Chapter 5

Solar Energy Potentials and Opportunity of Floating Solar PV in Indonesia

David F. Silalahi & Denny Gunawan

A. Overview of the Rapidly-Growing Solar Energy in Indonesia

Among ASEAN country members, Indonesia has the most abundant solar energy potential. It is measured by considering the areas of land mass and water bodies of Indonesia that can be utilized for solar panel farms. This fact is necessary to be realized by Indonesia because Indonesia is growing rapidly as the COVID-19 pandemic begins to become endemic. The growth of Indonesia will be associated with a demand for energy to power Indonesia's economy. However, Indonesia is also one of the highest polluters in the world. Thus, it becomes a dilemma for Indonesian growth. On one hand, Indonesia needs to grow its economy. It is expected that Indonesia could become the world's fourth-largest economy by 2050, and energy is a crucial part of it.

D. F. Silalahi & D. Gunawan
Australian National University, e-mail: david.silalahi@anu.edu.au

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On the other hand, Indonesia has also committed to tackling climate change and contributing to net-zero carbon emissions. This pledge is written in the 26th Conference of Parties (COP26) in Scotland, 2021. The Ministry of Energy and Mineral Resources has also laid out the plan to reach net-zero carbon emission by 2060 in Indonesia, which includes investments in renewable energy.

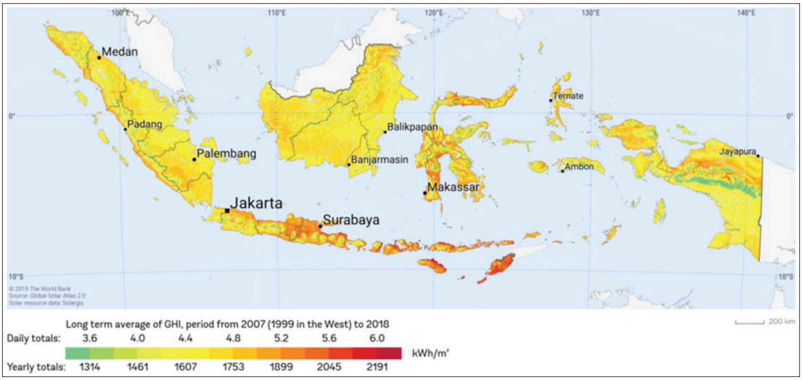
Indonesia is blessed with renewable energy. Based on the National General Energy Plan, it is suggested that the renewable energy potential in Indonesia is 443 GW, while 208 GW of it is from solar energy. This potential is huge and able to power Indonesia if it can be extracted. Indonesia's share of renewable energy is only 9.2% by 2019, far from Indonesia's target of the renewable energy mix, which is 23% by 2025.

Some efforts need to be performed to extract renewable energy, especially solar energy potential in Indonesia and increase Indonesia's renewable energy mix. However, solar energy is not always perfect. Technical challenges must be solved to ensure the abundant solar energy potential does not end to waste.

This chapter discusses the potentials and challenges of solar energy. Furthermore, this chapter concludes with an overview of floating solar photovoltaic (FPV) technology that can be a promising investment in Indonesia.

B. Solar Potential

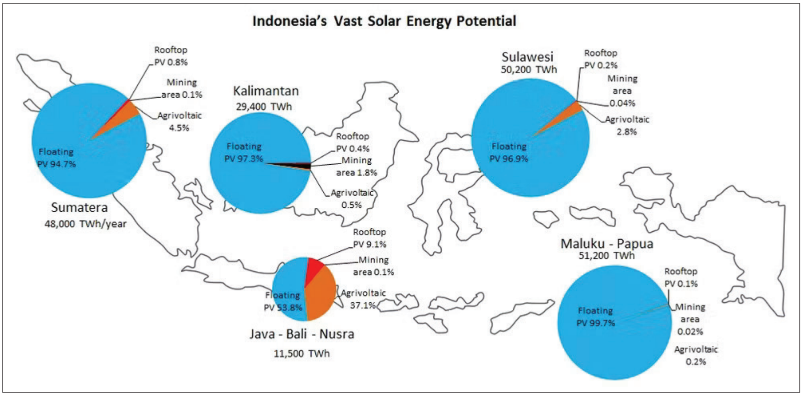
Indonesia is located in the equatorial region which allows the solar irradiation is relatively evenly distributed (Figure 5.1). Indonesia's average global horizontal irradiation (GHI) is 4.8 kWh/m2 per day (Solargis, 2017). According to the Global Solar Atlas PV study (2020), it is higher than the daily average GHI in Germany (2.9 kWh/m^2), Japan (3.6 kWh/m^2), China (4.1 kWh/ m^2), and Singapore (4.5 kWh/m^2).



Source: Solargis (2017)

Figure 5.1 Indonesia's Global Horizontal Irradiation Map

In the previous Indonesian National Energy Plan (2017), solar energy is suggested to be 208 GW. However, recently the potential has been updated to 3,294 GW (Antaranews, 2022). Institute of Essential Services Reform (2021) studied Indonesia's solar potential reaching 7,715 GW. Vidinipoulous et al. (2020) reported that Indonesia could generate 2,5431 TWh per year. A study by Silalahi et al. (2021) shows that the solar potential is much more immense. By locating the panels on rooftops and defunct coal mine sites, agricultural sites, and floating on the calm equatorial inland sea, Indonesia could harvest 190,000 TWh per year. The breakdown of the potential with a significant fraction of floating PV potential is shown in Figure 5.2.



Source: Silalahi and Blakers (2021)

Figure 5.2 Indonesia's Solar Energy Potential for Its Regions

The potential is much higher mainly because Indonesia has a sufficient calm maritime area considering floating PV potential. Figure 5.3 compares the reported potential in the terawatt hour unit. The estimates are different in number, but all the studies agreed that Indonesia's solar potential is vast.

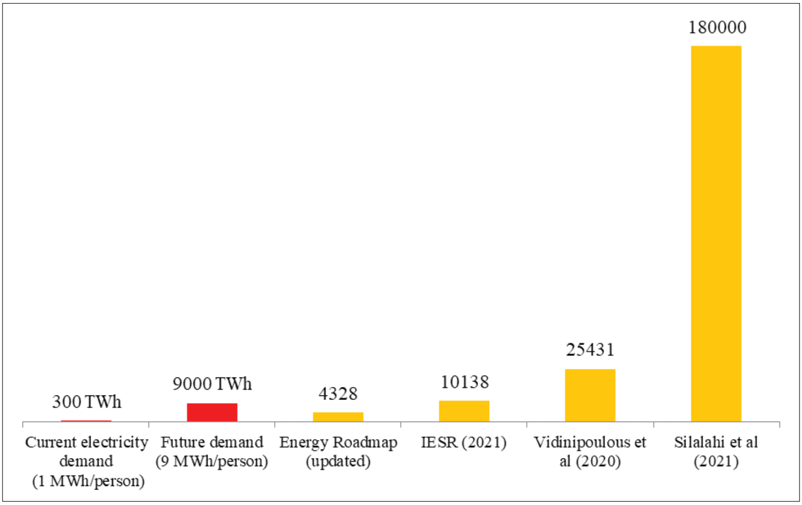


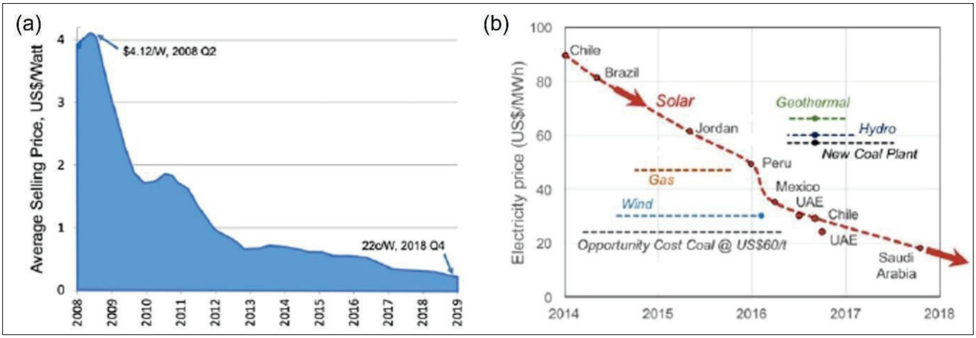
Figure 5.3 Indonesia's Solar Energy Potential Estimation in Recent Studies

C. Challenges of Solar Energy

As one of Indonesia's most prominent renewables solar energy is a great opportunity to act as an effective alternative to conventional energy sources. Harnessing abundant sunlight to provide on-demand energy would be vital to meet Indonesia's climate targets. However, several challenges to the growth of solar energy utilization exist and must be tackled.

1. High Capital Cost

One of the most common issues about solar energy is its high capital expenditure for solar panels. However, this cost-related problem is likely to be irrelevant now or soon as the price of photovoltaic modules has dramatically reduced over the past decade, as illustrated in Figure 5.4 (a) (Green, 2019). This cost reduction leads to a substantial drop in the levelized cost of photovoltaic-generated electricity (Figure 5.4 (b)).



Note: a. Decrease in the average selling price of multi-crystalline photovoltaic modules; b. Reduction in the Levelized electricity cost over time for photovoltaic and other sources
Source: Adapted from Green (2019)

Figure 5.4 Significant Reductions in Photovoltaic Module Price and Levelized Cost of Electricity

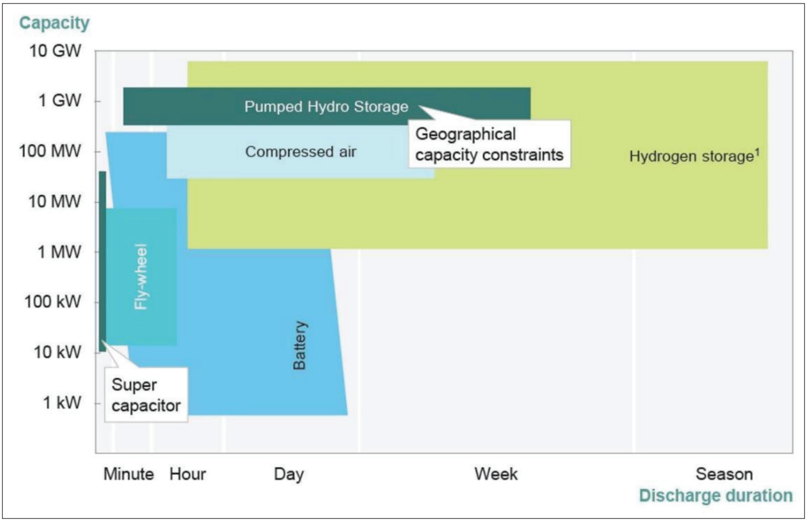
It is important to note that the drop in the levelized electricity cost shown in Figure 5.4 (b) is not solely due to the panel cost reductions but also due to more favorable financing conditions by stakeholders, including industries and the government (Green, 2019). Therefore, healthy investment conditions and supporting incentives are essential to decrease the solar electricity price even further and pursue the advancement of solar technology.

2. Intermittency of Solar Energy

The major problem with solar energy is its intermittency in terms of supply and demand. Solar panels require sunshine to produce electricity. When the irradiation is high, the electricity supply can exceed the demand. When it is not, solar-generated electricity supply cannot fulfill the demand, and therefore, fossil fuels are burned to keep the lights on. The variable nature of solar energy constrains its utilization as baseload power.

Adequate energy storage solutions are required to tackle its intermittency problem and ensure the stability of electricity grid. Numerous storage options with varying power capacities and discharge durations exist, as shown in Figure 5.5. For the short-term, batteries, supercapacitors, and compressed air are among viable storage solutions to support supply-demand balancing. However, they are unsuitable for long-term storage due to limited power capacity or storage timespan.

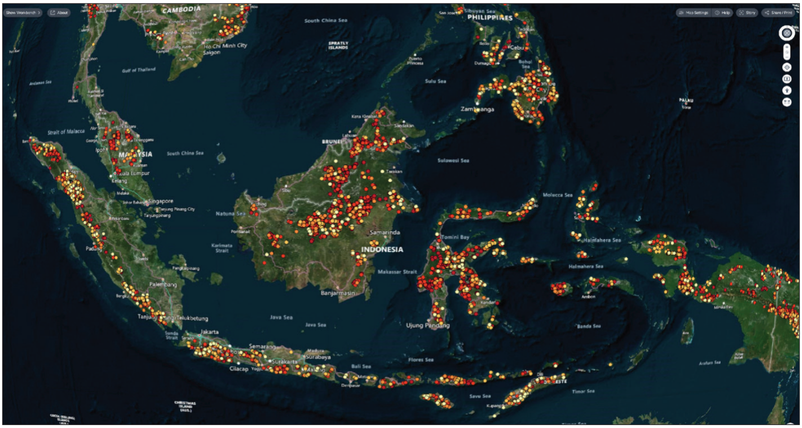
Pumped hydro provides an alternative solution for long-term solar energy storage. Typically, when the electricity supply from solar farms exceeds the demand, the excess energy can pump water from a lower level to a higher one. The stored energy can then be converted back to electricity when the solar-generated power is too little, allowing the water to fall through a hydroelectric turbine into the lower reservoir. This storage method accounts for more than 95% of worldwide power storage.



Source: Hydrogen Council (2017)

Figure 5.5 Options for Carbon-Free Energy Storage Solutions

Indonesia currently has no existing PHES systems. However, this will change soon because Indonesia has included 4000 MW of PHES in its electricity development plan. The 1000 MW Upper Cisokan Pumped Storage project, located in Cianjur, West Java, is currently being financed and approved, and is also planned to operate in 2025 (World Bank, 2021). The Matenggeng pumped hydro storage (943 MW) in West Java is expected to connect to the grid in 2028. The Grindulu pumped hydro storage (1000 MW) in East Java will operate in 2030 (RUPTL, 2021). The state electricity company Perusahaan Listrik Negara (PLN) plans to develop 4x250 MW PHES systems in Sumatera, which are expected to connect to the grid in 2029–2032 (RUPTL, 2021).



Source: Stocks et al. (2021)

Figure 5.6 Potential 150 GWh Greenfield Off-river Pumped Hydro Energy Storage Sites in Indonesia

Based on the Australian National University's Global Greenfield Atlas, 26,000 off-river PHES potential sites are identified in Indonesia (Stocks et al., 2021). The atlas includes eight combinations of storage energy volume (GWh) and storage power capacity, namely 2, 5, 15, and 50 GWh with 6 hours of storage and 5, 15, 50, and 150 GWh with 18 hours of storage. Figure 5.6 depicts the potential of 150 GWh off-river PHES. Indonesia has an enormous combined storage potential of 800 TWh. With so many options, energy planners can afford to concentrate on those with the lowest likely costs per unit of storage. A total of 321 TWh of high-class off-river PHES was identified in Indonesia (Silalahi et al., 2022).

Off-river pumped hydro storage, in contrast to conventional river-based pumped hydro storage, takes up a relatively small area, typically 200 hectares. Off-river PHES avoids the environmental costs of damming rivers, which aids in social acceptance (Silalahi and Blakers, 2021).

Indonesia could also store excess solar energy in a hydrogen form. Hydrogen is a novel way to keep energy in a large power capacity and long storage timespan. The excess solar electricity can be passed through a water electrolyzer to produce hydrogen during an oversupply period. When the power generated from solar farms is underperforming, the stored hydrogen can produce on-demand electricity using a fuel cell or a gas turbine. As a result, hydrogen offers a robust long-term energy storage option to maintain the solar electricity grid stability. More significantly, storing the excess electricity from solar energy as hydrogen can potentially widen the reach of renewable energy for deep decarbonization of hard-to-abate sectors, such as the chemical industry, petrochemical industry, and heavy transport.

Indonesia could build energy storage in the form of off-river PHES or hydrogen infrastructure. With a low daily, weekly, and seasonal variation of solar insolation, Indonesia does not require seasonal solar energy storage. Energy storage need to be only short term, mainly for day-night system balancing (Silalahi et al., 2021).

3. Land-Use Footprint of Solar Energy

Although current land use for solar energy is relatively small, it is predicted that in the future, with a decarbonized electricity grid, solar energy utilization will require significant land areas to be occupied. Defining the minimum efficiency standards for solar panels is essential to reduce land requirements for solar power plants (van de Ven et al., 2021).

On top of that, rigorous environmental and feasibility analysis needs to be conducted to determine where to put the solar panels. Several potential locations for developing solar farms that can minimize the land-use footprint include rooftops, abandoned mine sites, agricultural lands, and floating on suitable water bodies in Indonesia (Silalahi et al., 2021; van de Ven et al., 2021).

Rooftop solar panels do not need extra space and can accommodate the energy demands of residential, commercial, and industrial buildings (Silalahi et al., 2021). Co-locating solar panels in agricultural lands, known as agrophotovoltaic (APV), can be an attractive alternative in Indonesia as one of the world's largest agricultural countries.

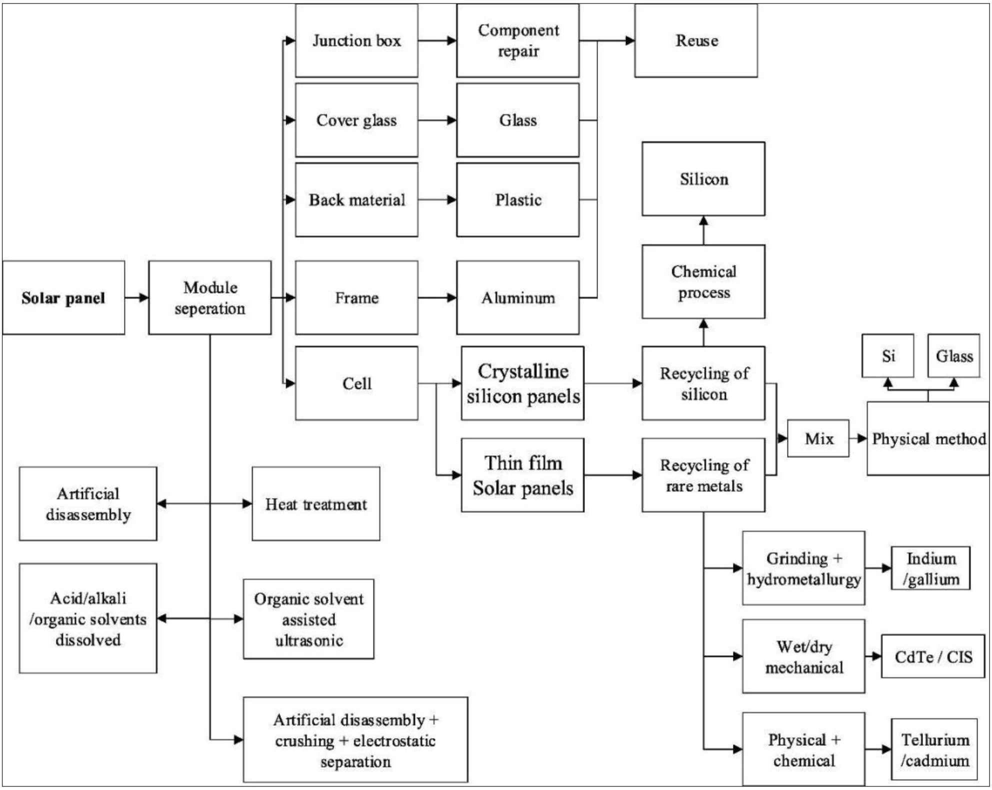
This APV approach could also benefit farmers by providing additional revenue streams (Silalahi et al., 2021).

Putting solar panels on former mining sites has also received significant attention to avoid land competition. With existing transmission lines and infrastructure in the abandoned mining sites, capital expenditure for developing solar power plants can be significantly reduced (Silalahi et al., 2021). Last but not least, floating solar photovoltaic is a promising technological option for Indonesia, with a huge fraction of water bodies, including freshwater and maritime. For instance, lakes and inland seas are suitable for floating solar panels as they typically have low wind speed and relatively calm water surfaces (Silalahi et al., 2021).

4. Hazardous Solar Panel Waste

Every solar panel has particular lifetime (typically around 20–25 years of service life) for its proper performance. After that, solar panels turn into a form of waste that adversely impact humans and the environment. Some photovoltaic cells contain hazardous chemicals, such as lead, selenium, tellurium, and cadmium. As an illustration, it is estimated that 33,205.36 tons of photovoltaic cell waste would create 62.26 tons of hazardous materials that may pollute soil and water, and affect human health (Tasnim et al., 2022). To address this issue, methods to recycle 100% of materials, from the glass, silicon, and metal frame, are required.

Significant efforts have been performed to develop techniques for solar module recycling. Moreover, the research predominantly focuses on silicon extraction and recycling rare metals. Regarding waste processing, there are three solar panel waste processing techniques: component repair, module separation, and recovery of silicon and rare metals (Xu et al., 2018). All those steps can be done using physical, thermal, and chemical processes as summarized in Figure 5.7 (Chowdhury et al., 2020).



Source: Xu et al. (2018)

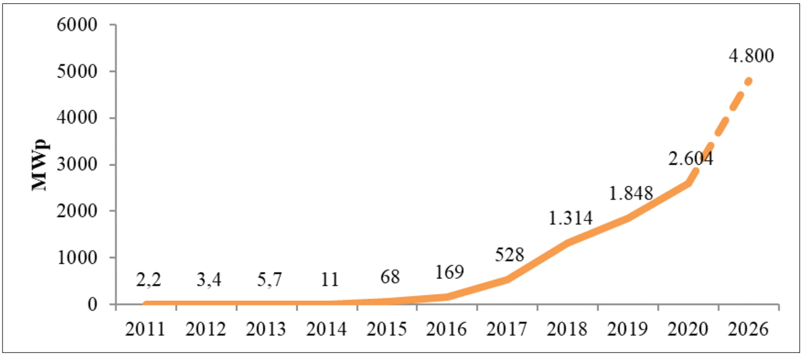
Figure 5.7 Various Recycling Techniques of Solar Panels

Several regulations regarding this matter are necessary as an addition to process the technological development for viable solar panel recycling. Unfortunately, Indonesia has not taken any measures to regulate waste solar panels. A clear recycling industry standard needs to be developed for waste management from solar power plants. The Government must set policies and regulations to encourage recycling and safe waste disposal.

C. Opportunity for Floating Solar Photovoltaic in Indonesia

1. Global Capacity and Cost Overview

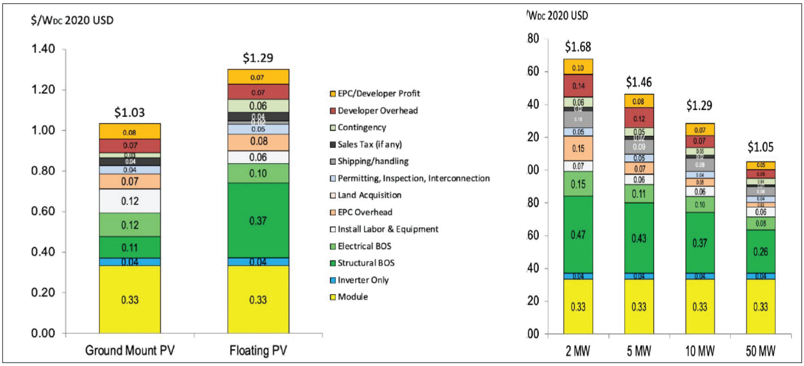
The quick drop in the price of solar photovoltaics (PV) encourages worldwide engineers to look forward to new ways to integrate more PV into power systems. However, the rise in ground-mounted PV installations could put more pressure on land use, particularly in locations where land is scarce and costly. Floating PV (FPV) offers a solution to this land problem and it has gained more attention. The global capacity of FPV systems grew from less than 1 MW in 2007 to 2.6 GW in 2020 (Cox, 2021). Moreover, it is projected to reach 4.8 GW by 2026 (Prnewswire, 2022). The trend of global FPV can be identified in Figure 5.8.



Source: World Bank (2019); Ramasamy et al. (2021)

Figure 5.8 Floating PV Cumulative Global Installed Capacity

NREL reported that the U.S. installed cost of a 10 MW FPV system is $1.29 per watt. It is $0.26 (25%) higher greater than a land-based PV system ($1.03 per watt). It is mainly due to the structural costs related to the floats and anchoring system (Figure 5.9 (a)). However, the larger capacity of the FPV the lower its system costs. The cost of a 50 MW FPV system is close to a 10 MW land-based PV system, as shown in Figure 5.9 (b).



(a) (b)

Note: (a) Cost Comparison of 10 MW FPV System and Ground-mounted PV System; (b) Cost of FPV System with Varying System Sizes

Source: Ramasamy et al. (2021)

Figure 5.9 Solar Panels Cost Comparisons

2. Advantages of Floating Solar Photovoltaic

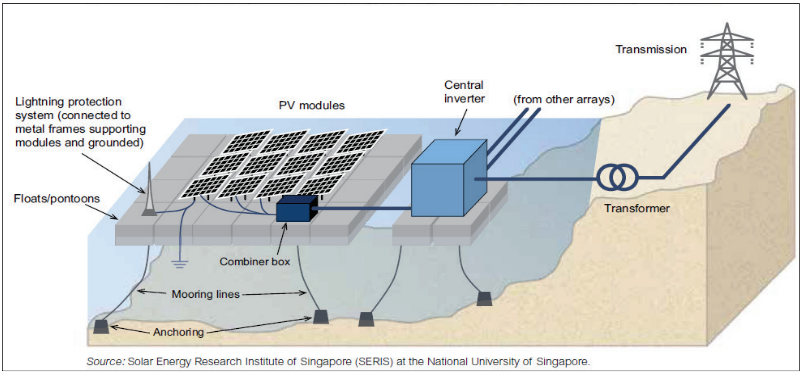
There are several key advantages of floating solar PV compared to land-based solar PV:

1. **No land occupancy.** The most significant benefit of floating solar panels is that the installations do not utilize land space, reducing land-use competition with agriculture or real estate, particularly in locations where land is relatively scarce and expensive.
2. **Higher solar panel performance.** Solar panel performance tends to decrease as temperatures increase. The water around the floating solar installation helps cool the solar panels, enabling the panels to generate electricity with higher efficiency. As reported in studies, the module temperatures are about 3°C to 15°C lower than land-based PV (Reindl, 2018; Liu et al., 2018; Dorenkamper et al., 2021). The performance ratio is 10% to 15% higher than typical rooftop PV systems (Reindl, 2018).
3. **Environmental benefits.** The floating solar panel structure covers the water's surface, reducing evaporation. Advantageous for areas susceptible to drought, as water loss to evaporation, can add up

over time and contribute to a shortage. The shade reduces the growth of algae in water bodies. Lastly, it generates low-carbon electricity.

3. Floating Photovoltaics Technology

Floating solar photovoltaics (FPV) are solar panels mounted on a designed structure to be able to float on a water surface. The design of an FPV is similar to a land-based solar PV system, except that it requires a floating structure to float the panels on the water's surface. The key components of FPV are PV modules, inverters, floating platform, anchoring and mooring system, cabling and combiner box, and transformer. A schematic of typical FPV is shown in Figure 5.10.



Source: World Bank Group (2019)

Figure 5.10 Schematic Diagram of Floating Solar PV System with Its Key Components

The floating structure and anchoring system are the main components that differ from the FPV system to the land-based PV system. This component is worth reviewing to decide on the suitable technology for designated floating PV sites. It contributes up to 30% of the total cost. In this chapter, we only discuss the floating system. There are three major designs of floating. The designs are pure-floats, pontoon and metal frame, and membranes and mat (Figure 5.11,

Figure 5.12, Figure 5.13). Table 5.1 summarizes the advantages and disadvantages of each design.

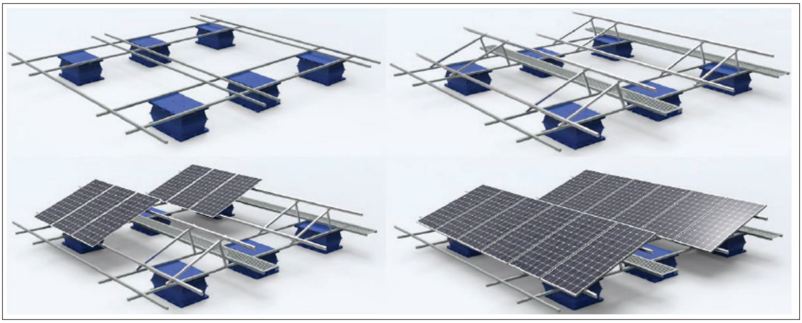
Table 5.1 Summary of the Advantages and Disadvantages of Pure Floats, Pontoons, and Metal Structure, Membrane, and Mats Floating Technology

Floating system	Pure floats	Pontoons and metal structure	Membrane and mats
Advantages	• Systems are easy to assemble and install • Systems can be scaled without major changes in design. • Few metal parts are required, minimizing corrosion. • Platform adapts to wave motion and relieves stress.	• The concept is simple. • Floats are easy to make and therefore can be easily sourced locally. • Wave movement between PV modules is less variable, thus reducing wear and tear on module connection components and wires.	• Conceptually simple and provides an easy base for installation and maintenance • being in direct contact with water; heat from sunlight is discharged into the water, thus lowering the operating temperature of the PV modules and increasing energy yield. • possible to float specially designed PV panels directly on water or in a semi-submerged manner • suitable for desert areas to prevent evaporation losses, to cover drinking water reservoir • able to withstand typhoon category 4 • able to withstand water level variation excess of 30 meters

Floating system	Pure floats	Pontoons and metal structure	Membrane and mats
Disadvan-tages	• Modules are mounted very close to water. It reduces air circulation and cooling effect of evaporation. It also generates a high-humidity environment for both PV modules and cables. • It is not cost-effective to transport pure floats over long distances, so they may need to be molded in nearby facilities • Constant movement may cause stress and fatigue to joints and connectors.	• With more rigid structures, waves cause stress to concentrate at certain points. • Structures are more difficult to assemble. • Access for maintenance can be difficult in certain designs. • Possibility of corrosion	• may not be easily scalable • more suitable for smaller-scale systems on reservoirs or irrigation ponds up to around 100,000 to 200,000 m2 in size • Tilting PV panel is not possible

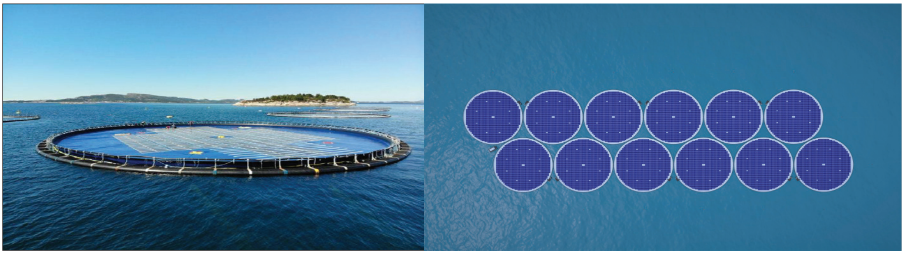
Source: World Bank Group (2018); Ocean Sun (2021)

Source: Ciet Et Terre (2021)
Figure 5.11 Pure Floats Design



Source: K-Water Research Institute (2019)

Figure 5.12 Pontoons and Metal Frames Structure by Scotra



Source: Ocean Sun (2021)

Figure 5.13 Floating Solar Technology Based on a Thin Hydro-elastic Membrane

D. Citing Floating PV

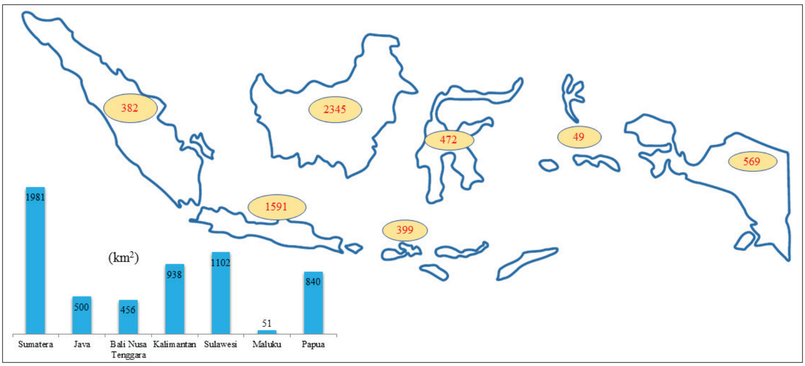
The critical question in discussing the development of a solar energy project is where to locate the solar panels. Is there enough space to host the required solar panels? Table 5.2 shows several recent floating PV projects and how large the area is occupied by each project. The figures vary for each site with an average of 0.8 MW per hectare. This figure might decrease as the efficiency of solar panels improves with the advancement of technology. However, it can be referred to as a conservative figure.

Table 5.2 List of Occupied Area in the Recent Floating PV Projects

Floating PV Projects	Capacity (MW)	Occupied area (hectare)	Capacity per occupied area (MW/hectare)
2021 - Kaohsiung, Taiwan - Ciel et Terre	4.1	8.7	0.5
2021 - Healdsburg, USA - Ciel et Terre	4.8	15.3	0.3
2021 - Xiqian, China - Ciel et Terre	21.6	30.7	0.7
2021 - Changhua, Taiwan - Ciel et Terre	22.8	29.7	0.8
2021 - Changhua, Taiwan - Ciel et Terre	10.3	22.6	0.5
2021 - Marouke Ike, Japan - Ciel et Terre	0.7	2.3	0.3
2021- Yunlin, Taiwan- Ciel et Terre	1.0	1.9	0.5
2021 - Banja, Albania - Ocean Sun	2.0	0.79	2.5

Source: Ciel et Terre (2021) and Ocean Sun (2021)

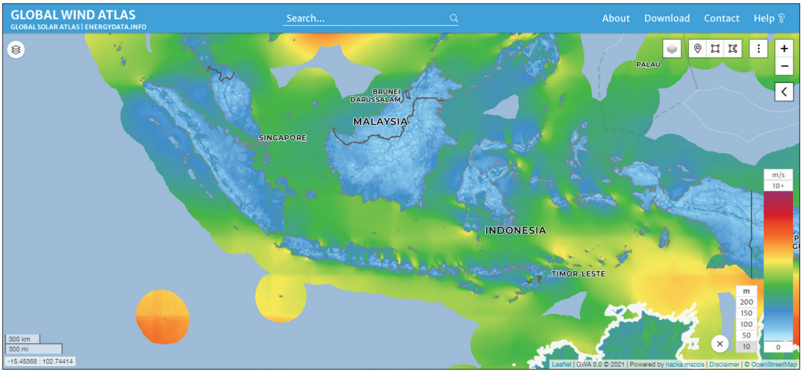
Finding a space for solar PV deployment in Indonesia is easy, with a land area of 1.9 million km^2 and a maritime area of 6.4 million km^2, the country has limitless possibilities to find unused spaces that can be transformed into solar farms (Geospatial Information Agency, 2020). Furthermore, the vast potential of floating PV is available in Indonesia. It could generate 180,000 TWh per year (Silalahi et al., 2021). The vast potential is mainly due to Indonesia having an adequate water surface. Indonesia has 5,800 lakes that can be found with a total area of 5,868 km^2 (Lembaga Ilmu Pengetahuan Indonesia, 2020). It is a vast space to explore for FPV deployment on freshwater.



Source: LIPI (2020)

Figure 5.14 Distribution of 5,807 Lakes with a Total Area of 5868 m^2 in Indonesia

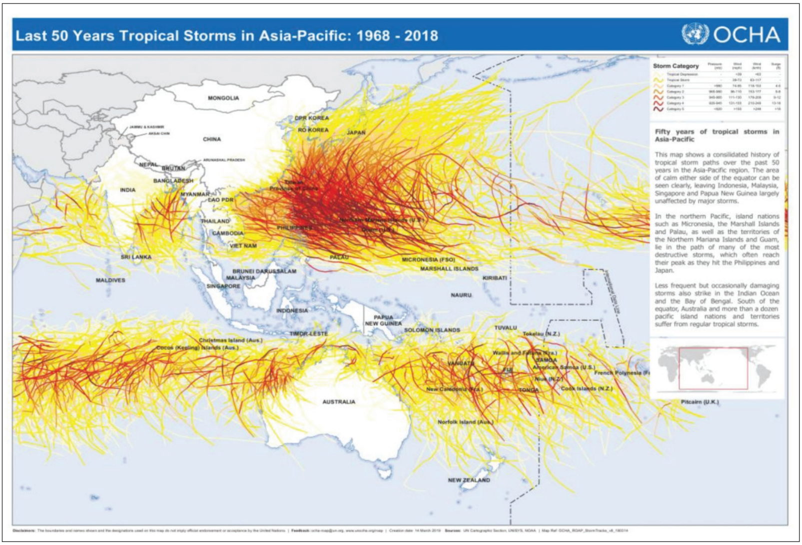
A large portion of Indonesia's maritime territory is protected by Sumatra, Java, Kalimantan, Sulawesi and Papua, as shown in Figure 5.15. A recent study reported that Indonesia has 708,000 km^2 of calm maritime area, with waves less than 4 m and wind speed less than 15 m/s (Silalahi et al., 2021). It is an ample space to host FPV. For example, the sea area along the eastern Sumatra, northern Java, between Kalimantan and Sulawesi, and the gulf in Sulawesi have relatively low wind speeds. As shown in Figure 5.15, the low wind speed at 10 m in the Indonesian maritime area is blue and green.



Source: Global Wind Atlas (n.d.)

Figure 5.15 Indonesia's Wind Speed at 10 M

The absence of tropical storms in Indonesia over the last 50 years raises confidence in the safety of installing solar PV panels (United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA, 2019). Figure 5.16 depicts the paths of tropical storms near Indonesia from 1968 to 2018. None of these storms has significantly affected Indonesia, Malaysia, Singapore, or Papua New Guinea.



Source: UNOCHA (2019)

Figure 5.16 The Last 50 Years of Tropical Storms in Asia-Pacific; 1968–2018

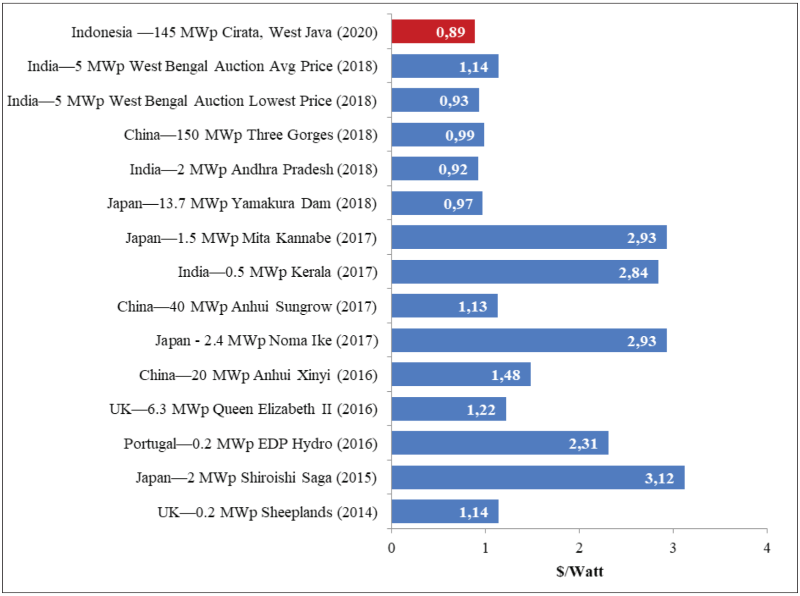
E. FPV Development in Indonesia

Indonesia does not have the facilities for commercial floating PV. However, it is about to change. In early 2020, Masdar (Abu Dhabi-based renewable energy group) and Indonesian energy company PT PJB agreed to build a 145 MW floating PV on a 225-hectare section of the Cirata Reservoir in West Java (PVTech, 2020). It is expected to operate commercially in 2022. In the mid of 2021, Sunseap signed a Memorandum of Understanding with the Batam Island authority to develop a floating PV combined with a battery system on Duriangkang Reservoir (Reuters, 2021). The floating PV is projected to have a capacity of 2.2 GW covering a 1,600 hectares reservoir area, the largest FPV in the world to date. A portion of the electricity will be exported to Singapore via a 50 km submarine cable.

The decreasing price of solar panels has lowered the investment cost significantly. In 2015, the Government set the selling price of solar PV projects up to 25 cents USD/kWh. Yet, the sales price from

Cirata 145 MW floating PV to PLN (Indonesian utility) is 5.8 cents dollar per kWh. Further, the recent bid price for Saguling 60 MW and Singkarak 90 MW floating PV are 3.74 cents USD per kWh and 3.68 cents USD per kWh, respectively (Newsletter, 2021). Saguling is an artificial reservoir (hydroelectric dam) in West Java, while Singkarak is a natural lake in West Sumatra with an existing hydroelectric power plant.

Although floating PV costs might vary due to site-specific design, compared to several projects in different countries, Indonesia's floating solar PV cost is already competitive compared to several projects in different countries. For instance, 129 million USD investment (PJB, 2020) in the 145 MW Cirata project equals 0.89 USD per Watt (Figure 5.17). It is lower than Japan's projects and similar to India's projects. This indicates that the floating PV is a promising way to supply low-carbon electricity for Indonesian.



Source: World Bank Group (2019); PT Pembangkitan Jawa-Bali (2021)

Figure 5.17 Floating PV Investment Costs Worldwide (Real and Auction Results)

F. Strategy for Future Solar Energy Deployment

The capacity factor of solar generation is now the lowest compared to all other forms of energy generation. By genuinely understanding the solar energy limits, we can solve the bottlenecks correctly. We can design our power grid accordingly by knowing the solar nature (no generation during nighttime). On the other hand, solar PV installations are much faster to build than fossil-based power plants and can be completed in months rather than years. It is favorable compared to coal, gas, hydroelectric, and nuclear plants that might take several years to complete.

By deploying at a huge scale (in Gigawatts), the cost of solar PV power in Indonesia is projected to be more competitive. Indonesia has consistently good solar irradiation. Economies of scale will take advantage, and there are large areas where deployment costs (including land access) will be low—particularly in the calm inland sea of Indonesia. It can be started by building floating PV in the safest space, such as existing hydroelectric dams, in the big lakes such as Lake Toba, and finally on the inland sea surface as the technology advances.

Moving towards the 2060 net-zero emissions target, public or business parties must participate. Religious leaders can encourage people about the importance of energy transition to keep the earth safe (Silalahi, 2022). As a breakthrough, the Government could also encourage communities to become involved in the renewable energy project. Community ownership allows high upfront investment sharing and enables more projects to develop. Community-owned projects have a specific purpose: focus on creating social benefits. A community-based renewable energy project has been developed in several countries like the United States and European countries, especially Denmark, Germany, the Netherlands, and the United Kingdom (particularly Scotland). One major benefit of involving the community is that it creates a sense of belonging that makes local people less reluctant to the project (International Renewable Energy Agency, 2020).

G. Conclusion

Indonesia could harness more unexploited renewable energy to achieve carbon neutrality in the future. Despite its challenges, floating PV technology offers a great opportunity to harness untapped Indonesia's solar potential. The abundant freshwater bodies and large calm maritime areas could host the solar panels. Its vast potential offers more opportunities to create green jobs, green energy, increasing Indonesia's role in the region. Not only solar energy for self-consumption but also exporting its energy for helping its neighbor to reduce carbon emissions.

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