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Watts on Water: A Sustainable Power Initiative on The Angat River Through Floating Photovoltaic Systems in Plaridel, Bulacan, Philippines

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***Abstract* - This study proposes a conceptual insight in renewable energy demand, especially in local municipality of Plaridel, Bulacan. Ground-mounted photovoltaic systems compromise other aspects such as agriculture, housing, tourism, etc. This opens the opportunity of using water bodies as suitable location for photovoltaic systems. However, this also comes with challenges such as compromising river-based or water-based activities. Fishing, tourism, and water flow can be hindered by these modules and this is the reason that makes not all water bodies as compatible to be used as project site for floating photovoltaic systems. Despite of these challenges, floating photovoltaic systems are much more flexible than ground-mounted photovoltaic systems, since maximizing the surface area of reservoirs or river widths are not necessarily needed to be covered, thus compromising the water-based activities is possible to be avoided and prevented. The shading that the floating photovoltaic systems provide also helps in preventing excessive water evaporation, maintaining the healthy environment of water-bodies for fishes and other aquatic animals. The water also helps the system by cooling its lower parts, which improves the efficiency of the solar panels by preventing overheating of the modules. Even though this study does not involve actual implementation of FPV systems in Plaridel, Bulacan and just a proposal for the deployment, it provides a grounded conceptual framework that researchers, engineers, and policy makers can use as reference for future implementation.**

INTRODUCTION

Driven by international goals like the UN's Sustainable Development Goals (SDGs), the world aims for renewable energy. The Philippines is a developing country that experiences rapid population growth and economic expansion that leads to an increasing demand for electricity. However, the Philippines is still significantly dependent on fossil fuels despite of being rich in renewable energy resources. The Philippines' dependency on coal-fired power surged 62% and named as the most coal-dependent country in Southeast Asia in 2023[1]. Moreover, the country's share of coal-generated electricity climbed to 61.9% in 2023 compared to 59.1% in 2022. The Philippines increased its dependency on fossil fuels for 79% in the year 2024, leading to just 21% of the country's electricity was generated from low-carbon sources. The largest clean electricity of the Philippines comes from three sources; hydro (8%), geothermal (8.3%), and share of wind and solar (3.8%) which are just a quarter of the global average of 15%. Despite this, the Philippines is aiming for 35% renewable electricity by 2030[2].

The Philippines geographic location is ideal for solar energy farming, receiving a solar radiation of 4.0 – 6.0 kWh/m^2 in a day[3]. However, the Philippines has a limited supply of flat, large tract of land that can be used for solar farms. The restrictions are due to the competition with agriculture for these flat lands. Due to the increasing population growth, urbanization also became one of the competitors of solar farms in these flat lands since providing housing or residence properties for the people are also priorities. The demand in land for various priorities presents a challenge in implementation of solar farms.

The Philippines, being an archipelagic country, is engulfed by huge portion water bodies.

Body	Area Coverage	Percentage
Land	299,735 km^2	14%
Water	1,900,265 km^2	86%
Total	**2,200,000 km^2**	**100%**

Table 1: Philippines' area coverage in percentage[4]

Despite of having inland waters as roughly 0.21% of the water bodies, it still presents a significant area of 406,328 hectares or 4,063.28 km^2 [5]. Therefore, this presents an opportunity to be an alternative for implementation of solar farms.

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FLOATING PHOTOVOLTAIC SYSTEMS

Floating Photovoltaic System, or also known as FPV Systems and sometimes photovoltaic power plants, refers to a system of solar panel modules that are mounted on floating bodies of water such as sea and inland waters. This system generates solar power without compromising valuable land areas[6].

FPVs work similarly to conventional solar panel system. FPV system is also consisted of solar arrays, the only difference is that the panels in this system are mounted on buoyant and water-resistant platforms that are typically made from high-density polyethylene or other plastics. This system are often installed on man-made bodies of water or in inland waters to avoid corrosion caused by saltwater. The electricity produced by the solar panels are in direct current and an inverter is used to convert that direct current into alternating current, making it available for use in homes, businesses, and the power grid[7].

FPV plants present several benefits in comparison with ground-mounted photovoltaics (PV) because FPVs do not occupy habitable and agricultural areas and can save water bodies through mitigating evaporation[8]. Floating type solar photovoltaic panels have also numerous advantages compared to land – based solar farms. FPV panels can take more sunlight due to fewer obstacles and also helps in increasing energy efficiency that results in higher power generation efficiency.

In an article published by Solaric, while solar panels work through photovoltaic cells that convert sunlight into electricity, this also makes the solar panels to experience extreme heat that results to their efficiency being reduced. Besides on lowering the efficiency, prolonged exposure to high heat can also speed up material wear which result in shortening the system's lifespan[9]. Moreover, raising module temperature above 25°C reduces efficiency by 0.4% - 0.5% per degree Celsius[10].

As aforementioned, FPVs helps in increasing energy efficiency and power generation efficiency because installing it on water bodies also helps in maintaining lower temperature underneath the panels which prevents overheating of the panels[11].

SolOcean, a brand of advanced floating photovoltaic systems, also implies various advantages in utilizing FPV systems: FPV systems helps in making efficient use of space because they do not require land which makes them ideal for areas with limited available land or expensive land. The system that is installed on the water bodies, such as lakes, reservoirs, rivers, and ponds can also provide a new perspective of utilizing them. The water bodies also help in cooling the solar panels, which not only increase the efficiency and energy output but also helps in reducing the thermal degradation of solar panels by lowering their temperatures.

The environment will also benefit in these FPV systems since covering water bodies with them will help in reducing the water evaporation. This is very beneficial especially to drought-prone areas and agricultural areas that prioritize water conservation. Limiting the sunlight penetration into the water will also reduce the growth of algae, improving the water quality.

Shading and obstruction, such as dust and dirt, affects the efficiency of energy generation. Water bodies have typically less dust compared to land and generally free from obstructions that cause shading. There will also be no need to spend money in purchasing expensive lands which will help the private companies or government sectors that will implement them economically.

The FPV systems are scalable and flexible which also allows easy installation and reducing expenses for maintenance. Climate change is also one of the challenges of using photovoltaic systems. This affects the agricultural area due to drought and suitable places for housing of the citizens. In the case of FPV systems, climate change also affects water level. Despite this, FPV systems reduces conflicts over land use against agricultural sectors and housing, and it can adapt to changing water level which makes them resilient to seasonal variations, especially in the Philippines that covers a huge area of inland waters[12].

UTILIZATION OF FPVS IN THE GLOBAL SCALE

Floating photovoltaic system is practiced around the world and is considered as a rapidly growing sector in renewable energy. This concept was officially coined when two Japanese companies Mitsui Engineering & Shipbuilding Co. Ltd. and Mitsui Zosen KK, filed a patent on FPV. This results in Japan being the pioneer country in this technology[13].

Japan's biggest floating solar plant is built on the surface of Yamakura Dam reservoir in Ichihara, Chiba Prefecture. The plant began its construction in December 2015, which was led by Kyocera Corporation, and covers an approximately 180,000 m^2 of surface area and utilizes 50,904 of 270-watt Kyocera solar modules that were installed to generate an energy of 16,170 megawatt hours (MWh) per year and a maximum output of 13.7 megawatts (MW). The floating solar plants began its operation on March 5, 2018 and it was announced that its operation is led by Kyocera TLC Solar LLC and the energy generated is sold to TEPCO Energy Partner, Incorporated[14].

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The top spot in the world's largest existing floating solar farms is located in China, which is the Anhui Fuyang Southern Wind-solar-storage, with an installed gross capacity of 650 MW. This solar farm was built on a flooded region, which was previously used for coal mining and China repurposed this 867-hectare degraded land into something more useful. It has 1.2 million PV modules that generates energy of approximately 700 million kWh annually. It helps the environment by offsetting 220,000 tonnes of coal annually and carbon dioxide by 580,000 tonnes[15].

Southeast Asia is one of the world's most dynamic regions which is projected to contribute over 25% of global energy demand growth between 2024-2035. The growth of energy demand comes from urbanization, industrialization, and electrification across industries, transportation sectors, and commercial buildings, which also creates significant possibilities and opportunities for new and innovative approach in power generation to sustain the region being a global economic powerhouse.

The Southeast Asia region is abundant with renewable energies: from wind, hydro, to solar energies. However, despite of the region having promising opportunities with renewable energies, geographic constraints became one of the greatest limitations. Nevertheless, this became the main reason why FPVs became a reliable source of renewable energies in this region.

Multiple countries in Southeast Asia implement and develop FPV systems, which gained momentum over the last 5 years, ranging from floating solar plant capacities of 45 MWp (Megawatt-peak) to 192 MWp from 2021 to 2024. The development of this technology in Southeast Asia are led by Indonesia, Singapore, Malaysia, Vietnam, Thailand, and Philippines[16].

UTILIZATION OF FPVS IN THE PHILIPPINES

The SN Aboitiz Power Group or SNAP Group develops and operates best-in-class renewable energy facilities in the Philippines. With 673 megawatts (MW) of total capacity, SNAP provides innovative, clean, and renewable energy for its customers and seeks to expand its portfolio by exploring, building, and investing in renewable energy facilities and complementary technologies[17].

As the SNAP Group has already proposed a water-based solar power in Magat Dam in Isabela, the National Irrigation Administration (NIA) ventures to floating solar power project on its dams and reservoirs. This proposed project features solar panels fixed to floats on the water surface. NIA offers its dams and reservoirs for the water-based project which can achieve the same purpose of increasing power production while saving agricultural lands. NIA Administrator Ricardo R. Visaya said that one hectare of solar field can produce one megawatt. With the Magat Dam having a reservoir of 4,500 hectares, a 200 hectare of water-based solar power will be possible, resulting to 200 MW power generation and 200 hectares of agricultural lands will be saved[18]. A 200-kW pilot project's switch-on activity was held on June 27, 2019. This project having an investment cost of Php 24 million Pesos, is the first non-hydro power project of SN Aboitiz Power and also the first floating solar project for NIA[19].

Another implementation of FPVs in the Philippines is the 4.99 MW project at Malubog Reservoir in Cebu. This makes the Philippines officially connect its first megawatt-scale floating solar power plant to the national grid. This power plant will directly supply clean electricity to the Carmen Copper mining site which covers about 10% of the mine's energy needs. This project is developed with Black & Veatch and Sungrow FPV technology to help the plant be engineered for extreme weather resilience which can withstand an ultimate wind speed of 75 m/s[20]. The solar power plant covers 3 hectares for its facility and has 8,540 floating solar panels. The design also allows the project to be scalable up to 50 MW, which would be enough supply not just 10%, but 100% of the mining operation using only renewable energy. The construction was completed in 15 months, with over 250,000 man-hours logged and no lost-time injuries, and was launched at around early August of 2025[21].

Moreover, ACEN, the Ayala group's energy platform, has a large-scale floating solar project in Laguna de Bay that may start delivering power into the Luzon grid by 2027. This is according to documents filed at the Department of Environment and Natural Resources' Environmental Management Bureau (DENR-EMB). ACEN has five floating solar projects spanning across Laguna de Bay with a total investment of P47.89 billion and an aggregate maximum potential output of 1,120 megawatts (MW). The construction of four blocks with a total maximum capacity of 560 MW will be led by AC Subic Solar and AC Laguna Solar, which are located on waters of Victoria, Santa Cruz, and Pila in Laguna. Additionally, a project with a maximum capacity of 140 MW is led by SolarACE4 which is located in Santa Cruz[22].

The Laguna de Bay is set in the eyes of various energy platforms and companies due to its huge area. However, fisherfolk and environmental advocates urged the Environment Secretary Raphael Lotilla to reject the floating solar power project in Laguna due to the reason that it has "adverse impact on the livelihood of more than 8,000 small fisherfolk and coastal residents." With respect to this, the environmental network Save Laguna Lake Movement (SLLM) called on Lotilla that the potential impacts of the projects on the socio-economic and environmental rights of

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affected coastal communities must be thoroughly evaluated. SLLM also noted that the said project will cover around 2,000 hectares of the country's largest inland brackish lake in its southern and eastern areas, which led to a widespread opposition from affected fishermen and residents to the imminent floating solar project. Moreover, the fisher's group Pambansang Lakas ng Kilusang Mamamalakaya ng Pilipinas (Pamalakaya) continues to be vigilant on Lotilla's programs for environmental protection and climate change mitigation[23].

These oppositions are also proofs that not every inland waters should implement FPV Integration. While FPVs help to avoid compromising the agricultural land, the usage and usefulness of the inland waters to nearby residents and municipality should also be considered.

As the country covers 406,328 hectares or 4,063.28 km2, among its inland water bodies, Angat river, a river system in Bulacan, shares a significant amount of area which is 1,085 km2. This makes a significant percentage of approximately 26%, making Angat river as an ideal place for the FPV implementation in Bulacan.

COVERAGE OF ANGAT RIVER

Plaridel is one of the municipalities of Bulacan and is one of the various municipalities that Angat River flows through, before eventually joining the Pampanga River. The width of the river was measured at five (5) different spots, namely; Matictic Bridge in Norzagaray, Sta. Lucia Bridge in Angat, Alejo Santos Bridge between Bustos and Baliuag, Pulilan – Plaridel Bridge between Pulilan and Plaridel, and Bagbag Bridge in Calumpit. The width of the river measured in Plaridel is 142 m (meters) and it is much lower than the width of the river that is measured to be 248 m in Alejo Santos Bridge[24]. However, Plaridel's section of the Angat River is still favorable for FPVs compared to Bustos' section of the river. Bustos' section is also connected to the Bustos Dam, one of the dams in the dam system of Angat River, making it not ideal for FPVs due to strong currents. On the other hand, Plaridel's section is located in a much downstream part of the river, allowing it to experience lower and more stable velocity flow of the river. This characteristic also makes the section to be an ideal place to anchor the FPVs.

This research focuses on the area of Angat River covered by Plaridel, Bulacan and a proposal for the implementation of FPVs anchored in its section of the river. The research aims to evaluate the technical, environmental, and spatial feasibility of deploying floating solar panels as an alternative and sustainable renewable power source for the locality of Plaridel.

USEFULNESS OF ANGAT RIVER TO PLARIDEL, BULACAN

Plaridel section of the Angat River is highly utilized because of its accessibility by having its several barangays directly fronting the river (Banga I, Banga II, Lumang Bayan, Poblacion, Parulan)[25]. The accessibility supports local agriculture by being the primary source for irrigation. Some of the residents that are living within the said barangays are even fishing in the river as it is very accessible to them.

Despite of the accessibility of the Angat River to the Plaridel, it is not being utilized for potable water distribution. Plaridel Water District, or commonly known as PLAWD, the water service provider for Plaridel Bulacan, distributes the potable water to the residents from two sources only: Deep well or underground water, and Bulacan Bulk Water Production, abbreviated as BBWP[26].

Source	Percentage
Deep Well	71.29%
BBWP	28.71%
TOTAL	**100%**

Table 2. PLAWD's Water Sources Percentages

Communities along Angat River, including Plaridel, have relied on the river for fishing, making it one of the important uses of the river. However, as time passes by, fishing became one of the livelihoods that is being threatened by climate change. In the past, fishing was a reliable source of income and could be the sole occupation for fishermen, but since certain species of fish are dwindling due to the effects of climate change, fishermen tend to look for alternative source of income. A fisherman who worked along the Angat River also stated that since fishing was not enough, they had no choice but to look for another job which is being a tricycle driver[28].

This proves that the implementation of FPVs along some parts of Plaridel's section of Angat River will not affect any important usage of the river since distributing potable water and fishing does not rely on it.

DENR GUIDELINES FOR FPV PROJECTS

The Department of Environment and Natural Resources, or also known as DENR, has established comprehensive guidelines for floating photovoltaic projects. This is through Administrative Order no. 2023-08, with respect to the FPV implementation in the Laguna de Bay[29]. These guidelines mainly addressed the pre-assessments before implementing FPV in an area which requires the collaboration with the DENR, Department of Energy or DOE, and other agencies. All this pre-assessment is due to considering the vulnerability of the Philippines to typhoons

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and flooding and as well as the impact of the project to existing uses of the water bodies such as fishing, irrigation, and drinking water supply.

OPERATIONS AND MAINTENANCE

International Energy Agency (IEA) is a Paris-based autonomous intergovernmental organization that provides policy recommendations, analysis and data on the global energy sector, in which its 32 member countries and 13 association countries represent 75% of global energy demand.

In a recent presentation made by IEA in their Technology Collaboration Programme, the mission in opereation and maintenance of floating photovoltaic systems consist of efficient mitigation of potential risks and maximized long-term PV energy yield.

The focus of risks mitigation for FPV systems are mainly the floaters, anchors, mooring systems, and electrical components, in which their regular inspection is crucial to ensure personnel safety and reduce possible downtime due to unexpected technical difficulties, therefore maximizing the long-term PV energy yield. It was also mentioned that providing training for the personnel and utilizing calibrated measuring and testing devices are also important to ensure continuous operation and safety[30].

FPV INTEGRATION IN ANGAT DAM

The Philippines produces over half of its energy supply coming from coal, oil, and natural gas, a proof of its continuous reliance on fossil fuels for electricity generation. This dependence makes the country vulnerable to global fuel price fluctuations, and worse, contributes to high energy costs and greenhouse gas emissions.

Solar energy is one of the renewable power sources to utilize in electricity generation. While the country, particularly in Central Luzon region, possesses abundant solar resources, the expansion of land-based solar farms is limited. Land values in this region are high and space is scarce due to competitions between agriculture, housing, and industrial development.

To address these challenges, Floating Solar Photovoltaic (FPV) technology is a favorable alternative approach which utilizes the surface of water bodies for renewable power generation. Despite being implemented in other areas such as Magat Dam in Isabela and Malubog Reservoir in Cebu, and proposed to Laguna de Bay, there is no similar project implemented in the Angat River System, especially in Plaridel's section. Utilizing Plaridel's section presents a strategic opportunity for FPV installation due to the area being accessible, and it experiences less turbulence when the dam releases water.

FEASIBILITY OF FPV IN PLARIDEL, BULACAN

Angat river is part of the dam system that is consisted of Angat Dam from the upstream part and Bustos Dam from the downstream part. The study explores an innovative alternative and approach to renewable energy generation within the locality of Plaridel, Bulacan. Implementation of Floating Solar Photovoltaic (FPV) system on the Plaridel's section of the Angat River provides an alternative energy solution that supports both local and national sustainability goals.

The study offers valuable insights for the Municipal Government of Plaridel and also to the nearby communities in optimizing the use of water surfaces for energy production without compromising the availability of flat land for agriculture, housing, and industrial development. The findings of this study can be a guide to local policymakers, planners, and engineers in assessing the technical and environmental feasibility of FPV system within the municipality.

METHODOLOGY

This study utilizes a design-based and conceptual engineering approach to develop a technically-grounded framework for the implementation of the proposed Floating Photovoltaic (FPV) system alongside the Plaridel's section of Angat River, Bulacan. It will focus on the system structuring, mathematical modelling, constraint definition, and energy contribution analysis. This will help in assessing the feasibility of FPV system deployment in a flowing river environment and parameter. This study will not involve the actual physical installation, numerical simulation, or on-site data collection. The framework will be evaluated through engineering logic validation, scenario-based assessment, and comparison with the existing FPV principles and implementation documented in the literature. This approach classifies the study to be a feasibility-oriented conceptual framework with the intention to guide the future FPV implementation in the river system, especially the Plaridel's section. This methodology will ensure that the FPV implementation will:

1. Remain hydraulically and structurally safe.
2. Do not compromise the usability of the river.
3. Utilize solar energy at its maximum potential.
4. Provides a measurable contribution to Plaridel's electricity demand.

Physical Layer of the River

This layer defines the actual physical conditions of the Plaridel's section in Angat River. This will serve as the boundary conditions for FPV development. These parameters

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will help in establishing non-negotiable physical boundaries of the FPV and justifying the need for design constraints, distinguishing the system from other existing FPV projects in the Philippines.

Parameter	Purpose
River width	Determines allowable FPV surface coverage
Flow velocity	Governs hydrodynamic drag and anchoring
Water level variation	Determines mooring adaptability
Downstream location	Indicates reduced turbulence

Table 3. River Physical Parameters

ENVIRONMENTAL AND SOLAR PARAMETER LAYER

This layer involves environmental factors that affect the efficiency or the performance of the FPV system. This includes the solar irradiance considering the obstructions, the ambient temperature, and the water temperature. This will help in comparing the efficiency and advantage of PV modules that has cooling interaction with water over the land-based solar installations. This will also help in representing how reduced module temperature improves energy yield of temperature-corrected photovoltaic modules.

FPV DESIGN AND CONSTRAINT LAYER

This layer represents the engineering decision core of the framework which defines the constraints and mathematical relationships.

Constraint Consideration	Purpose
River Surface Coverage Constraint	To ensure that the system will not cause obstruction of river flow.
Flow-Induced Structural Constraint	To ensure structural stability considering the hydrodynamic forces acting on the FPV structures and increased flow conditions for anchoring.
Navigation and Livelihood Preservation Constraint	To ensure that the river remains accessible.

Table 4. Design Constraints

Utilizing these constraints will help in making the best design for the FPV systems.

1. River Surface Coverage Constraint

$$C_r = \frac{A_{FPV}}{A_{river}}$$

Where:

C_r= Constraint ratio for the surface (dimensionless)

A_{FPV}= Covered area of the FPV system (m^2)

A_{river}= the total river surface area with respect to the deployment length (m^2)

This framework limits the constraint ratio to be C_r≤0.30 for design consideration.

2. Flow-Induced Structural Constraint

$$F_d = \frac{1}{2}\rho C_d A v^2$$

Where:
F_d = the hydrodynamic drag force acting on the FPV structure (N)
ρ = the density of water (kg/m^3)
C_d = drag coefficient of the floating structure (dimensionless)
A = Area of the FPV perpendicular to the river flow
v = average velocity of the river (m/s^2)

This formula will help in calculating the required anchoring force to ensure its stability under varying flow conditions.

$$F_{anchor} \geq SF\ x\ F_d$$

Where:

F_{anchor} = the required anchoring force (N)

SF = the safety factor applied (dimensionless)

3. Navigation and Livelihood Preservation Constraint

$$\frac{W_{usable}}{W} \geq 0.50$$

Where:
W_{usable} = the remaining river width after FPV installation (m)
W = total width of the river (m)

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This framework limits of the ratio of the available river width to the total width of the river to be at least 0.50 or 50%.

ENERGY CONTRIBUTION

The FPV system in the Angat River must prove its relevance in response to the fact that it will take a share of the river and its other uses. The main relevance of the FPV system is its energy contribution, especially to the municipality of Plaridel since it will take its development in the Plaridel's section of the river.

To establish the practical relevance of the FPV system, these formulas will help giving it values.

1. Plaridel's annual electricity demand:

$$E_{demand} = E_{avg}\ x\ n_p$$

Where:

E_{demand} = Plaridel's annual energy consumption (kWh/year)

E_{avg} = average energy demand (kWh/year /person)

n_p = number of populations

2. Annual energy production of FPV system:

$$E_{FPV} = P_{FPV}\ x\ CF\ x\ 8760\,\frac{hours}{year}$$

Where:

E_{FPV} = energy produced by the FPV system in a year (kWh/year)

P_{FPV} = installed FPV capacity (kW)

CF = capacity factor of the FPV system

3. Energy Contribution Ratio:

$$R_{energy} = \frac{E_{FPV}}{E_{demand}}\ x\ 100\%$$

Where:

R_{energy} = percentage of FPV system's energy contribution

E_{FPV} = energy produced by the FPV system in a year (kWh/year)

E_{demand} = Plaridel's annual energy consumption (kWh/year)

Contribution Ratio	Interpretation
$< 20\%$	Supplemental renewable source
$20 - 50\%$	Significant demand offset
$> 50\%$	Major municipal energy contributor

Table 5. FPV Energy Contribution Interpretation

VALIDATION APPROACH

The proposed framework is validated conceptually with the help of assessing the defined constraints and equations whether they respond logically under varying river and demand conditions. Scenario-based evaluation is used to verify that FPV deployment remains structurally stable, socially compatible, and capable of contributing meaningfully to municipal energy demand without violating river constraints.

RESULTS AND DISCUSSION

The proposed Floating Photovoltaic feasibility framework is applied to the proposed location of the pilot FPV systems, which is near the location of Pulilan-Plaridel Bridge. This location is identified in this study as the potential site for the first FPV system deployment in the municipality because of its close distance with the bridge, its accessibility, and exposure to the sun from sunrise to sunset. In order to allow mathematical framework to generate quantitative yet feasibility-level results, the analysis of this study incorporates literature-reported site geometry, instead of purely conceptual studies. The results will help in evaluation of spatial feasibility, structural implications, and the extent to which how the FPV deployment can contribute to Plaridel's electricity consumption.

SITE LOCATION

Using the map tool of Google Earth, the approximate length of the proposed site is approximately 300 meters and has a width that is perpendicular to the river flow of 40 meters. It was also indicated that the area of the proposed site is 11,985.73 m2 and is also located at 14°53'31"N, 120°52'13" E.

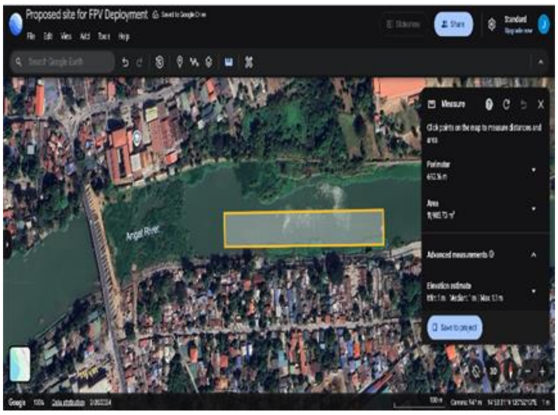

Figure 1. Proposed Site for FPV Deployment

RIVER SURFACE AREA AND FPV COVERAGE

The river width at the proposed installation site was obtained from the Angat River assessment conducted by the Philippine Atmospheric, Geological and Astronomical Services Administration (PAGASA) and was also cited in this

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study. Based on their assessment, the width of the river across the Pulilan-Plaridel Bridge is approximately 142 m, which was utilized as the width of the Angat River Plaridel Section. This width was treated as a fixed geometric or constant parameter for FPV feasibility assessment.

Using the river surface area relation,

$$A_{river} = W_{bridge}\ x\ L$$

where $\boldsymbol{W_{bridge}}$ is the literature-reported width of the Pulilan-Plaridel Bridge and $\boldsymbol{L}$ is the selected deployment length along the river.

$$A_{river} = 142m\ x\ 300m$$

$$\boldsymbol{A_{river} = 42,600\ m^2}$$

This equation leads to the river having a surface area of approximately 42,600 m2. This data is used to calculate the constraint ratio for the surface,

$$C_r = \frac{A_{FPV}}{A_{river}}$$

and given the constraint of C_r ≤0.30, the maximum allowable FPV surface area was determined as:

$$A_{FPV,\max} = 0.30\ x\ A_{river}$$

and with the A_{river} being 42,600 m^2,

$$A_{FPV,max} = 0.30\ x\ 42{,}600\ m^2$$

$$\boldsymbol{A_{FPV,\max} = 12,780\ m^2}$$

This result established a clear upper limit on the FPV deployment that preserves the hydraulic continuity of the river and minimizing the interference with existing and future river-based activities such as tourism, fishing, and transportation. This calculated area also represented the area feasibility of the proposed site since maximum allowable area of the site off 12,780 m2 can cover the proposed site of 11,985.71 m2. Compared to other FPV systems that often exceeds 50% surface coverage and compromises water-based activities, the proposed Plaridel FPV system prioritizes river functionality over capacity maximization.

STRUCTURAL IMPLICATIONS OF FLOW-INDUCED LOADING

FPV structures deployed in a flowing river are subjected to hydrodynamic forces. The anchors of the FPV system must withstand these hydrodynamic forces to ensure that the FPV modules will not be dragged by the current. These modules can also cause accidents, especially to people living in downstream area, if anchors are not properly designed. As shown in the methodology section, the equation for the hydrodynamic force is:

$$F_d = \frac{1}{2}\rho C_d A v^2$$

In order to maximize the safety in design, it is suggested to use the highest velocity that the river flows in rainy season. However, there are no data that indicates the velocity during rainy season, but data for flow rates of the river are available especially in news. Utilizing the discharge flow of Bustos Dam, which is part of the Angat River System and much closer to Plaridel compared to other dams, is the most conceptually compatible to use in Plaridel.

Bustos Dam released more than 700 CMS (cubic meter per second) of water during the rains brought by Typhoon Egay back in 2023[31]. This discharge by Bustos Dam is unusual and is considered as one of the peak discharges by the said dam. This will be used as the reference for the maximum river flow rate by the river in Plaridel Section since it is close to Bustos Dam as previously mentioned.

In a study published in Bulacan State University, the depth of the Angat River that flows to the Manila Bay has an approximate depth of 5 meters[32]. It was also mentioned in the Site Location section of this study that the width of the FPV system that is perpendicular to the river flow is 40 meters.

Calculating the approximate velocity of the river required these data as shown in the equations:

1. $Q = A_c\ x\ v$
2. $A_c = W\ x\ D$

Where:

Q = river flow rate

A_c = river cross-sectional area

W = width perpendicular to river flow

D = depth of the river

v = velocity of the river flow

Substituting the data gathered in the equation will lead to the river flow velocity of:

$$v = \frac{Q}{A_c} = \frac{Q}{W\ x\ D}$$

$$v = \frac{700\,\frac{m^3}{s}}{(40\ m)\ x\ (5\ m)}$$

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$$\boldsymbol{v = 3.5\frac{m}{s}}$$

FPV modules lay on the water surface, therefore making them parallel to the flow of the river. However, to make the design safest as possible, and circumstances that turns the modules perpendicular to the flow may occur, the drag coefficient of flat plates perpendicular to the flow will be utilized. Drag coefficient of these flat plates are typically 1.2 – 1.3 but multiple sources use 1.28 as value of the coefficient, such as NASA[33], CFD Land[34], and etc. Even though most of the sources are based in aerodynamics, the drag coefficient is independent of the nature of the fluid whether it is gas or liquid. What depends on the nature of the fluid is the drag force that may use the density of either a gas or a liquid.

Most solar panels that are used for commercial or utility purposes is about 1m by 2m. To have a better distribution of modules, the project site will be divided into multiple rafts with an area of 50 m2 each. The working equation is:

$$N_{raft} = \frac{A_{FPV}}{A_{raft}}$$

Where:

N_{raft} = number of rafts

A_{FPV} = maximum area of FPV system (12,000 m^2 as mentioned)

A_{raft} = 50 m^2/raft

Therefore, the number of rafts will be:

$$N_{raft} = \frac{12{,}000\ m^2}{50\frac{m^2}{raft}}$$

$$\boldsymbol{N_{raft} = 240\ rafts}$$

The number of modules per raft was also considered using the equation:

$$n_{m,r} = \frac{A_{raft}}{A_{module}}$$

With area of raft being 50 m2 and dimensions of a module of 2m by 1m results to area of 2 m2, the number of modules per raft n_(m,r) will be:

$$n_{m,r} = \frac{50\ m^2}{2\frac{m^2}{raft}}$$

$$\boldsymbol{n_{m,r} = 25\ modules\ per\ raft}$$

Finally, the hydrodynamic drag force is calculated as shown:

$$F_d = \frac{1}{2}\rho C_d A v^2$$

$$F_d = \frac{1}{2}\left(1000\frac{kg}{m^3}\right)(1.28)(50\ m^2)\left(3.5\frac{m}{s}\right)^2$$

$$\boldsymbol{F_d = 392{,}000\ N\ or\ 392\ kN}$$

Utilizing a standard safety factor of 1.5 – 2.0, the design force for each anchor will be:

$$F_{anchor} = SF\ x\ F_d$$

$$F_{anchor}@1.5\ SF = 1.5\ x\ 392\ kN$$

$$\boldsymbol{F_{anchor}@1.5\ SF = 588\ kN}$$

Or,

$$F_{anchor}@2.0\ SF = 2.0\ x\ 392\ kN$$

$$\boldsymbol{F_{anchor}@2.0\ SF = 784\ kN}$$

This design might be large but it considers the peak discharge of Bustos Dam and safety factor to ensure the safety of the modules, operators, and the people who lives near and downstream area.

Navigation and Livelihood Preservation

The results in this constraint shows the feasibility of the FPV systems in terms of social compatibility. A ratio of usable width to the covered width of the system that is more than 50% clearly shows that the FPV systems do not compromise the usability of the river.

Let the ratio of the widths as x, the working equation is:

$$x = \frac{W_{usable}}{W}$$

With usable width be the difference between the width of the river and the covered width of the system,

$$x = \frac{W - W_{FPV}}{W}$$

$$x = \frac{142\ m - 40\ m}{142\ m}$$

$$\boldsymbol{x \approx 0.72}$$

This shows that the 72% of the river's width is still usable for river-based activities and clearly shows that the ratio is greater than 0.5 or 50%.

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ENERGY PRODUCTION AND DEMAND SHARING

The pilot project for FPV deployment is small scale compared to the area of the river covered by the Plaridel and the whole Angat River system. Capacity factor of the floating solar plant is crucial in calculating its energy production. The capacity factor is not fixed and varies in the performance of each solar plant. However, to provide values in this study, conceptualized capacity factor will be utilized as the proposed FPV system is not yet existent.

A study conducted in Ghana shows capacity factor of monofacial floating photovoltaic system to be 17.44% or 0.1744 in average[35]. A standard 2m by 1m solar panel is also rated to have peak wattage of 400-500 Wp, but to be conservative, 400 Wp is utilized[36]. The working equation is: A study conducted in Ghana shows capacity factor of monofacial floating photovoltaic system to be 17.44% or 0.1744 in average[35]. A standard 2m by 1m solar panel is also rated to have peak wattage of 400-500 Wp, but to be conservative, 400 Wp is utilized[36]. The working equation is:

$$E_{FPV,m} = P_{FPV,m}\ x\ CF\ x\ 8760\frac{hours}{year}$$

$$E_{FPV,m} = 400\frac{Wp}{module}\ x\ 0.1744\ x\ 8760\frac{hours}{year}$$

$$\boldsymbol{E_{FPV,m} = \frac{611,097.6\frac{Wh}{year}}{module}}$$

This calculated energy is the approximate energy produced by a module in a year. To get the total number of rafts for the proposed system, the working equation is:

$$n_m = n_{m,r}\ x\ N_{raft}$$

Where:

n_m = total number of modules

$n_{m,r}$ = number of modules per raft

N_{raft} = number of rafts

Therefore,

$$n_m = 25\frac{modules}{raft}\ x\ 240\ rafts$$

$$\boldsymbol{n_m = 6,000\ modules}$$

Hence, the total energy produced by the FPV system is:

$$E_{FPV} = E_{FPV,m}\ x\ n_m$$

$$E_{FPV} = \frac{611,097.6\frac{Wh}{year}}{module}\ x\ 6,000\ modules$$

$$E_{FPV} = 3,666,585,600\frac{Wh}{year}$$

Or,

$$\boldsymbol{E_{FPV} \approx 3.67\frac{GWh}{year}}$$

This energy will be contributed to the municipality. However, to evaluate and interpret its contribution to the demand, the energy consumption of the municipality must be given first.

The most recent data shows that Plaridel has 114,432 population[37]. As of 2025, the average electricity consumption per person in the Philippines is 1,051 kWh per year[38]. Therefore, the energy demand of Plaridel in a year is:

$$E_{demand} = E_{avg}\ x\ n_p$$

$$E_{demand} = \frac{1,051\frac{kWh}{year}}{person}\ x\ 114,432\ people$$

$$E_{demand} = 120,268,032\frac{kWh}{year}$$

$$\boldsymbol{E_{demand} \approx 120.27\frac{GWh}{year}}$$

These data are used to show the energy demand sharing of the FPV system to the energy demand required by the municipality. The contribution ratio is:

$$R_{energy} = \frac{E_{FPV}}{E_{demand}}\ x\ 100\%$$

$$R_{energy} = \frac{3.67\frac{GWh}{year}}{120.27\frac{GWh}{year}}\ x\ 100\%$$

$$\boldsymbol{R_{energy} \approx 3.05\%}$$

Based on *Table 5. FPV Energy Contribution Interpretation*, it is shown that the pilot FPV system is a supplemental renewable source for the municipality. This result indicated that while the proposed pilot FPV system cannot fully supply the municipal demand, it can provide a meaningful contribution to local energy generation using an otherwise underutilized water surface. The proposed system is also just a pilot small-scale project compared to the length of Angat River covered by Plaridel.

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Based on the map tool of Google Earth, the length of the Angat River that is covered by Plaridel is approximately 14 kilometers or 14,000 meters. Therefore, the energy produced by the pilot FPV system is approximately 2.1% of the full potential of the FPV systems if the entire length of the Plaridel's section will be utilized with the same width and area of modules.

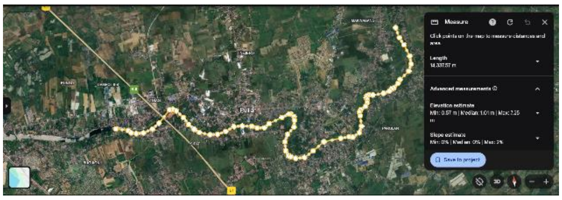

Figure 2. Angat River covered by Plaridel

CONCLUSION

This study conceptually provides an insight on how renewable energy sources greatly help the world. Despite being needed, renewable energy sources seem to be difficult to implement due to various circumstances that each country experiences. Therefore, it is important to look for more innovative application of renewable sources that is compatible to a country or a place with their respective challenges that they experience.

These FPV systems, if implemented, will utilize the unused potential of the greatest resource in Plaridel, Bulacan, which is the Angat River. The result shows with a proposed pilot FPV system that this technology can help in reducing the reliance of Plaridel in fossil fuels to produce power without compromising the existing and future usage of the river system. It also helps in maintaining the health of the river for its inhabited species of fish and aquatic animals by mitigating the problem of water evaporation due to climate change.

The design of FPV system also ensures safety and reliability in events of rainy season or typhoons. Even though the energy contribution of the proposed pilot FPV system is only 3.05%, it is just 2.1% of the full potential of the river as a location for FPV system. This shows that it still has a huge room for improvement if the implementation will happen and expanded. This greatly implies that this system can significantly help the municipality to be free and independent from fossil fuels and might also benefit the neighboring municipalities.

The outcomes of this study also demonstrate that the framework can be used by the researchers, engineers, and policy makers in implementing this innovative system by the local municipality for a greener and cleaner power.

REFERENCES

[1] Jacob, C. (2024, July 3). *Philippines overtakes China and Indonesia to be most dependent on coal-generated power - CNBC.*
[2] Ember. (2025, April 10). *The Philippines | Ember*.
[3] Li, X., Wang, H., Lu, Y., & Li, W. (2021). *A Critical Survey on renewable energy applications in the Philippines and China: Present challenges and Perspectives. Frontiers in Energy Research, 9.*
[4] R.T. Casas. (2014). *Focus on the sea more than land.*
[5] R.D. Guerrero III. (2022). *Commercially Caught Freshwater Fishes in the Philippines: Status, Issues, and Recommendations.*
[6] J. Oelker. (n.d.). *Floating Photovoltaics – Sustainable Energy Generation on the Water.*
[7] B. Becher. (2024). *What Are Floating Solar Panels?*
[8] Pouran, H. M., Padilha Campos Lopes, M., Nogueira, T., Alves Castelo Branco, D., & Sheng, Y. (2022). *Environmental and Technical Impacts of Floating Photovoltaic Plants as an Emerging Clean Energy Technology. IScience, 25(11), 105253.*
[9] Solaric. (n.d.). *How Does High Heat Affect Your Solar Panel Efficieny?*
[10] O. Bamisile, et. al. (2025). *The environmental factors affecting solar photovoltaic output.*
[11] A. Sahu, et. al. (2016). *Floating photovoltaic power plant: A review.*
[12] SolOcean. (n.d.). *What are the advantages of floating PV systems?*
[13] C.J. Ramanan, et. al., (2024). *Towards sustainable power generation: Recent advancements in floating photovoltaic technologies.*
[14] KYOCERA Europe. (2018). KYOCERA TCL *Solar begins operation of Japan's largest 13.7MW Floating Solar Power Plant.*
[15] Z. Ahmed. (2025). *World's Largest Floating Solar Farm.*
[16] N. Price, et. al., (2025). *FLOATING SOLAR FARMS Powering Southeast Asia's renewable future – Aurecon.*
[17] M.L. Hamududu. (2024). *SN Aboitiz Power Group International Centre for Hydropower.*
[18] National Irrigation Administration Central Office. (2018). *NIA OPENS ITS DAMS AND RESERVOIRS FOR FLOATING SOLAR POWER PROJECT.*
[19] National Irrigation Administration – Magat River Integrated Irrigation System (NIA-MARIIS). (2019). *FLOATING SOLAR AT MAGAT DAM FINALLY SWITCHED ON.*
[20] ESG News. (2025). *Philippines Connects First 4.99 MW Floating Solar Plant to Grid.*
[21] Power Philippines. (2025). *Carmen Copper Launches PH's First Megawatt-Scale Floating Solar Plant.*
[22] L.K. Esmael – Inquirer. (2024). *ACEN cues 5 Laguna lake solar projects for 2027.*
[23] M.J. Salcedo – Inquirer. (2025). *New DENR chief urged to reject Laguna floating solar project.*
[24] Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). (2024). *Angat River Assessment Values as of April 2024.*
[25] DPWH-Bulacan 1st District Engineering Office. (2024, June 30). *Procurement Monitoring Report.*
[26] Plaridel Water District. (2023). *2023 Annual Report.*
[27] Plaridel Water District. (2024). *CY 2024 Projects and Programs Accomplishment Report.*
[28] E. Chia, et. al., (2013). *Plaridel: Imagining a Sustainable and Resilient Future.* Future.
[29] Thedan. (2025, July 25). *DENR Floating Solar Rules PH | Triple i Consulting.*
[30] I. Tsanakas. (2024). *Operations and Maintenance (O&M) of Floating PV.*
[31] R.E. Lazaro. (2023). *Angat, other dams' water levels continue to rise – The Philippine Star.*
[32] R. I. Legaspi. (2014). *LAND USE PATTERNS AND CLIMATE-RELATED RISKS ASSESSMENT IN ANGAT RIVER MUNICIPALITIES: THE CASE OF PULILAN AND PLARIDEL.*

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 03 , March - 2026

[33] National Aeronautics and Space Administration. (n.d.). *Shapes Effects on Drag.*
[34] S. Pakravan. (n.d.). *What Is Drag in Aerodynamics? – CFD Land.*
[35] R.O. Yakubu, et. al. (2023). *Comparison of ground-based and floating solar photovoltaic systems performance based on monofacial and bifacial modules in Ghana.*
[36] HBOWA. (2025). *Size of Solar Panels Explained: Residential and Commercial Standards.*
[37] A.S.B. Bautista, et. al., (2022). *"Maja" A Sustainable Leisure Complex in Plaridel, Bulacan*.
[38] LowCarbonPower. (2025). *Electricity in Philippines in 2024/2025.*