Application of floating photovoltaic on dam reservoir in Indonesia

Application du photovoltaïque flottant sur le réservoir du barrage en Indonésie

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Abstract. Floating Solar PV (FPV) application is very suitable for areas with limited land availability, utilizing dam reservoirs or natural lakes. It also has several advantages in terms of environmental aspects, such as water conservation due to a decrease in the evaporation rate and inhibitions of algal growth by reducing sunlight intensity. However, the local specified guidelines for FPV plants in Indonesia are still unavailable at this moment yet. In recent years there have been several studies related to the potential of Floating Solar PV (FPV) installation in the Dam Reservoir in Indonesia by considering three aspects, i.e., (1) technical, (2) environmental, (3) legal and commercial aspects. This paper mainly presents two aspects: technical and legal. The technical aspect focused on the proposed design criteria by considering all the relevant local (national) and international standards. The legal aspect introduced a couple of issues regarding the electricity provision and the service level agreement provision. This paper also discussed Charlie dams as a study case for implementing the proposed criteria in this paper. Charlie Dam is an existing dam located in Central Java Province, Indonesia.

Résumé. L'application solaire flottante (FPV) est très appropriée pour les zones où la disponibilité des terres est limitée, utilisant des réservoirs de barrage ou des lacs. Il présente également plusieurs avantages en termes d'aspects environnementaux, tels que la conservation de l'eau en raison d'une diminution du taux d'évaporation et l'inhibition de la croissance des algues en réduisant l'intensité de la lumière solaire. Cependant, les directives locales spécifiées pour les usines FPV en Indonésie ne sont toujours pas disponibles pour le moment. Ces dernières années, plusieurs études ont été menées sur le potentiel de l'installation de PV solaire flottant (FPV) dans le réservoir du barrage en Indonésie en tenant compte de trois aspects, à savoir (1) technique, (2) environnemental, (3) aspects juridiques et commerciaux. .

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Ce document présente principalement deux aspects ; technique et juridique. L'aspect technique s'est concentré sur les critères de conception proposés en tenant compte de toutes les normes locales (nationales) et internationales pertinentes. L'aspect juridique a introduit quelques problèmes concernant la fourniture d'électricité et la disposition relative à l'accord sur le niveau de service. Cet article a également discuté des barrages Charlie comme cas d'étude pour la mise en œuvre des critères proposés dans cet article. Le barrage Charlie est un barrage existant situé dans la province centrale de Java, en Indonésie.

1. Introduction

Indonesia currently has around 255 large dams that are already in operation. As one of the areas in the dam, the reservoir has the potential to be utilized for Floating Solar PV (FPV). Based on a simplified simulation from 110 dams with a total surface area of around 224,000 ha, the FPV could generate an electric potential of 7,000-16,000 MW. Based on these considerations, Indonesia has the potential to utilize the reservoir area as a medium from FPV. In addition, FPV is very suitable for areas with limited land availability. It also has several advantages in terms of environmental aspects, such as water conservation due to a decrease in the evaporation rate and inhibitions of algal growth by reducing sunlight intensity.

Indonesia has a target of achieving the use of Renewable Energy (EBT) of 23% by 2025. For this purpose, Indonesia focuses on building its first floating PV (FPV) in Cirata Dam Reservoir as one of the national strategic projects (PSN). In addition, under the Dam Operational Improvement and Safety Project (DOISP), the government encourages research to implement the FPV in DOISP existing Dams that includes remedial works. The aim includes to generate self-sufficient revenues required for the next operational expenses.

Presently, the specified guidelines for FPV plants in Indonesia are still unavailable. In recent years there have been several studies related to the potential of Floating Solar PV (FPV) installation in the Dam Reservoir in Indonesia by considering three aspects, i.e., (1) technical, (2) environmental, (3) legal and commercial aspects. This paper will only focus on two (2) aspects, i.e., technical and legal aspects.

2 Technical aspects

There are several unique technical challenges in designing FPV in a man-made reservoir. To name a few: (1) Environmental loadings and limit states that are unique to the reservoir such as partial drying of the reservoir; (2) Unique response and stress distribution due to wind-capturing structure in the form of angled PV, installed on top of a relatively light floating structure with large footprint; (3) FPV location that is in the proximity of sensitive dam structures and its supporting structures, which most of the time has a significant impact when fail. To overcome these challenges, the reliability of FPV structures and the safety of the FPV-Dam system as a whole are assured through the adoption of the safety design guideline explained in this section. The majority of the guideline is adopted from the recently published DNVGL 0584 [1], with additional comments to put each point into context. Other international standards [2]-[14]; national standards, guidelines, and regulations [15]-[20]; and academic publications [21]-[28] were also used as reference.

2.1 Environmental conditions and loadings:

Several environmental loadings that are unique to FPV installed in a man-made reservoir are illustrated in Fig.1. Some special notes regarding these loadings in the guidelines are:

- Long-term direct field measurement data is always preferred but rarely available. In these cases, heuristic or theoretical models may be used to determine the environmental conditions provided that the model is properly calibrated using direct field measurement sampling and long-term secondary data.
- In most cases, the wind is considered as the primary environmental loading for the structures. Both the sustained wind (typically averaged over 1 hour period) and transient wind (including gust and squalls) need to be considered in the design. Furthermore, lateral of the wind profile needs to be accounted for, considering FPV has a large footprint. Most of the well-known wind models are calibrated against measurement over land; thus, its use in the reservoir environment needs to be done carefully.

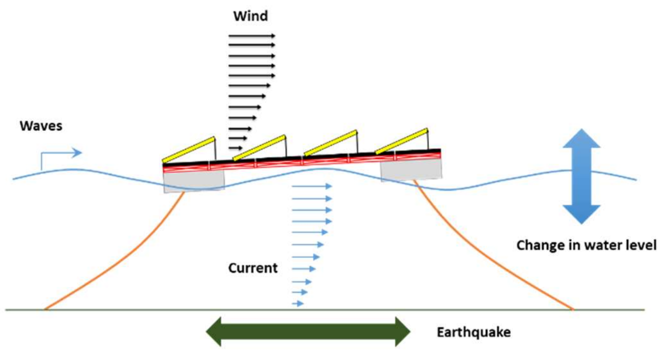

Fig.1. Environmental loads for FPV

- Based on experiences in other fields (e.g., floating wind, floating platform, etc.), waves contribute most to the cyclic loadings, especially on anchor, floater, and mooring connections. These cyclic loadings may cause fatigue, which in turn determine the required maintenance schedules and designed service life. Furthermore, the through and crest of the waves may cause free spans on floaters, which may cause an increase in bending and/or floater deflection. These so-called hydroelasticity and hydrodynamic effects need to be considered carefully in the design phase.
- Based on a hindcast study for lakes by Breugemm and Holthuijsen [27], higher wind fetch area (i.e., reservoir area on top of which the wind is blowing) and deeper water caused higher wave heights. Therefore, the wave action on structures may be negligible in shallow or small reservoirs. Besides the typical wind-driven waves, there are other sources of waves in man-made reservoirs that need to be accounted for, e.g., tsunami-like waves due to landslides, wave reflections on the reservoir banks, ship-induced waves, etc.
- Although current is typically small in man-made reservoirs, the guideline also outlined the methodology for calculating the inlet-outlet-driven current and wind-driven current.
- Significant water level change is observed and expected in many reservoirs in Indonesia. The change is typically higher than the typical tidal range in the Indonesian coastal area. In some reservoirs, the change in water level may reach 23m. This unique condition requires the design of mooring to accommodate such change, such that the station keeping capabilities is kept in both high and low water levels. Furthermore, some reservoir area is prone to drying and may cause the FPV to be stranded. If stranding condition is unavoidable, additional analysis and mitigation plan are required to avoid unwanted damage and guarantee that FPV is able to refloat once the water level is back to normal.

- Indonesia is located in a seismically active region; therefore, each FPV design needs to consider the earthquake risk to the structure. Based on the study by Jin et al. [23], slackly moored structures are less prone to earthquakes than tautly moored structures.
- Earthquakes may also cause dangers other than transferring load via mooring lines. For example, landslide-induced tsunami and destabilization of the anchor may be caused by the earthquake.

2.2 Design basis and acceptable design

As a design basis, the structure is assigned a consequence category based on the consequences of failure. For each consequence category, a target safety level can be defined in terms of an annual probability of failure. The annual target probability of failure is the same as the one from DNVGL-RP-0584 [1] and DNVGL-ST-0119 [5], which range from 10^{-4} to 10^{-5}, depending on the consequence level. However, based on field experience, this target safety level is very difficult to achieve in real-world conditions [22]. Therefore, the proposed guideline is adjusted so that the target safety level may be calibrated and then justified based on the FPV's design related to the Dam safety and based on site-specific conditions.

Just like in DNVGL-RP-0584 [1] and DNVGL-ST-0119 [5], the target safety level is met by applying Load And Resistance Factor Design (LRFD), also known as Limit State Design (LSD). Different limit states require different characteristic load, load factor, and material factor. However, the load and resistance factors given in the references are calibrated for floating wind structures [5] and may cause overdesign. In the future, more risk and reliability study is needed so that load and resistance factors can be calibrated against FPV structures.

To satisfy the requirement stated by the Decree of Minister of Public Works & Housing or *Peraturan Menteri PUPR RI NO.6 2020* [19], *i.e.,* that the FPV location should not disturb critical reservoir functions, the following criteria for choosing floating PV location shall be used, unless appropriate justification and careful consideration are shown in the design process:

- Floaters and anchors should be chosen in locations that avoid stranded conditions on any water level.
- Floaters should be chosen in locations where the static loading direction causes the floaters to drift away from spillways and other critical dam structures in the case of mooring or anchor failures.

In addition, the FPV location should always comply with the following criteria:

- FPV components should not block intake flow, dam/reservoir inspection routes, and regular bathymetric survey routes, nor cause significant backwater.
- All FPV components should be located inside designated safety zones and do not interfere with critical function of the reservoir structures such as the intake and spillway structures and should avoid unnecessary risk to floating PV (e.g., from existing activities such as aquaculture and tourism, from landslides, etc.)

To ensure the dam's safety, the FPV-dam system needs to be designed so that residual risk and probability of failure for the dam are low enough to be acceptable in the case of FPV failure. Three options may be chosen to obtain this goal, which is illustrated in Fig.2 and explained below:

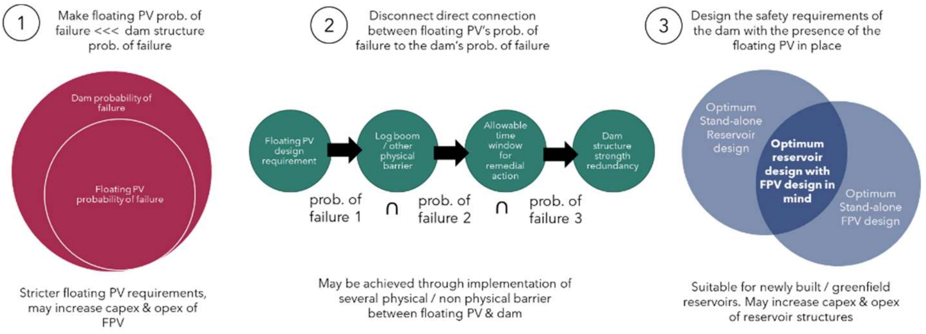

Fig.2.Three strategies to ensure the dam safety

1) Keep the floating PV probability of failure low. Preferably lower than the total probability of failure of the dam during the floating PV design service life. However, this will result in a high design requirement for the PV.
2) Disconnect the floating PV safety requirements from the dam safety requirements, where the probability of failure of the dam does not directly tie to the failure of PV. This may be achieved by designing a preventive mitigation plan (e.g., natural barriers, anti-drifting device, distancing, avoiding upwind locations of dominant winds, etc.)
3) Design the safety requirements of the dam with the presence of the floating PV in place. This is suitable for greenfield dams, where the dam may be designed to account for a possible FPV failure

3 Discussion on regulatory issues

Gadzanku et al. [29] discussed the barrier of floating PV (FPV) development in Southeast Asian countries. They argue at least three regulatory barriers that stall the development of FPV in this region. The barriers such as the uncertainty about water rights (in terms of utilization of dam reservoir) or lengthy, expensive, and unclear environmental approval process may delay the FPV project development and increase the project's cost. That barrier could make an investment in FPV unappealing.

Similar problems also appear for Indonesia. This paper also highlights the regulatory aspects that might cause barriers to the development of FPV. At least there are the regulatory aspects that may become an issue; the unclarity of electricity provision schemes, the regulation on electricity pricing, and lastly, the unclarity of utilization of reservoir area.

3.1 Electric power provision scheme

In Indonesia, electricity provision is predominantly run by PLN. However, the electricity act no 30 - 2009 opens the door for private sectors to be involved. Based on the existing regulations, at least three schemes could be followed by the private sector to involve in electricity provision in Indonesia. First, the private sector as an Independent Power Producer (IPP) could have an operational area. The second scheme is Power Purchased Agreement (PPA) contract with PLN, and the third scheme is by Power Wheeling Scheme. These three schemes are also the available options for the FPV developers.

Government regulation no. 25 - 2021 governs that a private sector is eligible to own an operational area. It means that the private sector could manage the whole electricity business, from power generation to distribution. However, in terms of floating photovoltaic at dam reservoir, this scheme might not be feasible due to the intermittency and the capacity of power production that might not be adequate to provide the electricity needed in a particular area.

Furthermore, most of the operational areas have been owned by PLN. Therefore, it is not recommended for an executing entity (Badan Usaha Pelaksana-BUP) in a photovoltaic power plant to pursue this path.

Presently, the most common scheme used to IPP is a PPA contract with PLN. However, the PPA contract should be given in open bidding. Therefore, this scheme is relatively risky for IPP solar PV operators using dam reservoirs as part of the infrastructure utilization scheme. Moreover, the unsolicited mechanism, commonly found in the PPP scheme (KPBU), is unrecognized in the PPA scheme. Furthermore, there is no right-to-match scheme in the PPA bidding as well. Therefore, a BUP will face a great risk of losing all initial investment that has been made for the project preparation to their competitor without any compensation even though they did all studies and project engineering design. The PPA contract also has to follow the electricity generation cost called Biaya Pokok Pembangkit (BPP) that regulates PLN on the electricity pricing. The BPP is discussed later in this article. The capacity of electricity provision in an area also has to follow the general plan of electric power provision known as *Rencana Umum Penyediaan Tenaga Listrik* (RUPTL).

The general plan of electric power provision or *Rencana Umum Penyediaan Tenaga Listrik* (RUPTL) regulates a ten-year electricity development plan for the operational areas, or *Wilayah Usaha*, of PLN. The RUPTL contains demand forecasts, future expansion plans, and electricity production forecasts. The RUPTL also indicates which projects are planned to be developed by PLN and private investors. Thus, RUPTL is important for the investment strategy in Indonesia. However, when an electricity provision project has been mentioned in the RUPTL, the energy sources and the commercial operation date (COD) for the individual powerplant usually have been decided.

The RUPTL is written based on the National Electricity General Plan (*Rencana Umum Ketenagalistrikan* Nasional – RUKN) and Regional Electricity General Plan (*Rencana Umum Ketenagalistrikan Daerah* – RUKD). The Ministry of Energy and Mineral Resources (MoEMR) is responsible for the RUKN, and the regional governments (Provincials and Regencies) are responsible for preparing the RUKD based on RUKN. Therefore, FPV developers should consider this RUPTL before deploying any investment.

Lastly, the Power Wheeling Scheme (PWS) allows any independent power producer (IPP) to sell its electricity production using business to business (B2B) contract scheme with their prospective buyer. This scheme (PWS) seems more promising for floating PV operators in dam reservoirs as they could sell the electricity without any obligation to follow the BPP. However, this power wheeling scheme has never been implemented since the government issued the regulation.

3.2 Electricity generation cost (Biaya Pokok Pembangkit - BPP)

As discussed in the previous section, the floating PV operators or developers should follow the BPP in electricity purchasing tariff for the PPA scheme. The BPP also varies across the country and usually follows the infrastructure readiness and demand. In the populated area with more demands, the BPP is relatively low. As shown in MoEMR regulation no. 169/2021 shows that the BPP at Java is 6.23 cents USD/kWh while at Lombok system is 11.77 cents USD/kWh.

The BPP usually increases or decreases following the fossil fuel market price at the time. The MoEMR no 169, the year 2021, shows that the BPP is slightly lower than the BPP based on MoEMR no 50, the year 2021. For instance, the BPP could vary from 6.23 cents USD/kWh to 11.77 cents USD/kWh. This variation should be included in consideration of the investment of floating PV on reservoir dam.

Another issue that is worth to be discussed here is the MoEMR standing point to renewable energy development. The MoEMR no. 4/2020 regulates that the BPP for the photovoltaic maximum is 85% from the BPP. This MoEMR regulation is problematic in terms of Indonesian commitment for the Net Zero Emission (NZE), since this regulation did not show Indonesian commitment to allowing renewable energy to be developed. However, the regulation is in the domain of MoEMR, and all floating solar PV should comply with this regulation. Therefore, this regulation could be an obstacle to developing floating solar PV in the dam's reservoir in Indonesia. This article argues that MoEMR should consider revising or doing de-regulation on this regulation (MoEMR no. 4/2020)

3.3 Reservoir utilization

A floating PV requires a particular body/water reservoir area to be utilized. However, the decree of Ministry of Public Works & Housing number 6/2020 indicates only 5% of the reservoir area that could be utilized for the floating solar PV. This regulation has no scientific explanation for how this number was determined, except from previous regulation concerning fish net on the dam reservoir. It is obvious, however, that a fix percentage of 5% or another number should also consider the condition differences at a specific FPV location. Among others, the depth, surface area, the quantity of water in the reservoir and its dam location: either on the mainstream or off mainstream would create different risks for the FPV as well as the other structures. Furthermore, this regulation has no reference in other countries as well. Table 1 shows a few floating PV examples that exceed 5% of the reservoir area.

Table 1. A few examples of Floating PV in reservoir areas in a few countries [30]

Countries	Installed Capacity (MW)	Annual Energy Production (GWh)	Area Reservoir (km^2)	Area Floating PV (km^2)	Area Floating PV/Area Res
Burundi	18,0	31,0	1,5	0,22	14,56%
Gabon	228,4	393,3	27,7	2,83	10,21%
Mauritius	41,4	82,1	3,3	0,51	15,61%
Namibia	353,0	879,8	5,2	4,37	84,66%
Rwanda	28,0	50,3	3,3	0,35	10,63%
Sierra Leone	56,0	112,2	10,1	0,69	6,91%
Eswatini	40,8	81,0	6,5	0,50	7,83%

Concerning the limit of the allowable area of FPV as a percentage of the reservoir area at Normal Water Level, there could be variations and not a single number after due consideration of several factors, such as:

- the probability of dam failure as a result of risk analysis at a current stage prior to the introduction of potential FPV on its reservoir;
- the location of the dam: either it is on the off-stream or the mainstream, especially if a cascade system is in place;
- the technical data of the dam in terms of its height, total reservoir area, operational conditions, and others.

4 Case study

A hypothetical case study of Charlie Dam (a disguised name) discussed in this paper. The dam is located in Central Java Province, where the FPV is planned to be built inside one particular section in Charlie dam, illustrated in Fig.3. Several notable existing conditions of the dam are:

- Historical data shows a relatively high landslide risk on the north-west bank
- No proper zoning regulation is present. The dam is utilized as a recreation area and some reservoir area is utilized for aquaculture.
- Located outside active fault. An active fault is defined according to PUSGEN/ National Seismic Centre (2017), the peak ground acceleration (PGA) for 5000 years returns period ranges between 0.4g and 0.5g
- The maximum water level and total reservoir area during flood condition is +78.75m and 900 ha, respectively. In comparison, maximum water level and total reservoir area during lowest water level is +50m and 100ha, respectively.

This embankment dam was built from 1952 to 1958 just a few years after the independence of Indonesia by referring to a design conducted during the Dutch colonial era with the main purpose of irrigation in the rural agriculture area and drinking water supply of a major urban city in the northern shore of Java Island. In addition, this reservoir is currently also attracting people to visit as a recreation destination for the 800 hectare of water surface at normal level containing around 90 million cubic meter of water. After more than 60 years in operation, there is an ongoing remedial works for the dam & other structures as part of the Dam Operation Improvement & Safety Program (DOISP). In parallel, another study was carried out regarding any possibility for the deployment of FPV on the reservoir in the effort to invite private sectors who are interested to enter the solar power as one of the green energy projects. The study aims to review all relevant aspects required for such kind of collaboration between the dam owner from the public sector and the investor, including but not limited to the technical, regulation, environmental, social, commercial, and financial aspects. The homogeneous earth fill dam of 38 meter in height has 168-meter length and 6 meter of width at its crest with elevation of +80.50 above mean sea level

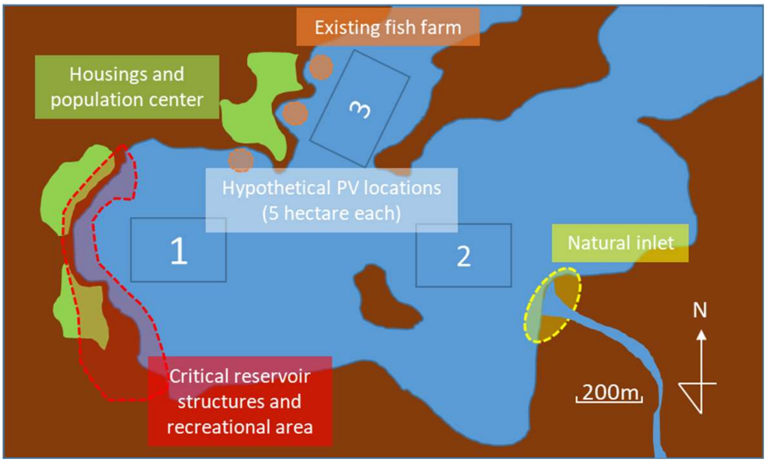

Fig.3. Hypothetical FPV locations and critical structures in one hypothetical Charlie reservoir section

The water depth around the area of interest (Fig.3) ranges from 0m (dry) to 16m, with the longest wind fetch length of 1.8km. On a typical operational environment (non-extreme weather, typically used for fatigue calculation), generated waves may be roughly approximated from the maximum monthly averaged wind of 10.5m/sec. This corresponds to a small significant wave height value of 0.4m. Note that these conditions can not be used for a detailed design basis. The detailed analysis and data on bathymetry, soil type, current velocity (speed and direction) and occurrence, wind velocity and occurrence, design wind fetch length, wave hindcast, and verification are needed for detailed design. Based on the difference in wetted area between the flood and lowest water level, the risk of stranding conditions is relatively high. If based on other analysis, if it is found to be impossible to avoid stranding conditions during the floating FPV's lifetime, additional detailed analysis for stranded and re-floating conditions are required

Considering that one hypothetical FPV location in Fig.3 is relatively close to the natural inlet, it may cause sedimentation. The presence of PV may affect the sedimentation through the following process:

- Decrease in turbidity due to decrease in wind fetch area
- Change in fluid flow velocity close to the surface
- Change in overall water temperature and vertical temperature distribution

All of the above may change the sediment settling time, settling velocity, and sedimentation locations. Therefore, further sedimentation analyses are needed to ensure that it will not hinder the operability of reservoir (e.g., its service life and flow control) and floating PV (e.g., accidental mooring burial, increase in mooring-reservoir floor contact, or increase in stranding condition). The advantages and disadvantages of each hypothetical FPV location are summarized in Table 2.

Table 2. Implementation Examples of Design Considerations of Three Hypothetical Floating PV Locations in Charlie Reservoir

Hypothetical Location	Advantages	Disadvantages
Loc. 1	• Proximity to shore and critical reservoir structures may reduce the length of transmission lines and provide easier maintenance access • Large available water body available for installation	• Proximity to an existing recreational area may increase the risk from human activities • Proximity to landslide risk • If the dominant wind direction is blowing towards the west, there is no safety barrier between the floating PV and critical reservoir structures on its left in the case of an uncontrolled drift event • Large wind fetch length on its right side

Loc. 2	• If the dominant wind direction is blowing towards the west, an island to the left of the floating PV provides a natural safety barrier between the PV and critical reservoir structures in the case of uncontrolled drift • Large available water body available for installation • Relatively small wind fetch length from all direction	• If the dominant wind direction is blowing towards the east or south, there is no safety barrier between the floating PV and critical reservoir structures on its bottom-right in the case of an uncontrolled drift event • May be harder to access and require longer transmission lines due to its location that is relatively far from any existing structures or population center • Sedimentation may be highly affected by the structure since it is close to a natural inlet on its right side
Loc. 3	• Any dominant wind direction will cause the floating PV to move away from any critical reservoir structure in the case of an uncontrolled drift event. • Proximity to shore and population center may reduce the length of transmission lines and provide easier maintenance access • Relatively small wind fetch length from all direction	• Relatively close to existing fish farm areas may increase the risk from human activities • Limited available water body for installation. The floating PV may also affect the water flow and sedimentation since it is located in a constricted area.

Due to Charlie d03029am is an existing dam; therefore, some issues related to the existing dam structures and environmental conditions need to be considered and solved before further actions regarding the design and installation of floating PV. The dam owner or operator shall initially determine the master plan of reservoir use by establishing the Zoning for FPV by considering tourism activities, fishing, and others., with prior discussions involving the local authorities and communities.

5 Conclusions

This paper discussed two aspects of applying the floating PV for Dam Reservoir in Indonesia, i.e., technical, and legal aspects. Several unique environmental loadings to FPV installed in a man-made reservoir, especially in Indonesia, are described.

Some issues regarding the regulatory barriers that potentially stall the development of FPV in Indonesia were discussed in this paper. At least three regulatory aspects may become major issues: the unclarity of electricity provision schemes, the regulation on electricity pricing, and lastly, the unclarity of utilization of reservoir area.

Finally, one case study was analysed in this paper. This paper introduces three hypothetical PV locations' advantages and disadvantages based on their practicality and dam safety at the study case location.

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