Review of Floating Solar Photovoltaic Researches in Indonesia

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Abstract The increase interest of emission reduction of electricity sector in Indonesia has driven the exploration of renewable sources including Floating Solar Photovoltaic (FPV). This article reviews the development of FPV researches in Indonesia through systematic literature review. The collected data were analyzed based on waterbody type, geographical location, system configuration, floating technology, cell technology, and simulation tools. The analysis shows that FPV research are predominantly assessing the potential of reservoirs, lakes, and seas spread across Indonesian archipelago. Among 34 provinces of Indonesia, the provinces of East Java, West Java, and Bali are being the most active provinces as location for FPV researches. On-grid systems are the most commonly explored options as it is supported by government policies and existing grid infrastructure. The review shows the increased interests on assessing the potential of FPV in the Indonesian renewable energy sphere considering 2/3 of the nation is covered by water.

***Index Terms*— Power generation, renewable energy, floating PV, FPV.**

I. Introduction

There is a high potential of solar energy in Indonesia that is characterized by solar radiation intensity of 4-5 kWh/m^2/day [1]. Nevertheless, land-based solar power plants may be inhibited in scale by the amount of available land, competing factors or interests to that land resource and land expense. The FPV systems became an alternative to overcome those issues; the underused water surfaces (reservoirs, lakes, dams) can support solar projects.

There are some technical and environmental benefits of FPV systems. The performance of PV modules in cooling effect of the underlying water surface has the capability to enhance energy production by 10 per cent over land-based systems [2]. Also, it has been reported that FPV installations can save water by alleviating water evaporation and algae proliferation, which leads to conservation of the water and enhanced water quality [3][4]. These are the features that explain why FPV is a favorable solution in countries such as Indonesia that is rich in inland water resources.

Over the last couple of years, there is a growing tendency to develop FPV projects in Indonesia. The Cirata Reservoir project with 192 MWp in West Java is sized to the largest in Southeast Asia currently, and the 100 kWp project at the Muara Nusa Dua Reservoir in Bali proves that small projects of only about 100 kWp can use FPV as well. Such projects contribute to national goals on renewable energy adoption in Indonesia as well as providing a means to more sustainable energy systems. However, development of FPV in Indonesia remains relatively early, both in scale of the projects and significance in terms of academic research in the field. A majority of studies conducted so far are on the system design and simulation rather than the actual performance analysis and issues of operation. That is why it is important to have a detailed picture of the existing research landscape that will reveal the gaps in knowledge, help develop future study directions and help make research more successful as well.

The review below is the current trend in Indonesia in FPV development and research. It examines the trends in preparation and source of power as well as the modalities of systems, technologies used in PV, simulators and types of floating structures. The aim remains to present a general picture of the FPV situation in the Indonesian country and indicate the most beneficial opportunities and threats to its further growth.

II. LITERATURE STUDY

A. *Floating Solar PV*

FPV are solar based power generation units, which are installed on the water surface of reservoir, lakes or dams. In this technology, photovoltaic modules rest on floating structures to transform solar energy into electricity. The advantage of having water on the bottom of the solar panel is a cooling system, which offers an improved use of the electrical energy generation of maximum efficiency of 10 percent in comparison to the land collections solar panel system. What is more, FPV will allow controlling the evaporation rates of water and algae growth on the reservoir surface [3].

B. *Potential for FPV Development in Indonesia*

Indonesia possesses considerable potential on solar energy and the mean of solar radiation strength in the amount of 4 5 kWh/m 2 /day [3]. One of the ways to maximize this potential without the need of large land areas is the application of FPV technology. Moreover, when FPV is situated on the surface of water, reservoirs, lakes, and dams, it will be able to decrease the evaporation of water and preserve the quality of water [4]. Finally, FPV systems are also able to facilitate energy conversion efficiency by up to 10 percent higher than the traditional land-based systems owing to the cooling effect created by the water surface [5].

C. Case Study of FPV in Indonesia

Some of the FPV projects have been effectively channeled in Indonesia. The FPV at Cirata Reservoir in West Java is one of the largest projects having a 192 MWp and thus, the largest FPV programme in Southeast Asia [6]. The project has played a role in augmenting the availability of clean energy and the attainment of the energy mix goal on the national side [7]. Moreover, it shows an example of the small-scale project which sustains the local energy needs, namely the FPV in Muara Nusa Dua Reservoir, Bali, 100 kWp capacity [1].

Fig. 1 A 100kWP FPV in Muara Nusa Dua Reservoir, Bali

D. Floating Technology in FPV Systems

The floating technology in FPV systems is a very essential part, which guarantees structural integrity, buoyancy, transparency and response to different water conditions. Various floating technologies are also developed to suit the size of installation, and site-specific contextures.

1. Mooring System

FPV arrays are secured in a predefined place by use of mooring system that permits restrained and controlled motion in order to accommodate any environmental variations like changes in the water level, wind, and water flow. It is normally composed of lines joined with the mooring (catenary or taut) linked with waterbed anchors. The system works to ensure structural stability and flexibility in a number of site conditions [8].

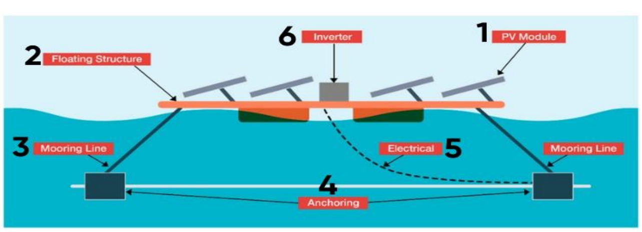

Fig. 2 FPV using Mooring Technology [8]

Figure 2 represents the major aspects of a Floating Photovoltaic (FPV) system. The modules PV which are mounted on the floating structure are used to convert sun radiation to electricity. A floating structure located underneath the modules provides buoyancy and other materials that are able to resist exposure to the environment (e.g. HDPE). In order to keep the system at the same level on the water surface lines (usually either steel cables or synthetic ropes) are attached between the floating platform and the anchoring locations in the waterbed (which may be concrete blocks or driven piles). These anchoring systems play a critical role in preventing the movement when subject to winds and water currents. The generated electricity is transmitted via electrical lines from the floating array to the onshore inverter, which plays a critical role in converting the direct current (DC) output from the PV modules into alternating current (AC) that is compatible with the electrical grid.

This system offers flexible vertical movement, good stability under wave and current conditions, and cost-effectiveness. However, it requires precise design and careful tension management to avoid structural stress [8].

Historically, the mooring system originated from offshore oil and gas applications. Its first adaptation to FPV was initiated in Japan by the National Institute of Advanced Industrial Science and Technology (AIST) in 2007, during early FPV pilot projects. These early mooring systems demonstrated high effectiveness in adjusting to water level changes, inspiring their broader use in subsequent FPV projects globally

2. Anchoring System

The anchoring system secures the FPV platform to the waterbed, preventing lateral drift caused by wind, water currents, or waves. It commonly uses dead weight anchors, drag embedment anchors, or pile anchors, selected based on site-specific bathymetry and soil conditions [9].

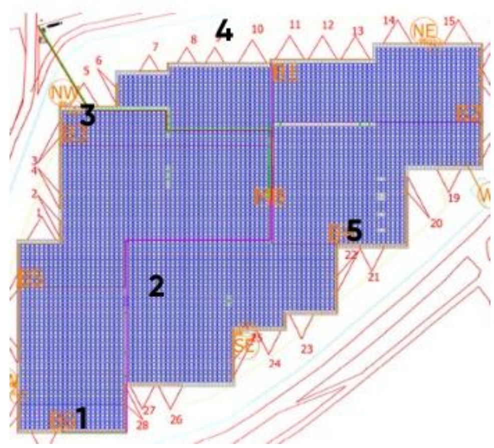

Fig. 3 Anchoring System in FPV Installation at Tokushima, Japan [9]

Figure 3 illustrates the main components of a FPV installation. The floater (1) is the main floating platform which holds the whole array of Pav modules. Floaters are usually good quality and high density polyethylene (HDPE), which makes it buoyant and strong on the water. The solar modules (2) are mounted over the floaters and this is configured to convert solar energy into electrical energy and is positioned with the aim of exposure to sunlight. The PV system has a system configuration composed of an inverter (3) whose task is the conversion of the direct current (DC) harvested by the PV modules converted into an alternating current (AC), but adapted to the grid or locally consumed. An anchoring system (4) is used in order to keep a floating platform stable and in its place. The system is used to solidify the structure with the lakebed and to keep it anchored hence it cannot drift away as a result of the wind or waves movement. There is also an anemometer (5) calibrated to measure the speed as well as the direction of the wind coming in, which is extremely necessary in environmental monitoring and the safety as well as reliability of the FPV system.

The anchoring points are linked to the boundaries of the FPV array by steel cables or tensioned mooring lines which are distributed equally at the perimeter of the structure. These cables are also tightened to stabilize the position of this platform and to minimize the movement of the structure particularly under the dynamic influence. The diagram in the figure depicts the FPV modular platform with numerous anchor lines along the corners pointing into the seabed solidifying the fact that the position is fixed. [9].

Anchoring mechanisms offer good position stability, long provision services and low maintenance. They provide however little flexibility in adjusting to the change of water level and can be difficult to deploy at deep water or in hard sea beds [9]. Such systems came out of offshore maritime engineering and were initially implemented into an FPV system in places like Japan and South Korea, especially in still inland waters.

. The anchors are usually made from corrosion-resistant materials like reinforced concrete, stainless steel, or galvanized iron, ensuring durability and strength in submerged environments.

3. Pontoon System

The pontoon system serves as the primary floating structure that directly supports the PV modules. It is composed of modular, lightweight pontoons—usually made of high-density polyethylene (HDPE)—designed to ensure even load distribution and maintain optimal panel tilt angles for maximum solar exposure [10]. These pontoons are interconnected to form a stable floating platform upon which the PV modules are mounted.

Each PV module is securely fixed to the pontoon array using steel brackets and reinforced cables or tensioned wires that anchor the modules to designated connection points, ensuring structural integrity even under environmental stress such as wind and wave forces. In practical applications, the wiring and anchoring points are strategically positioned around the array and often connect to external mooring or anchoring systems to further enhance platform stability.

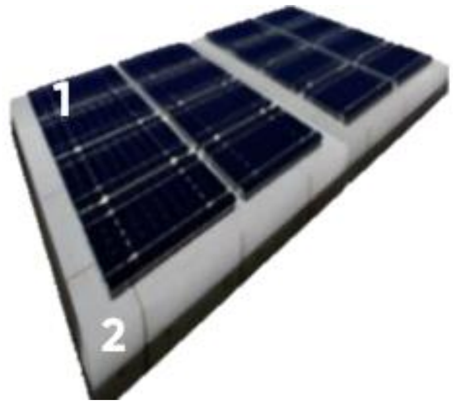

Fig. 4 FPV using Pontoon Technology [10]

The illustrated pontoon consists of a single modular HDPE unit with a top-mounted PV module. The top surface (2500 mm × 1000 mm) supports the solar panel, while the pontoon height is approximately 400 mm. These units are designed to interconnect side-by-side, forming a larger floating array capable of supporting multiple PV modules in parallel. Figure 4 shows a simplified unit for illustration; in practical applications, hundreds of such units are combined for commercial-scale deployment. The legend indicates the top section as the PV module and the lower box as the HDPE pontoon.

Figure 4 illustrates the two primary components of a pontoon-based FPV system. The PV module (1) is installed on top of the pontoon surface and functions to convert solar radiation into electrical energy. This module is placed to have the best amount of sunlight so that more energy is converted. The PV module is supported (1) by the pontoon (2) which is the principal floating body. The pontoon is normally made of high-density polyethylene (HDPE), which not only provides buying power but also structural support to the whole system, thus making the whole system stable under different ground and weather conditions.

The pontoon system is also characterized by flexibilities, scalability, ease of installations and transportation, that is, it can be used in various water conditions. It however has low load capacity and can be subject to material degradation when exposed to long term UV [10]. Such systems became popular in the first half of 2010s, especially through the use of standardized modular designs based on HDPE in developing countries such as India, France and Indonesia.

4. Barge System

Barge system is restricted to a big and firm floating device that sustains considerable structural and electrical weight in terms of PV modules, inverters as well as auxiliary components. It most often finds use in massive FPV systems deployed at deeper waters or offshore where there is more risk of exposure to waves. To form the barge, materials constructed are usually strong and durable including steel or reinforced concrete due to the difficult conditions in the marine territory as well as the durability in the long term [11].

PV modules in this system can be installed on the surface of the barge with the help of structural frames and can be bound efficiently with tensioned steel cables or with substantial bolts to the strengthened positions of the platform. These anchor components are created in such a way that they guard against mechanical pressure due to winds, waves and thermo-expansion. The electrical parts which include inverters and control units are commonly amongst them and are placed within the barge itself making it a central point where power station becomes compact.

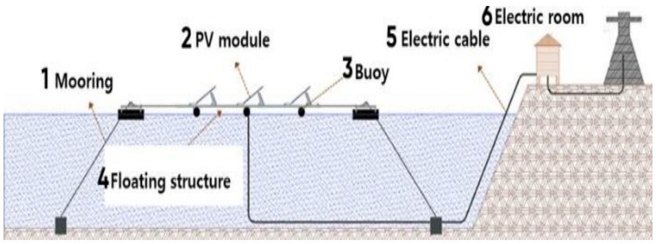

Fig. 5 FPV using Barge Technology[11]

Figure 5 shows main parts of an FPV system explored by barge technologies. The mooring (1) is made of flexible cables or lines that arrest the barge system to underlying fixed underwater locations thus giving lateral stability to the barge against the forces of nature like water currents and winds. Structural frames or support racks can be used to mount the PV modules (2) in a frame on top of the barge, onto which they would serve the purpose of converting sunlight to electrical energy. To increase the flotation levels and keep the platform in balance, peaking care out on the edges of the platform, buoys (3) are applied and minimize the tilting and the influence of the waves. The center point of the system is referred to as the floating structure (4) and it is a rigid barge platform commonly composed of steel or reinforced concrete. It does not only support the PV arrays but several electrical parts as well, providing structural rigidity even in offshore or deepwater environments. Electric cables (5) are laid across the barge to transport the electricity produced by the PV modules to processing units and any exposure to water is guarded against. Finally, the electric room (6) is a designated area within the barge that houses inverters and control systems, allowing for a centralized and compact configuration of power conversion equipment.

The layout of anchoring points and cable arrangements is designed to evenly distribute mechanical load and ensure structural integrity. In some projects, external mooring lines are also applied to stabilize the entire structure within a fixed area.

Barge-based FPV structures were inspired by maritime logistics platforms and have been deployed in large-scale projects, particularly in China and Thailand. Their rigid frame enables the integration of complex electrical infrastructure and makes them highly suitable for utility-scale FPV applications in deep or high-wave zones [11].

5. Floater System

The floater system provides buoyancy for the FPV array and typically uses HDPE or similar durable materials engineered to endure prolonged exposure to UV radiation, temperature variations, and water conditions . Each floater unit serves as a modular support block, which when interconnected, forms a continuous and stable platform for mounting photovoltaic (PV) panels. [12].

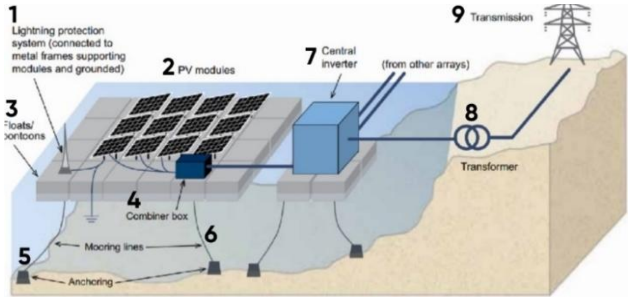

Fig. 6 FPV using Floater Technology [12]

Figure 6 illustrates the key components of a comprehensive Floating Photovoltaic (FPV) system. On the top of the array is lightning protection system (1), which safely dissipates the lightning strike rather than allowing them to reach sensitive electrical system or parts of the installation in order to increase the level of safety and operating life of the installation. The SFRP (1) is positioned on the top of the floating island, on which the PV modules (2) are fixed, and PV modules represent the main units to generate energy and transform solar radiation into the direct current (DC) electricity. Supporting these modules are the floats or pontoons (3), usually of high-density polyethylene (HDPE), and these add buoyancy and strength to maintain the entire FPV array above the water and stationary. In the combiner box (4) the electrical production of a group of PV modules is joined and the combiner box also has protection in the form of fuses and surge suppressors; this box consolidates the current. The anchoring system (5) guarantees the stability of the floating system, being composed of fixed underwater structures (such as concrete blocks or piles) resisting the wind and water currents. The mooring lines (6) attached to these anchors connect to a floating platform and are made of either steel cable or synthetic rope and can only move within a limited range because of changes in water level, but also serve to establish stability in the platform so that it does not shift laterally. DC electricity that is produced then gets directed to the central inverter (7) which does the most important job of converting the electricity to alternating current (AC) electricity that can be absorbed by the grid. This AC is then transferred to transformer (8) where the voltage is stepped up and then sent into long distance transmission with efficiency. Lastly, the transformed electricity at the FPV site is transmitted by the transmission line (9) and the onshore power grid or at the point of use is accessed directly.

PV modules are also mounted on top of the floaters, a feat achieved by using mounting bracket and further strung into position by the use of steel cables or reinforced tension wires to tie the module frame to the preselected anchoring locations on the floaters. These anchoring points are not only part of the design of the floaters, but also are laid out across the array in a strategic manner so as to provide structural stability. External mooring lines or anchoring systems may also be present in many of the installations, often to keep the whole structure of the FPV in a fixed position and to resist environmental loads (i.e., winds or wave forces). [12].

The durable, light weight, and UV, and chemically resistive properties of floater systems make them appreciable. Nevertheless, they are susceptible to biofouling, and they might need to be cleaned regularly. The systems are usually installed on small-scale FPV projects or pilot programs in Southeast Asia, such as Indonesia, because of its modular structure, speed of deployment, and affordability [12].

6. Conventional Floating System

A conventional floating system is a common design incorporated with modular floaters, mooring lines, and anchoring systems to offer a structural foundation and anchoring support to FPV arrays [13].

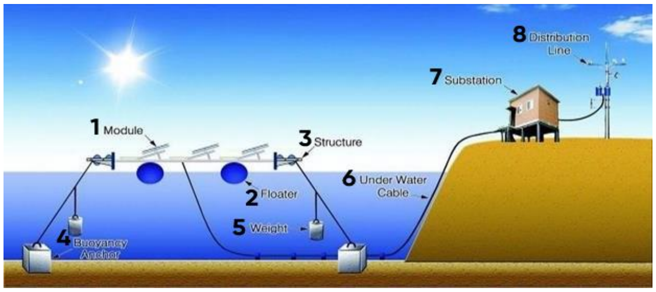

Fig. 7 FPV using Conventional Floating Technology [13]

The figure 7 shows the illustration of structural and electrical parts of typical Floating Photovoltaic (FPV) installation. The solar modules (1) are located at the top of the platform and they trap the sun light and transfer it to direct current (DC) electricity. These modules are fixed firmly on a supporting system (3), which connects the floaters to each other as well as ensures accurate tilts and orientation of the PV modules. Floaters (2) are used to keep the platform floating, and these are normally made of high-density polyethylene (HDPE) or any other waterproof material that would stabilize the system on the water surface. Buoyancy anchors (4) are used to hold the system in place of the water surface. These anchors are linked to mooring systems and apply floating techniques or semi-floating techniques to stabilize the platform depending on different environment conditions. Also, ballasts or counter weights (5) as leveling devices (weights) are also provided so to reduce the movement of the structures under the actions of wind or waves to increase the overall stability. The electrical energy produced by PV modules in the floating array is transported by water sub-sea cable (6) to a substation (7) that can be installed in the platform or in nearby shore. This is where the power is processed and the voltage is stepped up to allow its efficient distribution. Lastly, the generation of electricity converted to alternating current is fed to either the national grid or immediately to the end-users via the distribution line (8) and the process of energy transportation via floating generation and to practical application is complete.

Such a system is inexpensive, warranted, and can be suitable to different inland bodies of water. It is, however, not so applicable to offshore scenarios and might not offer the same stability to a barge based systems in event of rough water [13].

The traditional system is usually used in initial rounds of establishing FPV particularly in institutional or research establishment. It is a combined system based on using cheap modularity and easy stabilization means.

The advantages of each type of floating technology are specific and this has led to the selection of the technology depending on the level of the project, the depth of the water, the nature of waves, the cost element. A combination of such technologies guarantees the safety, efficiency, and lifespan of FPV.

III. RESEARCH METHOD

This research used the method of systematic literature review as the means of studying the trend of development, technological side of FPV, and research interests in Indonesia. These were the data collected of this research, namely by means of thorough research in the serious scientific databases, Google Scholar, Scopus, IEEE Xplore, and national portals of journals. To conduct the search, the following unique keywords were used, “PLTS Terapung Indonesia”, “Floating Solar PV Indonesia”, “Floating Photovoltaic Research”, and “Renewable Energy Indonesia”.

The first datum of this work consisted of 45 pertinent journal articles and conference proceedings published between 2018 and 2025. According to the search activities, the first applicable publishing sources about FPV systems in Indonesia appeared since 2018. There are no relevant articles found in credible sources earlier than that year, which shows that published research on FPV in Indonesia started to appear since the year 2018.

The selection of literature was based on specific inclusion criteria. Articles had to focus FPV systems that were implemented or analyzed within Indonesian territory. Publications were required to contain adequate technical, simulation, design, or analytical content. Both national and international articles were considered as long as they presented empirical or simulated data relevant to FPV development in Indonesia.

Each selected article was carefully reviewed and classified into several categories. The classification includes the geographic location of FPV research., the type of waterbody used (such as reservoir, lake, sea, pond, or dam), the research focus (including design, simulation, or performance analysis), the type of system configuration (on-grid, off-grid, or hybrid), the floating structure technology applied (mooring, anchoring, pontoon, etc.), the type of PV module used (monocrystalline, polycrystalline, thin-film, etc.), and the simulation tools employed (such as PVsyst, SAM, MATLAB, and others).

To support the analysis, the classified data were visualized using bar charts and other graphical representations to illustrate the distribution and trends in FPV installations across different provinces and waterbody types, the surface area utilized by each waterbody type, the dominant research scopes and simulation tools, and the technologies and PV module types commonly used in Indonesia.

The results were then analyzed to identify key trends, opportunities, and gaps in the development of FPV in Indonesia. Special attention was given to the dominance of on-grid system configurations, the leading roles of certain provinces like East Java and Bali, and the widespread use of simulation tools such as PVsyst. The study through this method will give a full picture of the condition of the development of FPV in Indonesia and it can shed light to aid in future studies and policies done in the industry of renewable energy.

IV. RESULT AND DISCUSSION

Based on the findings of systematic collection of journal data, a final number of 45 articles about FPV research in Indonesia were found. The articles comment on multiple things, such as design, simulation, assessment of performance, and economical viability of the FPV systems deployed in several provinces and water bodies of Indonesia. The choice of following the national and the international publications will give a full picture of the research situation in this field at the moment. All the journal articles used as the primary references for this study are listed in References [1] – [58] and Table I, serving as the foundation for the analysis and discussion presented in this paper.

TABLE I
SUMMARY OF RESEARCH IN REFERENCE PAPER

Topics and Researchers	Technical Specs of FPV	Floating Technology	Location
Technical design, Islamy et al. (2018) [14]	2.480.000 Wp, Monocrystalline, On-Grid	Barge	South Sulawesi
Analisis risiko Pembangunan, Wirawanet et al. (2018) [15]	1.000.000 Wp, Monocrystalline, On-Grid	-	Kei Kecil Island, Southeast Maluku, Indonesia
Actual Development Process, Permana et al. (2019) [16]	12.250.000 Wp, Monocrystalline, On-Grid	Pontoon	Saradan, Subdistrict Madiun Regency, East Java.
Cooling Effects on Performance & Economics, Sukarso et al. (2020) [17]	145.000.000 Wp, Monocrystalline, On-Grid	-	Reservoir Cirata, West Java
Economic Feasibility Study of Utility-Scale FPV, A.A. Untoro et al (2021) et al [18]	145.000.000 Wp, Monocrystalline, On-Grid	Anchoring & Mooring	West Bandung, West Java
FPV Energy Output Simulation With Pvplanner, Elieser Tarigan (2021) [19]	560.000.000 Wp, Crystalline Silicon (c-Si), On-Grid	Pontoon & Anchor	Malang, East Java
Offshore FPV vs Onshore PV Performance Comparison, Radhiansyah et al (2021) [20]	400.000 Wp, Monocrystalline, Off-Grid	Mooring	Pulau Kodingareng Lompo, Makassar, Sulawesi South
Potential FPV Locations for Education and Research, Karnoto et al (2021) [21]	1.846.000 Wp, Monocrystalline, On-Grid	-	Universitas Diponegoro, Semarang, Central Java
Surabaya City Power Needs Simulation Using FPV, Elieser Tarigan (2021) [22]	1.255.000.000 Wp, Crystalline Silicon (c-Si), On-Grid	Mooring	Northwest coastal area of Surabaya City, East Java
Documentation of FPV Construction, Asep Hidayat et al (2022) [23]	145.000.000 Wp, Monocrystalline, On-Grid	Anchoring & Poonton	Bandung, West Java
Construction Review + Numerical Simulation of Solar Power Plant, Ivan Marupa et al (2022) [24]	145.000.000 Wp, Monocrystalline, On-Grid	Sistem mooring dan pontoon	Reservoir Cirata, West Java
FPV Simulation Bagaskara et al (2022) [25]	22.6 Wp, Monocrystalline, Off-Grid	-	Malang, East Java
Performance Analysis, Carbon Emissions, and Economics Dawam Faizul Amal et al (2022) [26]	32.900.000 Wp, Monocrystalline, On-Grid	Anchoring & Mooring	Sambinasi Village, Ngada Regency, East Nusa Tenggara
Initial Design of Solar Power Plant, Rifqi Firza Ananda et al (2022) [27]	5.000.000 Wp, Monocrystalline, On-Grid	Anchoring & Mooring	Kudus, Central Java
Simulation of FPV Energy Output, Elieser Tarigan (2022) [28]	12.600.000 Wp, Crystalline Silicon (c-Si), On-Grid	Pontoon & Mooring	North Sumatra, Indonesia
Inspection of solar power plant installation and quality testing, Akbar Pratama et al (2022) [29]	5.200 Wp, Monocrystalline, On-Grid	Pontoon & Mooring	Taman Mini Indonesia Indah (TMII), Jakarta.
Environmental impact evaluation of FPVs, Suwartha et al (2022) [30]	9.360 Wp, Monocrystalline, On-Grid	Pontoon & Mooring	Universitas Indonesia, Depok
Technical design of FPV, G. Muchtar et al 9 (2023) [31]	6.120.000 Wp, Polycrystalline, On-Grid	Floater	North Sumatra
Study of Technical Potential and Design of Solar Power Plant, C.O. Mangatur et al (2023) [32]	76.440.000 Wp, Monocrystalline, On-Grid	Anchoring & Mooring	Batur, Kintamani District, Bangli Regency, Bali
Investment and feasibility study of solar power plants, Nugraha et al (2023) [33]	846 Wp, Monocrystalline, On-Grid	Anchoring & Mooring	South Jakarta, DKI Jakarta Province
Evaluation of FPVperformance, Herlambang et al (2023) [34]	200 Wp, Monocrystalline, Off-Grid	Floater	
Utility-scale FPV project development and potential impacts, Siregar et al (2023) [35]	145.000.000 Wp, Thin-Film CIS, On-Grid	Pontoon & Mooring	West Java

Optimizing the use of reservoirs for FPVs, Aris Rinaldi et al (2023) [36]	145.000.000 Wp, Monocrystalline, On-Grid	Pontoon & Mooring	West Bandung, West Java
Feasibility Study of FPV Potential, Elieser Tarigan (2023) [37]	3.320.000 Wp, Monocrystalline, On-Grid	Pontoon	Tanjungan, Mojokerto, East Java
Technical design and feasibility of FPVs, Handoko Rusiana Iskandar et al (2023) [38]	145.000.000 Wp, Monocrystalline, On-Grid	-	Saguling, Cirata & Jatiluhur
FPV system design, M Paisal et al (2024) [39]	1.450.000 Wp, Monocrystalline, On-Grid	Anchoring & Mooring	Badung,Bali
Bilateral investment collaboration study, Debritanio Caesario et al (2024) [40]	145.000.000 Wp, Monocrystalline, On-Grid	Pontoon & Mooring	Cirata, West Java
FPV Design, Nugroho et al (2024) [41]	100 Wp, Monocrystalline, Off-Grid	Conventional	Lampung
Energy Potential Study of IoT-Based FPVs, Biantoro et al (2024) [42]	1.040.000 Wp, Monocrystalline, On-Grid	Anchoring & Mooring	West Bandung, West Java
Output Power Analysis of FPV Prototype, Ajeng Bening K (2024) [43]	200 Wp, Monocrystalline, Off-Grid	Floater	Jakarta
Economic Analysis of The Combination of FPVs And Micro Hydro Power Plants, Gayatri et al (2024) [44]	1.400.000 Wp, Monocrystalline, On-Grid	-	Buahan Kaja Village, Payangan District, Gianyar Regency, Bali
Feasibility study for the construction of solar power plants, Cinantya et al (2024) [45]	474.480.000 Wp, Monocrystalline, On-Grid	Anchoring & Mooring	Batam
Review of the development of FPV technology in Indonesian waters, Naiborhu et al (2024) [46]	166.040.000 Wp, Monocrystalline, On-Grid	Pontoon & Mooring	Bandung, West Java & the Strait of Malacca
Overview of the FPV system, Handy Satria et al (2024) [47]	474.480.000 Wp, Monocrystalline, On-Grid	Anchoring & Mooring	Reservoir Cirata, West Java
Comparison of the life cycle of floating and land-based solar power plants at the same location, Budi et al (2024) [48]	192.000.000 Wp, Monocrystalline, On-Grid	Anchoring & Mooring	Reservoir Cirata, West Java
Construction of FPVs, Kurniawan et al (2024) [49]	30.000.000 Wp, Monocrystalline, On-Grid	Anchoring & Mooring	Balikpapan, East Kalimantan
FPV design analysis, Nainggolan et al (2024) [50]	583.000.000 Wp, Monocrystalline, On-Grid	Anchoring & Mooring	Lake Toba, North Sumatra, Indonesia
Feasibility study of FPV, Sukadana et al (2024) [51]	100.000 Wp, Monocrystalline, On-Grid	Anchoring & Mooring	Reservoir Muara Nusa Dua, Denpasar, Bali
Analysis of FPV performance, Wirgiyanto et al (2024) [52]	5.360 Wp, Polycrystalline, On-Grid	Anchoring & Mooring	Serpong, South Tangerang, Banten
Technical-economic feasibility analysis, Rifansyah et al (2024) [53]	145.000.000 Wp, Monocrystalline, On-Grid	Pontoon & Mooring	Reservoir Cirata, West Java
Techno-Economic Comparison, Bahrul Ulum et al (2024) [54]	9.360.000 Wp, Monocrystalline, On-Grid	Anchoring & Mooring	Karangkates, East Java
System Performance of 13 FPV Arrays with PVSyst 7.4 Simulation, Pujianto et al (2024) [55]	145.000.000 Wp, Monocrystalline, On-Grid	Anchoring & Mooring	Reservoir Cirata, West Java
Techno-economic Analysis, Abiyasa et al (2024) [56]	100.000 Wp, Monocrystalline, On-Grid	Anchoring & Mooring	Reservoir Muara Nusa Dua, Bali
FPV Systems as an Alternative Power Source, Esparza et al (2024) [57]	2.000.000 Wp, 553.000 Wp, 31.000 Wp, Monocrystalline, On-Grid	Anchoring & Mooring	Bungin Island – West Nusa Tenggara, Gili Ketapang – East Java, Kalenan – Maluku
Solar–water nexus on local implications of the procurement and deployment of the first FPVs project in Indonesia, Rudolph et al (2025) [58]	145.000.000 Wp, Monocrystalline, On-Grid	Pontoon & Mooring	Reservoir Cirata, West Java

A. Publication Trends and Paper Types in FPV Research

To understand the development of research related to FPV in Indonesia, an analysis was conducted on the number and types of scientific publications that have been published in recent years. Figure 8 shows the proportion of publication types based on their categories, namely national journals, international journals, national seminars, international seminars, and international conference proceedings. Meanwhile, Figure 9 illustrates the trend in the number of publications from 2018 to 2025. These data provide an initial overview of the dynamics and intensity of research in the field of FPV over time.

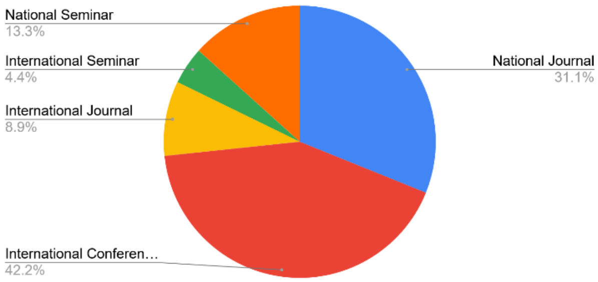

Fig. 8 Articles and papers of FPV research in Indonesia

The analysis presented in Figure 8 shows that international conference proceedings dominate the publication landscape, accounting for 42.2% of the total. This dominance indicates that most FPV research in Indonesia is published in temporary forums that commonly accommodate preliminary studies, basic design evaluations, or feasibility assessments that do not yet require long-term validation. Publications in international conferences are often preferred due to their faster selection process and the opportunity to present early-stage research to global audiences, even when the methodological depth remains limited.

National journals are the second most common publication type (31.1%). This dominance is not primarily driven by administrative requirements but rather by the local application context of most FPV studies in Indonesia. Many of these studies focus on site-specific cases involving reservoirs, lakes, or particular water bodies, which are significantly influenced by Indonesia's tropical climate and national regulatory environment. This is more applicable when it comes to publication in national journals that have interested readers with a focus on unique context of Indonesia. Moreover, the poor availability of funding and collaboration at an international level means that the national journals are more convenient and viable publishing destination [61].

EEOC seminars (13.3%) can serve as an appropriate venue in presenting a preliminary study or a research on a lower level. The national seminars normally aim at capturing editing and corrections by the local scholarly groups prior to further editing and acceptance of the research to be published as a global journal research. This is attributed to several reasons such as insufficient usage of complex methodologies, the failure to have long-term validation as well as difficulties of preparing scientific papers in English, which fit the strict standards of high-ranking international journals.

The international seminars is the least percentage (4.4 percent), which implies that involvement of Indonesia researchers in international seminars devoted to FPV in particular is limited. This could be because not many international seminars are carried out in this niche field, on the one hand, and the tight budget, which does not allow attending the seminar, on the other hand.

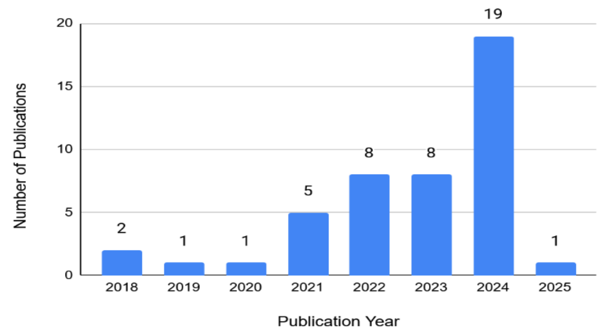

Fig. 9 Annual Publications on FPV Research in Indonesia

The publication trend over time, depicted in Figure 9, gives an evidence on an increased development in FPV research in Indonesia between 2018 and 2025. The number of publications between 2018 and 2020 was quite smaller (one or two publications per year). This tendency shows the introverted phase of the FPV study in Indonesia at the time of this period. There was a tremendous rise in publications since 2021 and the statistic had even increased in 2022 and 2023 with 20 publications in 2024. This swell is directly connected to the introduction of significant FPV initiatives in Indonesia and intense regulatory support, which include Presidential Regulation No. 112 of 2022 on the Acceleration of Renewable Energy Development, which has drawn more attention among the academic bodies and practitioners of the industry to conduct research in this area.

The fall of publications in 2025 is not expected to be because of decline in research interest but lack of comprehensiveness of data taken during the time of analysis. On the whole, this tendency underlines the fact that the FPV research in Indonesia is becoming an actively developed sphere and is more and more accepted as one of the strategic domains of assisting renewable energy movement in the country.

B. Distribution of FPV Capacity Based on Waterbody Types in Indonesia

The characteristics of waterbody have an important role in deciding the installed power capacity in the development of FPV systems in Indonesia. As shown in the chart below, total installed FPV capacity, in Watt-peak, is divided by waterbody types that include lakes, reservoirs, dams, seas, and ponds. These facts show that lakes and reservoirs lead in terms of FPV development due to a higher level of technical applicability to such geography and the ability to build solar plants with a large capacity.

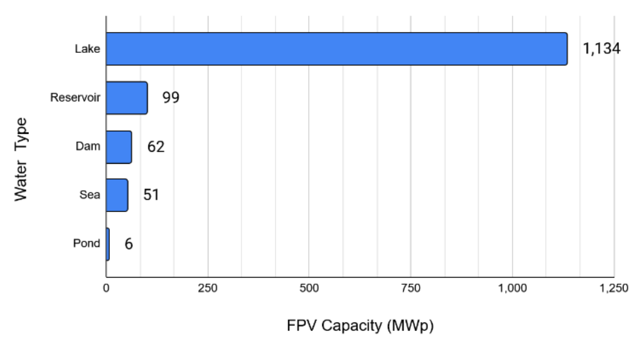

Fig. 10 FPV Research on Installed Power Capacity by Water Body Type in Indonesia

Based on Figure 10, lakes have the biggest capacity of FPV about 1,134 MWp followed by reservoirs of about 99 MWp. The two types are prevalent in the deployment of FPV since they have large surface areas and fairly stable water topography that is quite advantageous technically on the installation and long-term utility. FPV dams rank third with 6 MWp, followed by seas at 51 MWp. Although seas provide large potential areas, their harsher environmental conditions such as strong wave forces, salinity, and the risk of corrosion make marine FPV installations technically more challenging and cost-intensive.

Ponds account for the smallest installed capacity, at only 6.12 MWp, which is likely due to the limited surface area typically available at these smaller water bodies, restricting large-scale solar deployment. Additionally, ponds may lack the infrastructure support, accessibility, or energy demand profiles that make them viable for utility-scale development. These findings emphasize the strategic preference toward large and stable inland water bodies for optimal floating solar PV installations in Indonesia.

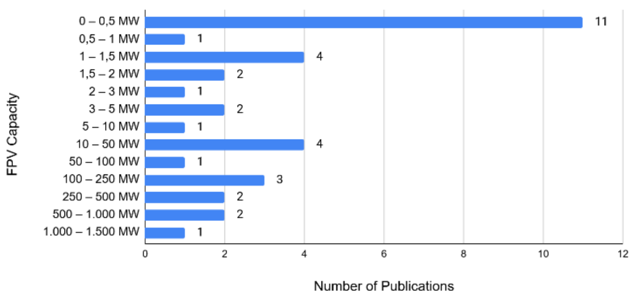

Fig. 11 FPV Research by Installed Capacity Range in Indonesia

Based on Figure 11, the graph shows the distribution of the number of FPV sites based on the power capacity group in kW. The majority of the sites fall within the 0 – 0,5 kW capacity range, with 11 recorded sites. This trend indicates that FPV projects in Indonesia are predominantly developed in small-scale configurations. Additional clusters are found in the 1 – 1,5 MW and 10 – 50 MW ranges, each comprising four sites. The 100 – 250 mW category accounts for three sites, while installations in other capacity groups are less common, ranging from one to two sites per group. This distribution pattern emphasizes that FPV development in Indonesia is currently more prevalent in small to medium-scale projects, with large-scale installations remaining relatively rare.

According to the National Renewable Energy Laboratory (NREL), the International Renewable Energy Agency (IRENA), and the International Energy Agency (IEA), photovoltaic (PV) power plants, including FPV are generally classified into three capacity scales:

1. Small-scale PV (0 – 20 MW): Typically includes residential, small commercial facilities, or community-based solar projects [59].
2. Medium-scale PV (20 – 100 MW): Covers mid-sized utility projects, industrial zones, or rural electrification systems [60].
3. Large-scale PV (>100 MW): Generally refers to national utility plants, large grid-connected systems, and major renewable energy hubs [61].

When mapped against these classifications, most FPV systems in Indonesia currently fall under the small-scale category (0 – 20 MW), particularly in the 0 – 500 kW group. This is consistent with the global trend that FPV installations are typically initiated at smaller capacities to minimize investment risks, ensure technical feasibility, and test long-term system reliability. However, a limited number of medium and large-scale FPV projects are emerging, with capacities exceeding 100 MW, indicating Indonesia's growing capability and ambition to develop utility-scale FPV in the near future. [62]

This capacity distribution reflects Indonesia's current FPV development strategy, which emphasizes gradual scaling, starting from small and site-specific projects, towards more substantial contributions to the national energy mix as technological expertise and project financing mature.

C. Distribution of FPV Locations Based on Water Type

The selection of waterbody types is a key factor influencing the development strategy of FPV in Indonesia. Figure 12 presents the number of FPV plant locations categorized by waterbody types, including sea, dam, reservoir, lake, and pond.

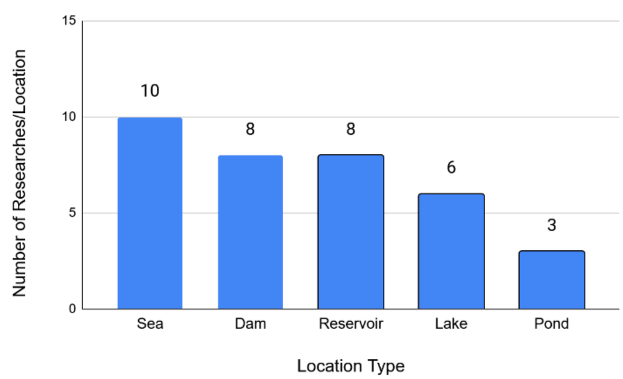

Fig. 12 Distribution of FPV Research Locations by Water Type in Indonesia

Based on Figure 12 bar graph, the number of FPV locations across various types of water bodies is presented. The data shows that most FPV installations are found in the sea, with 10 locations, followed by dams and reservoirs, each with 8 locations. Lakes host 6 installations, while ponds have the fewest, with only 3 locations. This points out that seas are the most desirable locations of FPV installation perhaps because there would be plenty of surfaces during the deployment and high radiation levels.

FPV is more common in the bigger and more permanent water bodies-whether or not seas, dams and reservoirs than smaller ones, including ponds. It is so because of a number of main factors, such as (land availability, system stability, energy efficiency, and economies of scale) Land Availability – Huge water bodies like seas, dams and reservoirs provide huge spaces that could accommodate large-scale FPV facilities without spatial constraints. In contrast, ponds are normally small and they are therefore unsuitable in the development of high-capacity solar power systems [63].
System Stability – The water bodies also are more likely to retain water in large water bodies than in ponds, which are

more prone to evaporation or use of water in some other activities. The stability plays an important role in providing the structural stability of FPV systems and stability in energy production [64]. Efficiency and Connectivity – Sites like reservoirs, dams can be combined with the available power plant infrastructure, like transmission lines or hydro plants. This helps connect and distribute easily the created electricity. In contrast, ponds usually do not have direct connection to grid, which raises some additional investment costs [65]. Economies of Scale – research into FPV systems on a larger scale allows for economies of scale which lowers the unit costs of individual components including tether systems, anchoring equipments and floating structures. Such advantages are small in ponds where the size of installation is smaller [66].

D. Distribution of FPV Locations by Province in Indonesia

The location of FPV in different provinces in Indonesia can be seen based on the bar chart as depicted in figure 13. East Java also dominates in number of FPV installations and it has a total of 7 installations. This is followed by West Java and Bali, each with 4 locations, and Jakarta with 3 locations. Other provinces such as North Sumatra, Central Java, and East Nusa Tenggara (NTT) each have 2 locations. Meanwhile, South Sumatra, Riau Islands, East Kalimantan, and Southeast Maluku have the lowest number, with only 1 FPV location each. This indicates that the development of FPV is still concentrated in certain provinces, particularly in Java and Bali.

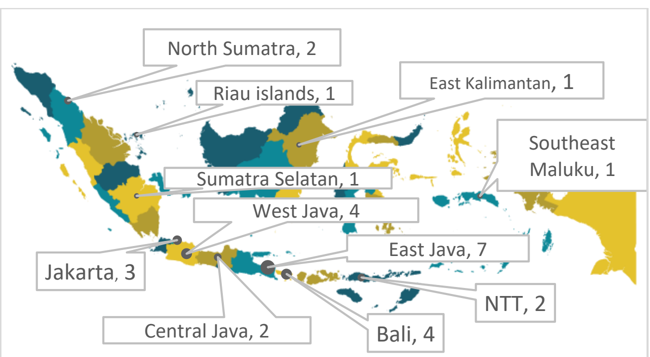

Fig. 13 Number of FPV Research Locations per Province in Indonesia

The concentration of FPV development in Java and Bali is influenced by several key factors, including regional policies, supporting infrastructure, high energy demand, and strong public and private sector support. Provinces in Java and Bali have implemented more progressive regulations promoting renewable energy compared to other regions in Indonesia, such as Presidential Regulation No. 22 of 2017 on the National Energy General Plan (RUEN), Regional Energy General Plans (RUED) in East Java, West Java, and Bali, Bali Governor Regulation No. 45 of 2019 on Clean Energy Bali, and Presidential Instruction No. 7 of 2022, which mandates PLN to expand the use of renewable energy. Furthermore, these provinces benefit from the presence of large reservoirs and dams suitable for floating PV installations. Notable examples include Sutami, Karangkates, and Wonorejo Reservoirs in East Java; Jatiluhur and Cirata Reservoirs in West Java (with Cirata being the largest FPV installation in Southeast Asia); and the Muara Nusa Dua Reservoir in Bali. These locations allow for large-scale solar plant construction without land acquisition challenges and offer direct connection to PLN's electricity grid [67]. Java and Bali are also Indonesia's economic and industrial centers, thus having very high electricity consumption. According to data released by PLN, more than 60 percent of electricity consumption in this region occurs nationally. In this regard, the development of FPV in Java and Bali is prioritized to increase energy security and break dependence on fossil fuels [68]. The region's well-developed grid infrastructure and potential high returns on investment make it highly attractive to investors. Government and private sector contributions to the development of Java and Bali particularly in terms of financial investment play a crucial role in accelerating research on FPV systems in this region. Renewable energy projects are further encouraged by incentives offered by the ministry of energy and mineral resources (ESDM), PLN and Environmental Fund Management Agency (BPDLH) [69]. Finally, the role of universities and research institutions is also important, especially in East Java, there are a number of dams and reservoirs in East Java namely the Sutami, Wonorejo, Bening, Bajulmati, Selorejo and Sengguruh that possess all the ideal characteristics of the FPV system: stable water levels, expansive surface areas and minimal disruptions to the environment in contrast to marine based FPV systems [70].

E. Area Coverage of FPV by Water Type in Indonesia

Figure 14 shows the total surface area use of Floating photovoltaic (FPV) in the water bodies of Indonesia amongst the various categories of the water body. The statistics indicate that the major floating FPV areas are reservoirs and seas, respectively constituting 136 000 and 135 000 m in area. This is then followed by lakes at 55,778 m 2 and dams at 526,570 m 2. It is important to mention that the area covered with floating solar installations is the lowest on ponds, as it takes only 0.7 m2. This implicates that water bodies with high and stable discharges like reservoirs and seas form a better option to floating solar systems because they are huge in terms of area coverage and enhanced structural capability.

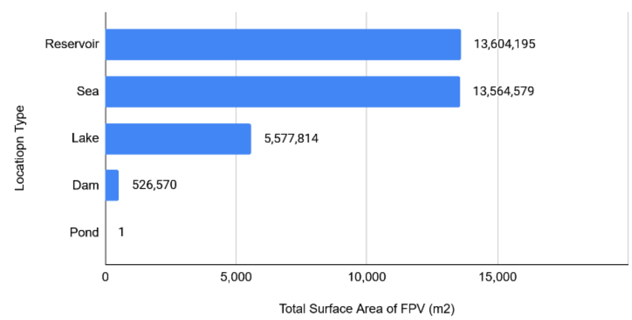

Fig. 14 Surface Area of FPV Installations Based on Water Types in FPV Research in Indonesia

Other features of water like reservoirs and seas are the main options to be developed into FPV systems than other water bodies due to the presence of the large tracts of land which enables large installations without affecting land use. Reservoirs often already have electrical infrastructure because they are used for hydroelectric power plants, making integration with the electricity grid easier. In addition, the calmer surface of water reservoirs compared to the sea supports the stability of FPV systems. Meanwhile, the sea has a high level of solar radiation and minimizes obstacles that can reduce the intensity of sunlight, thereby increasing the efficiency of electricity production. FPV systems in reservoirs also provide the additional benefit of reducing water evaporation, which is important for maintaining water availability for irrigation and other needs. In addition, reservoirs and seas have the potential for smaller environmental impacts than lakes or dams, because reservoirs are artificial areas, while the sea can be used in areas that do not disrupt fishing and shipping activities. Although challenges such as corrosion due to salt water in the sea or maintenance requirements remain, these factors make reservoirs and seas more ideal locations for the development of FPV systems than dams, lakes, or ponds.

F. System Configuration Types of FPV in Indonesia

FPV can be implemented using various system configurations depending on their operational objectives and energy distribution strategies. In Indonesia, the main configurations include on-grid, off-grid, and hybrid systems.

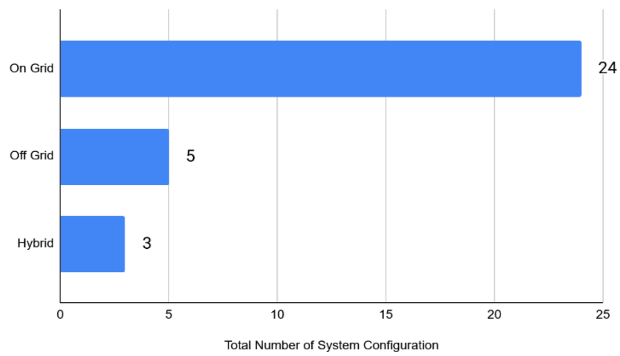

Fig. 15 Types of FPV Operating Systems in Research (On-Grid, Off-Grid, Hybrid)

Based on the bar graph in Figure 15, 24 installations have been done and are dominated by on-grid systems. This is much more than that of off-grid systems that only have 5 project, and hybrid systems that also have 3 installations. This allocation trend shows that the national preference of having grid-connected FPV solutions is high.

The reasons why on-grid FPV systems dominate in Indonesia, as shown in Figure 15, are several supporting reasons. One of them is the effectiveness and reliability. On-grid systems guarantee constant power delivery and enable surplus energy to be fed into the national grid, eliminating the need for costly local energy storage systems. This configuration optimally harnesses solar resources while maintaining stability of the grid.

Further, the economic dimension has a noticeable impact. On-grid systems are economically advantageous as they do not need a battery bank. Batteries are expensive, not economically viable for large-scale applications, and have a short lifespan. Therefore, the absence of battery systems helps to reduce both capital and maintenance costs. This approach provides a sustainable answer to the problem since the grid functions as a virtual battery.

Moreover, the on-grid FPV systems' benefits are reinforced by the Indonesian government. PLN and MEMR have established feed-in tariffs and net-metering as incentive policies. This aims to foster the utilization of renewable energy and meets the national objectives of raising renewable energy in the energy mix.

Additional support from the Indonesian government further facilitates the implementation of on-grid FPVs. PLN along with MEMR has implemented policies such as feed-in tariff and net-metering. These policies are set to fast-track the expansion of renewable energy deployments in line with the national policy directed towards increasing the share of renewable energy in the energy mix.

On-grid FPVs FPV systems offer greater integration and scalability. Other generation sources like hydropower can easily be integrated and expanded incrementally. On-grid FPVs are flexible and cost-effective because the ability to scale up without the need for additional energy storage.

Most FPV projects are sited on reservoirs or dams which are already linked to grid infrastructure. This close proximity to reservoirs and dams diminishes the cost of transmission which adds to the attractiveness of grid-connected systems over-off grid systems particularly in remote locations.

In contrast, off-grid and hybrid systems are typically implemented in remote or island regions, where grid access is unavailable or unreliable. These systems require energy storage components and complex load management, making them more expensive and technically demanding. As a result, their adoption remains limited despite their potential to support rural electrification.

In conclusion, the dominance of on-grid configurations reflects a rational balance between technical feasibility, economic efficiency, and policy alignment. As FPV continues to scale in Indonesia, grid-connected systems will likely remain the foundation of future deployments.

G. Research Focus Trends in FPV Studies

Figure 16 shows the distribution of research focus categories in FPV studies conducted in Indonesia. The data indicates a strong emphasis on design and simulation stages, with 30 studies focusing on system design and 25 studies focusing on simulation, while only 6 studies address performance analysis. This trend reflects the relatively early development phase of FPV technology in Indonesia, where most research efforts are directed toward establishing optimal system designs and evaluating performance scenarios using simulation tools such as PVsyst, MATLAB, and Helioscope.

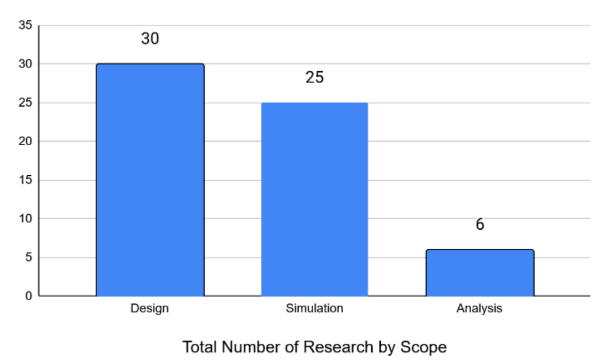

Fig. 16 Scope of Research Categories in FPV Research in Indonesia

Several factors explain this trend. Design and simulation are more cost-effective, faster, and flexible than field analysis, as they do not require physical installations or long-term monitoring. Performance analysis is more complex because it needs real operational data over time, which is still limited in Indonesia. Additionally, researchers are currently focused on technology optimization and innovation to improve floating structures, mooring systems, and panel configurations.

The availability of advanced simulation software also supports this research focus, allowing detailed performance evaluations under various environmental conditions. Moving forward, more studies on real system performance are needed to validate simulation results and ensure long-term system reliability.

H. Simulation Tools Utilized in FPV Research

The bar chart shown in Figure 17 illustrates the use of various tools in FPV research. PVsyst emerged as the most used simulation software, appearing in 12 studies, indicating its dominance in system performance modeling. Excel followed with 4 uses, probably for data analysis and calculations. Other tools such as SAM, SolarGIS PVplanner, MATLAB, Helioscope, and Global Solar Atlas were each used twice, while PVGIS, MIKE 21 FM, RETScreen, and IoT Blynk were mentioned only once.

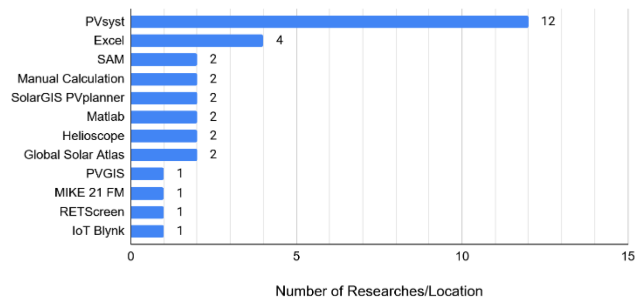

Fig. 17 Use of Software and Simulation Tools in FPV Research in Indonesia

PVsyst's popularity is attributed to its comprehensive features, including energy yield simulation, shading analysis, system loss evaluation, and the ability to integrate local meteorological and hydrological data—critical for FPV systems. Its capability to compare simulated and actual performance data also supports validation and optimization, making it a preferred choice in academic and technical research.

I. FPV Technology

Figure 18 shows the various uses of floating system methods in FPV in Indonesia. Based on the graph shown, the mooring method is the most widely used floating method with a total of 15 studies, followed by anchoring with 10 studies and pontoons with 8 studies. Other methods such as floaters, barges, and conventional have a much lower level of use, only used in 3, 1, and 1 study, respectively. The widespread use of the mooring method reflects the advantages of this method because it provides flexibility and stability against changes in water levels, so it is more often chosen in the development of FPV systems in various locations in Indonesia.

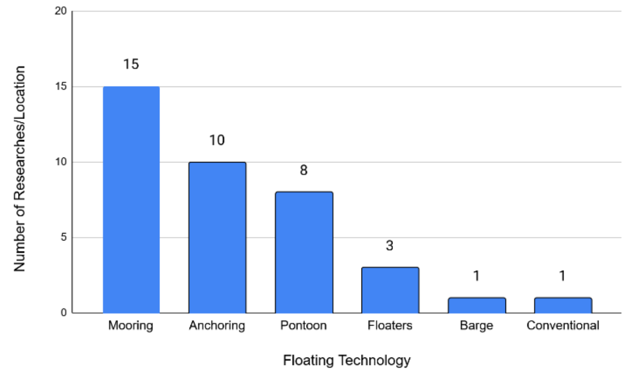

Fig. 18 Floating System Methods Used in FPV Research in Indonesia

The mooring system is widely favored because it allows the FPV platform to maintain its position while adjusting to dynamic environmental factors such as wind forces, water currents, and fluctuating water levels. This is of particular advantage because of the vertical flexibility, wave and current stability, ability to apply to a wide range of water depths and is also economically attractive considering it is relatively cheap to establish compared to permanent fixed structures. Mooring systems are a great advantage in FPV applications since they provide very good flexibility against water level change particularly in dams and reservoirs. They enable floating structure to move vertically without experiencing loss of stability and also their flexible mooring lines have the ability of reducing the effect of waves and water stream. Everything mentioned earlier is supplemented by the fact that mooring systems are more cost-effective and can be installed in shallow and deep waters which makes them a universal and effective solution.

Contrarily, the anchoring system fixes the source of the floating structure to the waterbed to avoid horizontal movements. The long service life, low maintenance demands and high environmental force resistance given by anchoring systems have made them famous. They work well in relatively stagnant waters that include lakes and reservoirs which experience little change in water levels. The anchoring system is a plus since it projects the FPV platform to stay at a particular point even when the winds or the direction of water flows are high. It can withstand extensive FPV installation of long-term operation and the anchors are constructed using quality material such as concrete or stainless steel, which necessitate minimum maintenance activities. The stability of anchoring makes it a good location option in a location where the water level is consistent and that the environmental factors are predictable.

The pontoon provide the solar arrays with buoyancy and rigidity to resist the effects of either over-tilting or under-tilting, whilst offering a degree of protection to the solar arrays against wave action. Structures known as barges are not as popular but act as sturdy large-capacity FPV platforms, especially those that are deeply installed or offshore. Floaters and traditional systems often are simple modular systems or hybrid systems applied in smaller-sized and simpler systems.

The high influence of the mooring and anchoring technologies on the development of FPV in Indonesia testifies to their ability to adapt to a local hydrological, climatic, and geographic environment and the efficiency of this method in making the system stable and operating effective.

J. PV Technology Used in FPV in Indonesia

Figure 19 illustrates the distribution of photovoltaic (PV) technologies used in FPV across Indonesia. The data reveals that monocrystalline PV modules dominate with 27 documented uses, significantly outnumbering other types. In contrast, crystalline silicon (c-Si) appears in 3 cases, polycrystalline in 2, and thin-film CIS in just 1 case.

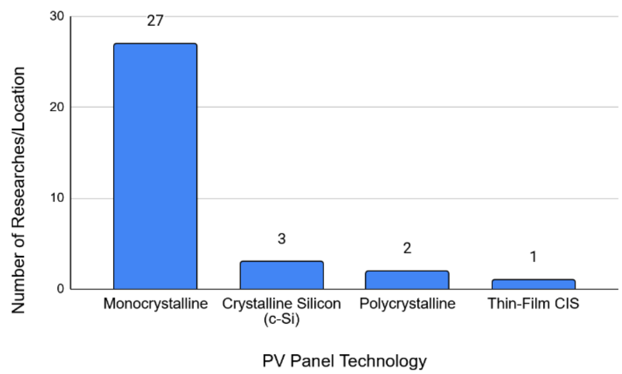

Fig. 19 Types of PV Module Technologies Used in FPV Research in Indonesia

The overwhelming preference for monocrystalline technology in Indonesia's FPV installations can be attributed to its high efficiency, superior durability, better low-light performance, and long operational lifespan, making it particularly well-suited for FPV applications where space, environmental resilience, and system efficiency are critical [71].

Monocrystalline PV modules offer the highest efficiency among commercially available solar panel technologies, typically ranging from 18% to 22%, compared to polycrystalline (15%–18%) and thin-film modules (10%–12%). This high efficiency allows monocrystalline panels to generate more power in limited surface areas, which is a significant advantage for FPV where the available installation space on water bodies is restricted [71].

Moreover, such modules as monocrystalline are characterized by durability and a relatively low degradation. Research data show a design life of these modules is at 25 to 30 years with the longevity of manufacturers of such module sureties of up to 25 years. This is because they provide a stable source of energy over a long period and hence suitable investment in FPV projects that needs stability in the supply of energy during long-term operations [71].

Monocrystalline panels inherently possess one of the most important advantages, and that is namely exceptional functioning in situations of low solar irradiance, i.e. they are more effective in regions where the solar reflection can vary, or during cloudy days. Additionally, the monocrystalline panels usually exhibit a smaller temperature coefficient; i.e. performance of the panel does not reduce precipitously with increasing module temperatures. This attribute is especially useful under Indonesia climatic conditions where FPV are likely to be affected by high surface temperatures [71].

FPV system wise, monocrystalline module has a specific advantage since it offers space advantage, enhanced resistance in humid areas, and high tolerance to heat. All these reasons resonate well with the business needs of FPV, which needs to endure high levels of humidity, sudden changes in temperature and is subjected to extended periods of water [71].

Case-wise, polycrystalline, thin-film modules are in general cheaper, but also have lower efficiencies and are not preferred in FPV applications where high energy yield is paramount. It is observed that module performance, module longevity and reliability appear to be becoming a major trend in Indonesia in the implementation of FPV systems depicted by the data used in this study.

V. CONCLUSION

This article presents the development and research patterns of FPV research in Indonesia based on available literature from 2018 to 2025. The reviewed studies primarily focus on the potential use of large and stable water bodies, such as reservoirs, lakes, and seas. East Java, West Java, and Bali are the provinces frequently used as research subjects. These locations are technically feasible and strategically constructed in terms of infrastructure and energy needs. Most FPV research models the systems as on-grid, supporting scalability, grid compatibility, and cost-effectiveness. Regarding PV cells, most studies choose monocrystalline due to their best performance and efficiency. Regarding mechanical support or floating structures, mooring and anchoring methods are the most commonly chosen due to their greater reliability and versatility for various local water environments.

Indonesian green solar energy research in the field of FPV is still dominated by system design and simulation, particularly using PVsyst and MATLAB. However, relatively little has been done, particularly on long-term performance analysis, indicating a gap in research findings regarding operational data monitoring, which could potentially be addressed through further study. Overall, this review reflects a growing academic interest in renewable energy generation by assessing its potential in providing sustainable and clean electricity.

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