and supportive government policies [13].

Some representative FITs for FPV installation financial incentives announced by countries include, for example: FITs for FPV are higher than those for ground-mounted PV in Taiwan and China; extra bonuses for renewable energy certificates in Korea; and high FITs for solar PV generally in Japan; and extra added value for FPV generation under the compensation rates of state incentive programs in Massachusetts, United States. In addition, several governments have policies to encourage the development of renewable energy, for example, ambitious renewable energy targets in South Korea, Taiwan, and China; realization of solar power plants in India; dedicated tendering processes for FPV in Taiwan, China, and India; and openness on the part of the entities managing the water bodies, such as bids for water-lease contracts in Korea.

2.3.2. Disadvantages

Oliveira-Pinto and Stokkermans [26] reported that FPV systems in offshore/marine environments face many problems, including not yet having a commercially available technology for the RL of marine FPV and mooring and anchoring configurations. It is estimated that mooring systems cost 10% of total capital expenditure on average for a wave energy converter [82].

Furthermore, it is complicated to install the FPV system in challenging offshore/open sea environments, including lifting, towing, maneuvering, and positioning heavy structures [83]. Investing in materials that can match requirements for the lifetime of the system throughout the entire project is needed because marine environments are exposed to water, salinity, humidity, and environmental stress cracking [84]. The cost of installing a marine FPV system is one of the disadvantages because it is higher compared to other marine renewable energy and currently an immature sector [26]. Sea water is also a disadvantage for FPV systems. It is related to corrosion and potential induced degradation [85]. Because of submerged installation in the sea water environment, algae, marine invertebrates, and other small aquatic species attach and accumulate on the outer surface of submerged offshore structures, causing an increase in their size and changes in other physical properties [86]. Marine FPV systems may be an artificial shelter; therefore, it attracts many birds that can harm the system.

In addition, Acharya and Devraj [61] demonstrate that FPV technologies remain a novel sector that face many challenges, including: technology challenges (unavailability of FPV-specific standards/technical guidelines, unavailability of waterbody data, FPV plant component safety and its long-term reliability, absence of local manufacturing, and unavailability of bathymetry and other water-related studies); environmental and social aspects; installation challenges (clearances for FPV projects, waterbody ownership, and transportation of floating platforms); operation and maintenance challenges; and quality [61]. They explained clearly the disadvantages/challenges of FPV systems.

2.4. Overview of Floating Photovoltaics Technologies

Ranjbaran et al. [87] showed that it is possible to deploy an FPV system in the marine environment using methods similar to installing an FPV system in inland water bodies. Basically, the FPV system consists of solar PV modules, cables, pontoon, an independent float structure, and mooring system [16].

However, the differences between onshore and offshore environments are significant, including wind loads, wave loads, salt, and the ecosystems. Therefore, the development of new concepts for offshore FPV systems is necessary. As with any new technology, it is essential to overcome technical challenges, particularly FPV systems installed in offshore/opened sea environments. Mooring/anchoring systems must be designed to withstand strong wave and wind effects (Table 1). The table shows several kinds of floaters, mooring, and anchoring, together with their characteristics, which have been used for installing FPV systems in many countries worldwide. As a result, floating PV installations always move to some extent in accordance with the changing force of waves and winds in the sea. Moreover, PV panels are also considered to be suitable in marine environments [88].

Table 1. Variations of mooring/anchoring types in FPV systems.

Name	Authors	Characteristics	System
Type of Floaters			
Zon op Zee (Solar-at-Sea) [89]	Dutch companies and research organizations including TNO, MARIN, ONE-Dyas, and Oceans of Energy	-Easy to expand modules capable of withstanding rough seas up to 13 m.	Figure 20.
HeliFloat [90]	HeliFloat, Vienna University of Technology	-This platform can withstand rough seas while remaining stable. The platform can be lifted from 10 to 15 m above sea level.	Figure 21.
Floating Solar Park [91]	Moss Maritime	-Suitable for both onshore and offshore locations. The designed modules are based on the location and weather. -Each module contains a platform on top, which is supported by vertical columns. -A flexible connection connects to the modules. -Float can withstand wave heights of up to 3–4 m.	Figure 22.
SolarSea [92]	SwimSol, Vienna University of Technology	Model is designed for nearshore, can be faced with waves of tropical shallow-water lagoon with 1.5 m of wave height, the currents, tides, extreme UV, humidity and is corrosion-proof.	Figure 23.
Ocean Sun [93]	Ocean Sun	-The design can be used for aquaculture farms near the shore and semisheltered waters. The modules are installed on the double keder that are welded on the thin and flexible reinforced membrane, which allow the structure and PV modules to move smoothly with waves	Figure 24.
Mooring			
Mooring Layout			
Catenary Mooring [94]	Rosa-Clot and Tina, 2020	The system is designed based on self-weight and friction of the line with sea bed to stimulate the required restoring force. This system requires a larger mooring footprint.	Figure 25.
Taut Mooring System [94]		The system made for restoring forces from the line deformation more than its weight. Moreover, it is generated by axial elastic stretching. It requires a smaller mooring footprint.	Figure 26.
Hybrid Mooring System [94]		This system can have catenary mooring or taut mooring characteristics. It reduces the mooring footprint significantly.	Figure 27.
Mooring Makeup			
Chains [95]	Chakrabarti, 2005	Stud-link chains are stronger compared to studless chain. It provides more stability to the link and makes it easier to handle.	Figure 28.
Wire Ropes [96]		-Wire ropes are manufactured from multiple wires of metal (steel) that are twisted together into a helical pattern to form strands, which improves the strength and reduces the crushing effect. A coating on the rope strands decreases its corrosion.	Figure 29.
Synthetic Fiber Ropes [97]		-Synthetic fiber ropes are light, elastic, and low-cost compared to other materials. They can be used in deep water, as they reduce a large amount of the vertical loads, and also reduce the complexity in the installation.	Figure 30.
Anchoring			
Deadweight [98]	Wang and O'Loughlin, 2014	-Deadweight is a heavy object made by concrete or steel, placed over the soil. -The common designs of deadweights are sinker, squat clump, mushroom, and wedge.	Figure 31.
Drag Anchors [99]		-Fluke area and penetration into the soil are two parameters for estimating holding capacity. -High-holding capacity and can load up to 30–40 times its weight.	Figure 32.
Plate Anchors [100]		-Shape of a plate that is embedded deeply in the soil and is installed in different ways.	Figure 33.
Pile Anchors [101–109]		-Cylindrical with an open end and made of steel. -Can penetrate into the soil by using a different installation procedure.	Figure 34.

Figure 20. Zon op Zee (Solar-at-Sea).

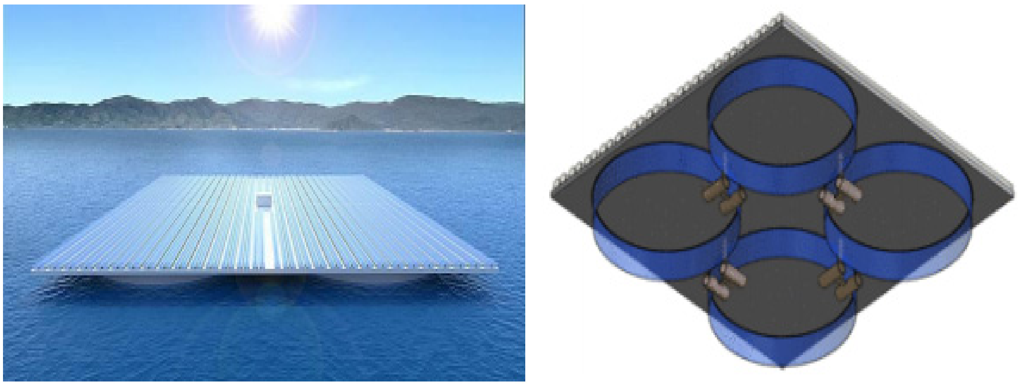

Figure 21. HelioFloat offshore platform.

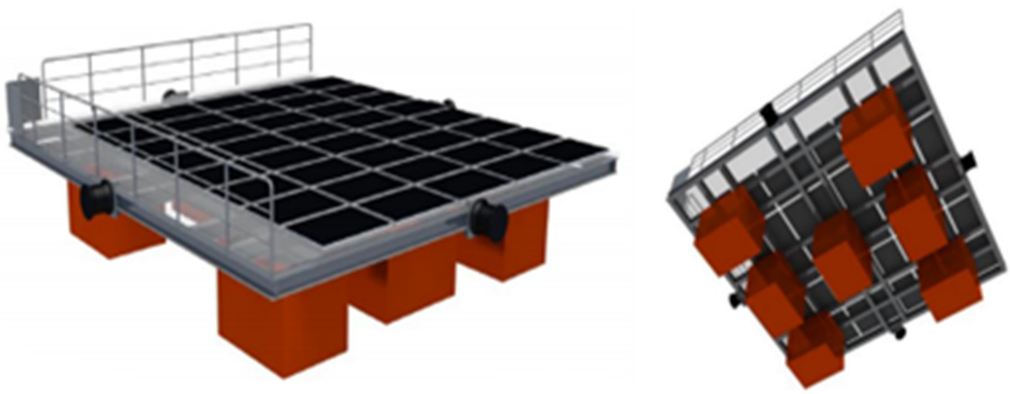

Figure 22. Floating Solar Park.

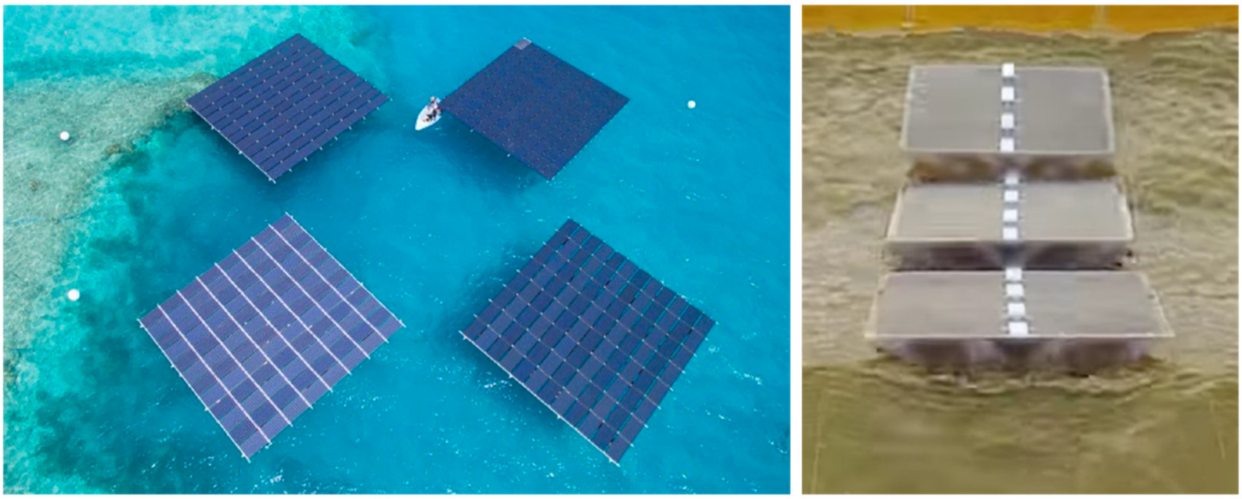

Figure 23. SolarSea.

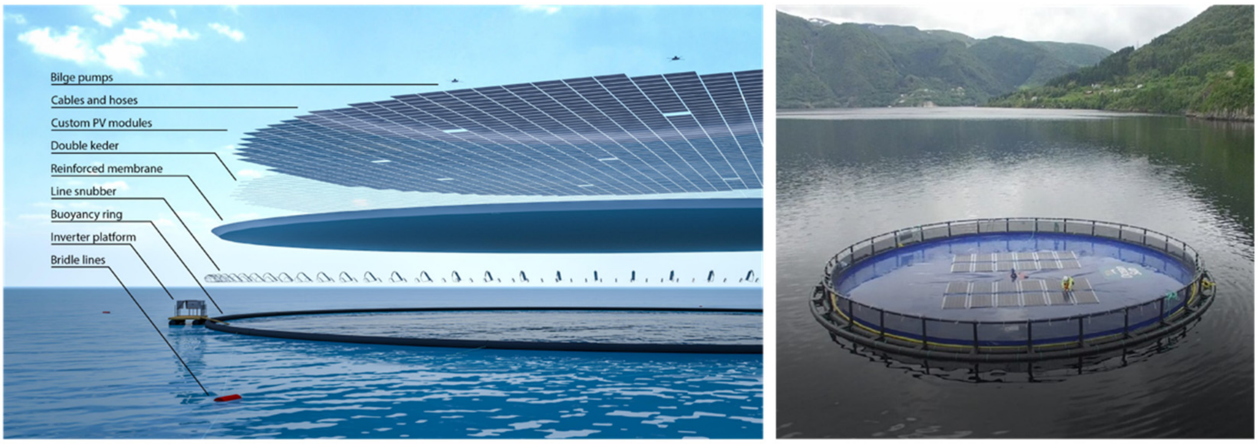

Figure 24. Ocean Sun.

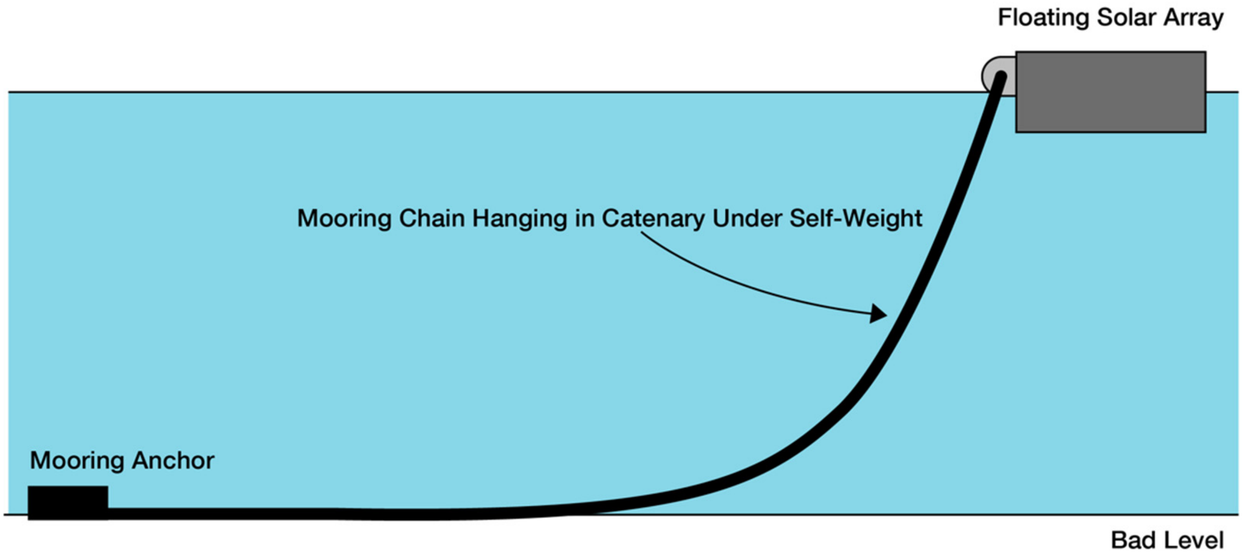

Figure 25. Catenary mooring system.

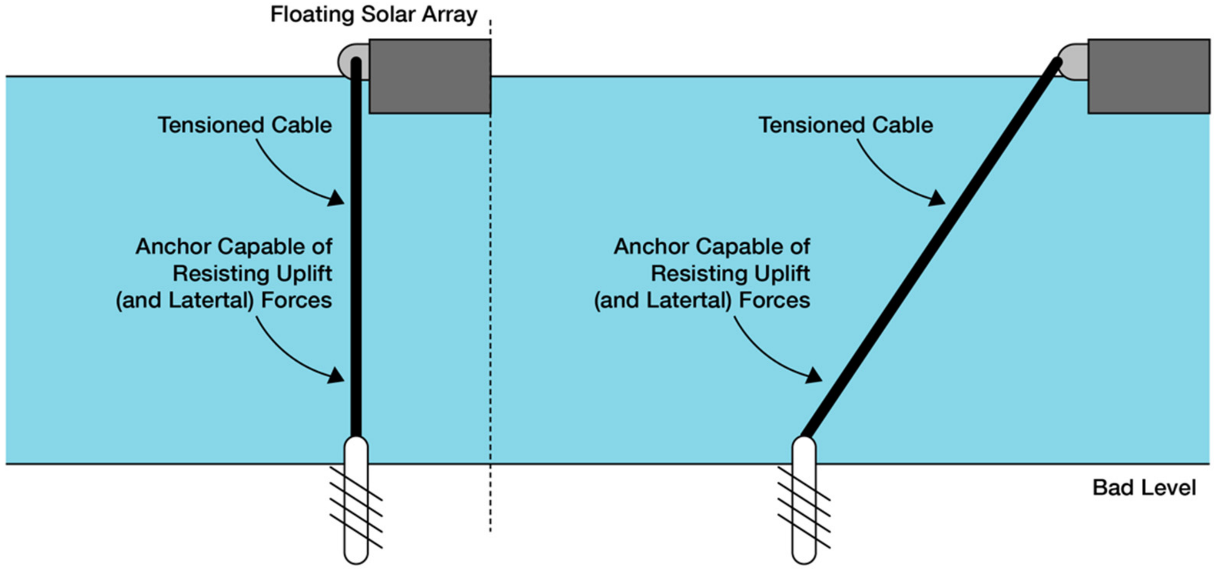

Figure 26. Taut mooring system.

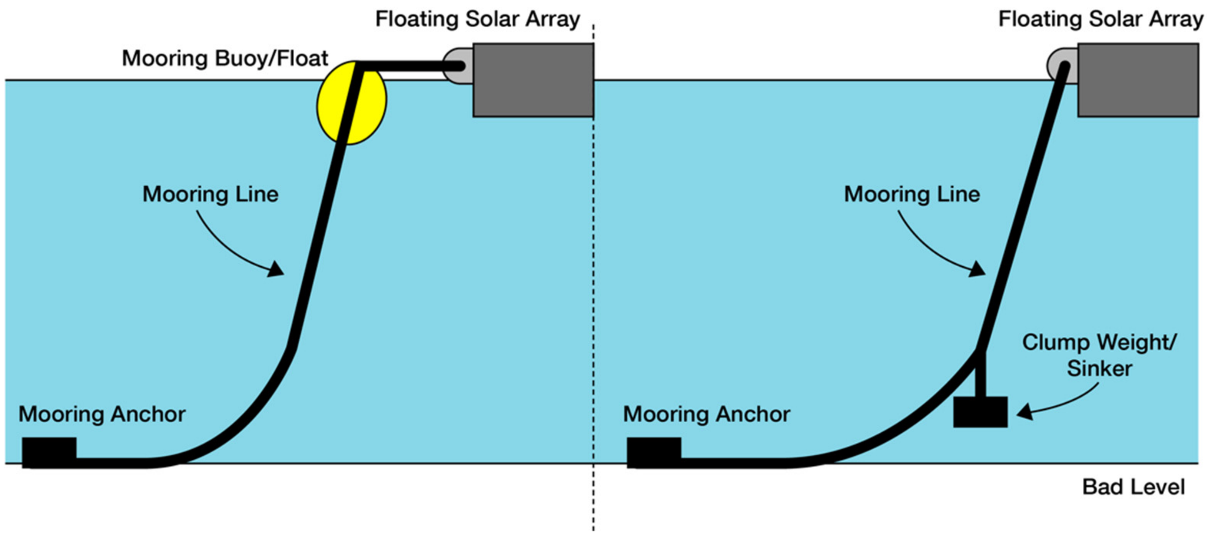

Figure 27. Hybrid mooring system.

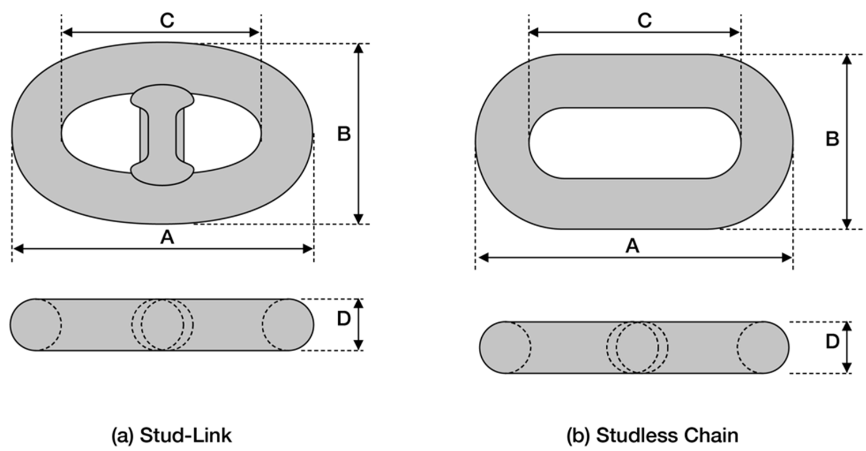

Figure 28. (**a**) Stud-link chain and (**b**) Studless chain.

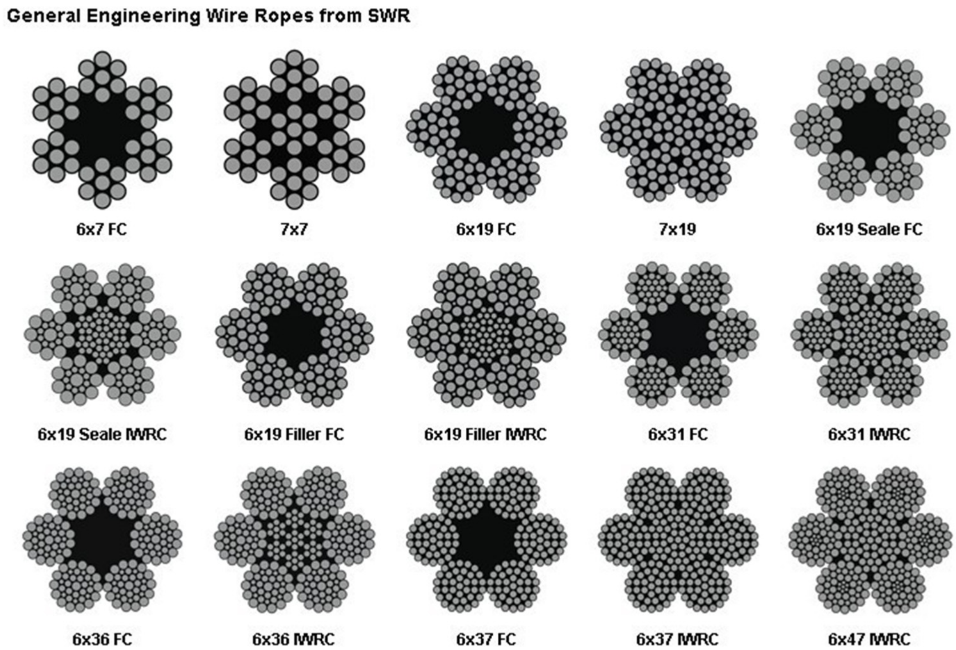

Figure 29. Wire rope.

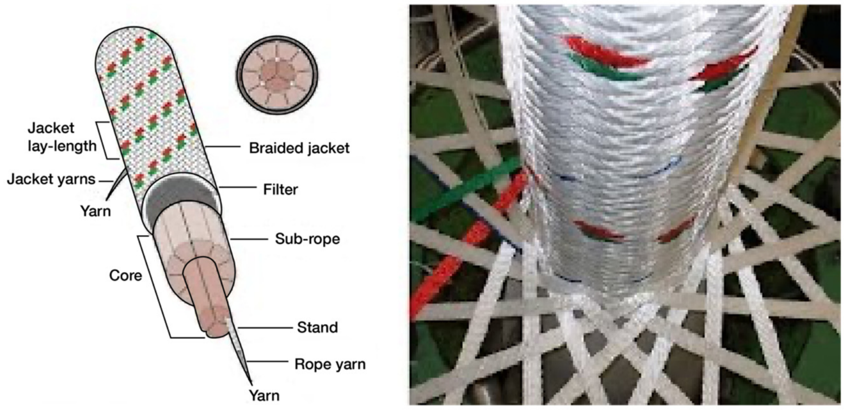

Figure 30. Synthetic fiber ropes.

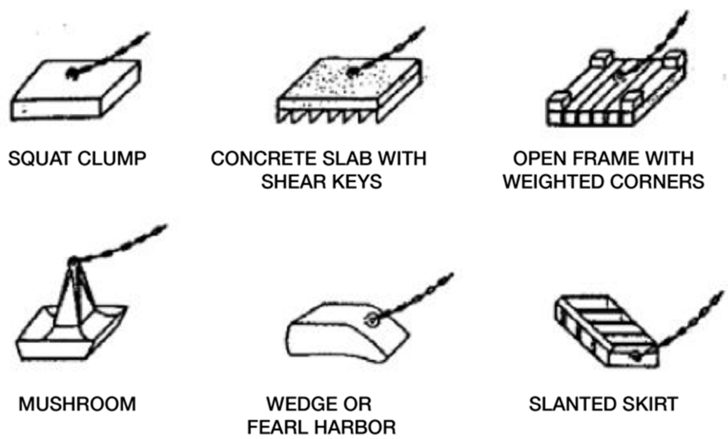

Figure 31. Deadweight anchors.

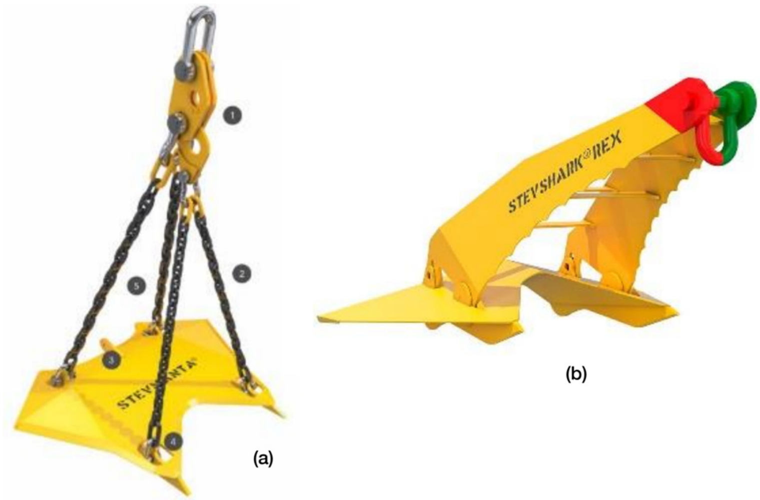

Figure 32. (**a**) Drag anchor and (**b**) vertical load anchor.

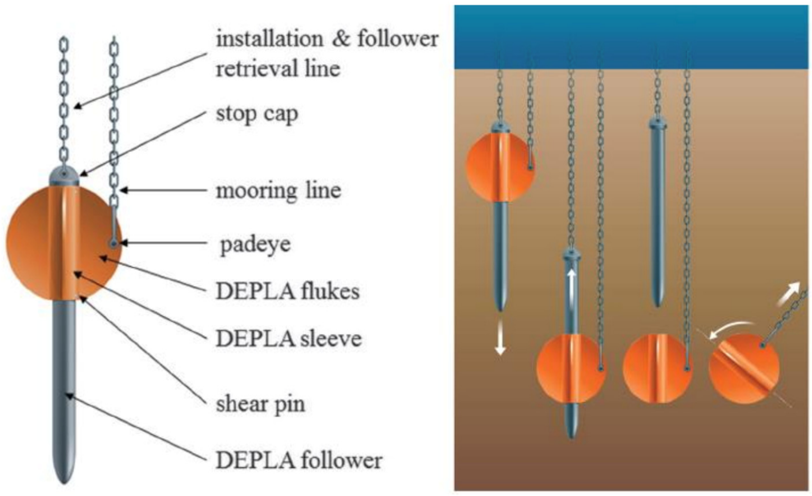

Figure 33. Plate anchor.

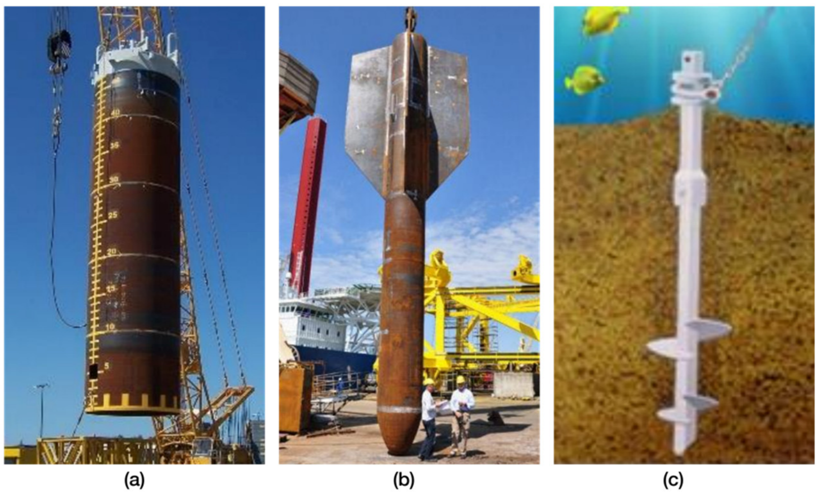

Figure 34. Pile anchor, torpedo anchor, and screw or helicoidal anchor respectively [101]. (**a**) Pile anchor, (**b**) torpedo anchor, and (**c**) screw or helicoidal anchor respectively.

For PV modules, according to IRENA [88], further growth of the solar PV industry will be largely due to reducing the balance of systems (BoS), which is the main reason for almost the entire total installed system cost, and has the most potential to reduce the cost. To achieve this, lower cost cell materials, decreasing the cost for making cells, and increasing cell efficiency levels, must all be included. In this field, the technology has improved. According to Vázquez and Rey-Stolle, the longevity of a PV module is estimated at about 25 years. The same result was found by Won et al. with module nominal power decreasing by about 13.9% after 25 years [102,103]. Figure 35 gives an overview of the PV technologies and concepts developed through time.

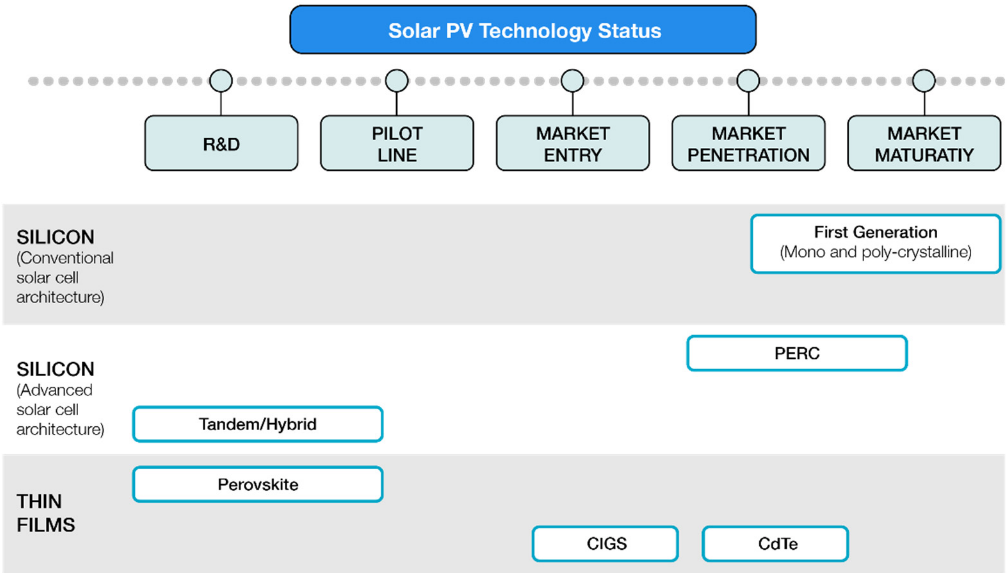

Figure 35. Status of solar FPV technology worldwide.

Crystalline silicon (c-Si) panels are materials in the first generation of solar PV panels and share 95% of worldwide PV production [104]. A PERC cell is made using advanced silicon cell architecture. In construction, PERC cells are nearly similar to a typical monocrystalline PV cell, but the main composition is the integration of a back-surface passivation layer, which is able to improve the cell's efficiency based on the layer of material on the back of the cells [105].

Thin film technologies are the second generation of PV. The semiconducting materials are few micrometers thick [106]. These technologies have components such as silicon-based thin film (amorphous (a-Si), micromorph silicon (a-Si/c-Si), and nonsilicon-based (perovskites, cadmium telluride (CdTe), and copper-indium-gallium diselenide (CIGS)). They are less expensive, so can be produced at a commercial scale. Furthermore, Lee and Ebong provide a full review concerning thin-film cells. Three types of thin-film cells were analyzed concerning conversion efficiency, evolution, commercial technologies, market, and the future of this material for PV modules [107].

2.5. Future of FPV System in Offshore

The future of FPV systems is extremely dependent on its commercial viability and its competition with other nonrenewable and renewable sources of energy in the current market. Based on the reduction of the cost of materials for producing PV panels and the cost of PV installation, the total cost has gradually been reduced. The combination of marine FPV systems with offshore wind farms could be an efficient and sustainable solution to improve energy production [26].

As it is not necessary on the land, FPV systems could increase by double the existing installed capacity of solar PV [13]. Moreover, FPV technology is becoming mature, which is evidence for opening up a new frontier for global expansion of renewable energy and giving large opportunities for many countries and markets around the world. In addition, many experts strongly believe that offshore floating solar "*may be the next frontier*" [108]. Solar photovoltaic (PV) panels in offshore waters are one of the essential future green energy sources. By combining FPV systems offshore with aquaculture and wind power in the same location, this innovative technology allows for a more efficient use of available space [108,109].

To date, although FPV technology has been installed onshore, it is still novel for offshore areas. There are few studies related to the FPV systems in offshore/marine environments. Yousuf et al. [16] also suggested some future studies to limit the risk and improve the efficiency of FPV systems offshore, including: verifying the effects of sea water on the structure and function of PV modules; analyzing the impacts of electrical devices (converters) on the surface of water and on their efficiency and performance; investigating the effects of FPV systems on water quality, ecosystems, ecology footprint, and other environmental factors; expanding studies concerning the capacity and performance of FPV power plants; designing optimum FPV systems to decrease the effects of the marine environmental factors; expanding the life cycle of FPV systems; and decreasing the material costs of FPV modules.

3. Conclusions

FPV systems offshore have developed and matured because of gains in energy production, based on the results obtained for the FPV sector onshore, in which FPV systems are set up in water bodies such as lakes, reservoirs, and dam impoundments. However, to date, FPV in offshore areas is still a novel sector around the world. Therefore, there are several studies in-progress that will adapt FPV systems in offshore/marine environments in a mature way, including PV modules and the effect of environmental factors on FPV systems. Some installations of FPV systems offshore around the world are presented, particularly in developed countries, such as Japan, South Korea, the United Kingdom, and China.

Based on the previous results, which were studies on FPV systems in onshore and offshore locations, there are many advantages, particularly the possibility for matching worldwide energy demand, reducing environmental pressure, and solving the scarcity of habitable land issue. Furthermore, FPV systems offshore also present several disadvantages, such as the exposure of FPV systems to waves, wind loads, salinity, and aquatic species, all of which affect the life cycle and efficiency of energy production. Specifically, it is necessary to design standard and suitable practice guidelines for nearshore and offshore FPV systems environments.

There are several successful FPV projects that have been operating in several countries around the world, together with FITs, which are given by governments to open an opportunity to develop FPV systems offshore. Furthermore, it offers an excellent opportunity to provide energy for islands that severely lack energy. This review gives an overview of the possibilities to apply FPV systems offshore worldwide.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

FPVT	Floating Photovoltaic Technology
EGAT	Electricity Generating Authority of Thailand
SPM	Single Point Mooring
OFPV	Offshore Floating Photovoltaic
FITS	Feed-In-Tariffs
PERC	Passivated Emitter and Rear Cell/Contact
EDB	Economic Development Board

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