J. Electrical Systems 20-5s (2024): 758-777

[1]Jeffrey T. Dellosa

[1]Ronieto Mendoza

[2]Robert Kerwin C. Billones

[2]Yong Sheng

Simulation and Economic Modelling of a Floating Solar Photovoltaic (FSPV) System using PVSyst

***Abstract:* -** This paper examines the economic feasibility of implementing a Floating Solar Photovoltaic (FSPV) system in a Philippine Lake using the PVsyst simulation tool. The study involved a detailed simulation of the FSPV system's performance, considering various environmental and technical parameters. Key aspects such as system configuration, energy yield, and financial metrics including payback period and net present value were analyzed. Results indicate that the FSPV system could significantly contribute to local energy needs while proving to be a financially viable investment due to substantial reductions in CO2 emissions and lower energy costs compared to traditional power sources. According to assessments and simulations performed using PVSyst software, the FSPV system would possess a capacity of 10 kWp, with an expected available energy output of 13,599 kWh per year and an expected energy consumption of 12,940 kWh per year. The economic modeling of the FSPV system revealed a relatively short payback period of 4.8 years, with a net present value of Php 741,732.00 and a substantial return on investment of 227.5%. The Levelized Cost of Energy (LCOE) was estimated at Php 6.18 per kWh. The study underscores the potential of FSPV systems to meet the renewable energy needs of isolated communities by leveraging local water bodies for solar installations.

Keywords: floating solar photovoltaic system (FSPV), PVsyst, renewable energy sources, economic modelling, simulation of FSPV system, floating solar for community

I. INTRODUCTION

1.1 Background of Study

The release of Carbon dioxide (CO_2) from various sources has long been a matter of concern for environmental stakeholders worldwide. CO_2 is one of three Greenhouse Gases (GHGs) that have increased in the atmosphere since pre-industrial times, and it has been established as a primary cause of climate change [1-7]. Developing countries are particularly susceptible to the adverse effects of climate change [8-9]. The Paris Agreement, specifically, has provided a framework for countries to take determined action in reducing CO_2 and other GHG emissions by promoting the adoption of renewable energy systems, with the goal of mitigating the impact of climate change [10, 11-15].

As a result of the Paris Agreement, many countries have set ambitious goals to reduce their greenhouse gas emissions and transition towards a more sustainable and carbon-neutral economy. These efforts have led to a significant increase in renewable energy investments and the development of new technologies to reduce CO_2 emission targets and goals [16-20]. To achieve these goals, it is essential to accelerate the deployment of renewable energy systems, improve energy efficiency, and promote sustainable land use practices. Additionally, there is a need to promote international cooperation and collaboration to share knowledge, technologies, and best practices, particularly between developed and developing countries [21-25].

Renewable energy systems (RES) are widely recognized as clean energy sources, producing minimal waste, and contributing to sustainable development. They play a crucial role in addressing future economic and societal needs [26-32]. Among the RES, the floating solar photovoltaic (FSPV) system as shown in Figure 1 is a promising and currently the emerging solution for reducing CO_2 and other greenhouse gas emissions, thereby mitigating global warming, and slowing down the impacts of climate change [33]. FSPV systems are typically deployed in a large-

[1] Center for Renewable Energy, Automation, and Fabrication Technology, Caraga State University, Butuan City, Philippines

[2]Department of Manufacturing Engineering, De La Salle University, Manila, Philippines, Mechanical and Material Engineering, School of Engineering, University of Hull, United Kingdom

[1]jtdellosa@carsu.edu.ph, [1]rnmendoza@carsu.edu.ph, [2]robert.billones@dlsu.edu.ph [3]Y.Sheng@hull.ac.uk,

scale manner in megawatt (MW) scale that complements hydroelectric powerplants, or a standalone power plant as can be noted in various countries such as Japan, Korea, or in China [33]. Typically, large-scale deployments are connected to the grid and somehow cover the cost effectively, hence, resources needed to deploy is negated.

Figure 1. A floating solar PV system [33]

Due to the increasing popularity of FSPV systems as a viable alternative to land-based solar systems, it is imperative to enhance our understanding of their potential and limitations [34-36]. However, the current lack of knowledge and approaches for assessing the economic potential of FSPV system in a smaller-scale context can impede their development and deployment. There are uncertainties in terms of the feasibility of designing and developing an off-grid small-scale FSPV system, including its economic feasibility as applied in smaller sizes applications for specific communities. This study seeks to perform a simulation and economic modelling of an FSPV system to determine its viability of implementing this emerging technology in solar PV systems to a particular community in the Philippines that desperately need energy source. The country possesses vast water resources, including lakes spread across various regions of the archipelago, which motivates this study.

1.2 The Philippine lakes, floating solar photovoltaic systems (FSPV), and economic modelling

A. Brief Background of the Philippine Lakes

In the Philippines, there are over a hundred freshwater lakes, ranging in size from a few hundred to a thousand hectares, with a combined area of over 200 thousand hectares. The communities surrounding these lakes benefit greatly from their economic contributions, particularly in fishing activities [41]. The top five largest lakes in terms of area in the Philippines are the Lake Lanao, Taal, and Laguna de Bay, and they are considered the most well-known due to their various domestic and aquaculture uses [41]. It is possible to implement floating solar photovoltaic (FSPV) technology on these lakes, which could further enhance their potential.

B. The Floating Solar Photovoltaic (FSPV) Systems

The concept of using floating installations for solar photovoltaic (PV) systems is a newer idea that has gained popularity as an emerging technology in the field of renewable energy [18-22] to [42-46]. Floating solar photovoltaic (FSPV) is a specific type of solar PV application where PV panels are designed to float on water bodies [21] to [45]. FSPV systems are commonly installed in hydroelectric reservoirs [19,22] to [43],[46], irrigation dams [23, 24] to [47],[48], and even abandoned depleted mines [25-27] to [49],[50].

In FSPV systems, solar panels are mounted on pontoon-based floating structures that are anchored and moored to keep the panels in a fixed location [28] to [51]. The use of FSPV protects productive land and prevents the conversion of agricultural land into a solar PV farm [21,29] to [45],[52]. Unlike ground-mounted systems, floating solar has not yet been widely commercialized and is primarily deployed as a demonstrator project in various countries [30] to [53], including one in the Philippines [31] to [54].

The benefits of floating solar have gained attention in the past decade due to its advantages beyond providing clean energy. Several reports suggest that floating solar PV systems offer advantages over traditional land-based solar PV systems. These benefits, as cited in [19, 22, 32-35] to [43],[46],[55]-[58], include economic viability due to reduced real-estate costs, the cooling effect of water which improves energy yield, shading provided by the FSPV panels on the water that reduces the rate of evaporation and improves water quality by lowering algae growth, and lesser accumulation of dust on the panel arrays due to the relatively dust-free environment of water surfaces compared to land.

C. The economic modelling and simulations for FSPV

Economic modelling and simulations can be useful tools to evaluate the financial viability of FSPV systems. Floating solar PV systems are a type of renewable energy technology that involves installing solar panels on floating platforms, such as reservoirs, lakes, and ponds [68].

Economic modelling can help assess the costs and benefits of floating solar PV systems, including the capital costs of installation, maintenance and operations costs, and the potential revenue generated from electricity sales. The modelling can also consider different financing options, such as debt financing or equity financing, and evaluate the financial risks associated with the project [68].

Simulation models can be used to evaluate the performance of the floating solar PV system under different scenarios, such as changes in weather patterns, changes in electricity prices, and changes in demand for electricity. This can help identify potential risks and opportunities for the project and inform decisions on project design and management.

Moreover, economic modelling and simulations can also help policymakers evaluate the potential impact of government incentives, such as tax credits or feed-in tariffs, on the financial viability of floating solar PV systems. This can inform policy decisions to support the development of renewable energy technologies and contribute to the transition towards a more sustainable energy system [68]. Some of the software tools commonly used for numerical modeling and simulation of floating solar PV systems include [69]:

- PVsyst: A software tool for modeling and simulating the performance of solar PV systems, including floating PV systems.

- SAM (System Advisor Model): A software tool developed by the National Renewable Energy Laboratory (NREL) for modeling and simulating renewable energy systems, including solar PV and wind energy systems.

- Homer Pro: A software tool for modeling and optimizing hybrid renewable energy systems, including solar PV and battery storage systems.

PVsyst, however, is the most widely used software tool for modeling and simulating the performance of solar photovoltaic (PV) systems, including floating PV systems [70]. Compared to other simulation tools, PVsyst offers several advantages: (1) comprehensive modeling: PVsyst offers a comprehensive modeling of solar PV systems, including detailed models for PV modules, inverters, and batteries. This also includes models for shading analysis, which can be important for floating PV systems where shading from adjacent modules or other objects can impact system performance; (2) PVsyst has a user-friendly interface that makes it easy to input data, set up simulations, and analyze results. It also offers a range of graphical tools for visualizing data and results; (3) accurate performance prediction: PVsyst has been extensively validated and shown to accurately predict the performance of solar PV systems. It considers a range of factors that can impact system performance, such as module temperature, shading, and degradation over time; (4) PV module database: PVsyst includes a database of PV modules from different manufacturers, which can be useful for selecting the most appropriate module for a specific application; and (5) cost-effective: PVsyst is relatively affordable compared to other simulation tools, making it accessible to a wide range of users.

However, it's important to note that no simulation tool is perfect, and the accuracy of the results depends on the quality and accuracy of the input data. It is recommended to validate the simulation results with on-site measurements and monitoring to ensure the accuracy of the model. It's also important to consider other factors, such as system design and installation, operation and maintenance, and environmental and economic factors, when evaluating the feasibility of a floating PV system. There is not a single "most preferred" simulation tool for floating solar PV systems, as different tools may be preferred depending on the specific needs and requirements of the user.

A research article titled "Simulation and performance analysis of a floating photovoltaic system using PVsyst software" by K. S. Reddy, P. S. Kumar, and S. K. Tripathy, published in the journal Renewable Energy, demonstrated the effectiveness of PVsyst for simulating the performance of a floating solar PV system [71]. The authors used PVsyst to model the system's performance under different weather conditions and found that it provided accurate predictions of energy output. The study also compared the results from PVsyst simulations with experimental data and found good agreement, indicating the reliability of the software for floating solar PV system simulation.

The paper investigated the use of PVsyst software for simulating and analyzing the performance of a floating solar photovoltaic (PV) system. The study includes a detailed description of the design and installation of the floating PV system, which was installed on a water tank with a capacity of 100,000 liters. The system included 20 PV modules with a total capacity of 5 kWp and a floating structure made of high-density polyethylene (HDPE) foam [71]. The authors then used PVsyst to simulate the performance of the system under different weather conditions, including clear sky, cloudy, and partly cloudy conditions. They also compared the results of the simulations with experimental data obtained from the actual system. The study found that the PVsyst simulations provided accurate predictions of the energy output of the system, with an average error of less than 4% [71]. The authors also used the simulation results to perform a sensitivity analysis and determine the impact of different factors, such as shading and temperature, on the performance of the system. The study found that shading had a significant impact on the performance of the system, with even partial shading of a single module resulting in a reduction in energy output by 20% [71]. The authors suggest that PVsyst can be a useful tool for optimizing the design and performance of floating PV systems and for predicting their energy output under different weather conditions [71].

II. METHODOLOGY

The research in this paper utilized a descriptive research design. To gather information relevant to the investigation, a desktop study was conducted. For determining the potential resources required, officials were consulted through field visits and community representatives were engaged in discussions. Furthermore, preliminary evaluations of the target area were performed to gather data. To assist the authors in conducting the study, a review of relevant studies was undertaken. The team used available maps and information from relevant websites to pinpoint the potential location of the study site and determine the geographical characteristics of the area. This step was also necessary to obtain the latest data on photovoltaic power potential, global horizontal radiation, direct normal radiation, and other applicable factors for analysis. This was done to avoid duplicating previous investigations. Based on the potential resources available for the FSPV system, an analysis was conducted to determine the optimal system size and necessary components.

2.1 Modelling and simulations for FSPV in Lake Mainit using PVSyst

PVSyst is a powerful software tool used for the design and analysis of photovoltaic (PV) solar energy systems. The software can perform a range of simulations to model the performance of a solar energy system. As seen in Figure 2, the following are the steps involved in PVSyst simulations:

a) Define the location and site parameters: The first step is to define the location of the solar energy system and input the relevant site parameters such as longitude, latitude, altitude, and weather data.

b) Define the system configuration: Next, the system configuration needs to be defined, including the number and type of PV modules, the inverter type and rating, the type of mounting structure, and other relevant system components.

c) Define the electrical parameters: Once the system configuration is defined, the electrical parameters such as the DC wiring, the AC wiring, and the transformer configuration need to be defined.

d) Simulate the performance of the system: PVSyst can simulate the performance of the solar energy system based on the inputs provided. This includes calculating the energy yield, the performance ratio, and the overall system efficiency.

e) Analyze the results: Finally, the results of the simulation need to be analyzed to determine the feasibility of the solar energy system. This includes assessing the financial viability of the system, the payback period, and the overall return on investment.

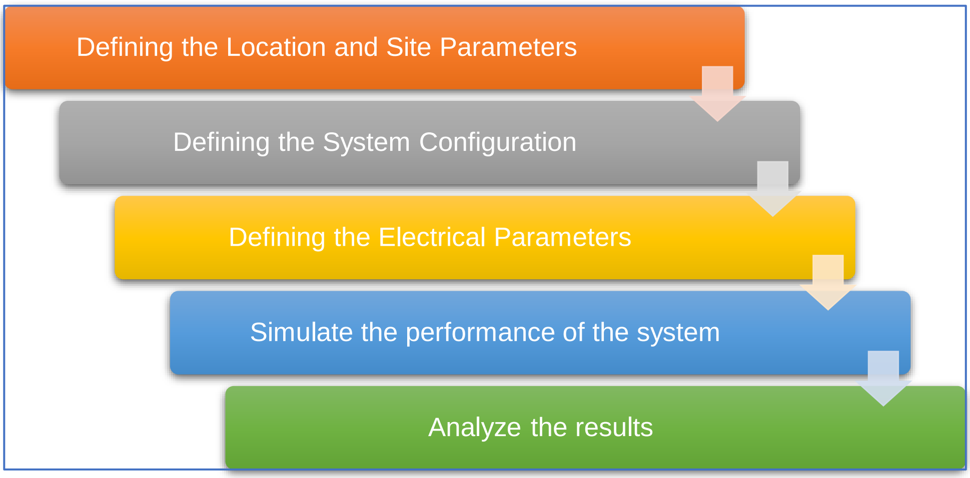

Figure 2. Steps required for the modelling of an FSPV system

2.1.1 Sources of meteorological data and site location

Meteorological data can be obtained from NASA-SSE (https://power.larc.nasa.gov) or Meteonorm (https://meteonorm.com/en), along with other websites that provide such information. The availability and intensity of solar radiation greatly affect the output of any solar-PV system, making it crucial to determine the optimal tilt and azimuth angles based on the system's global position for effective solar radiation collection. The other site parameters are solar PV orientation, tilt angle, azimuth, and shading.

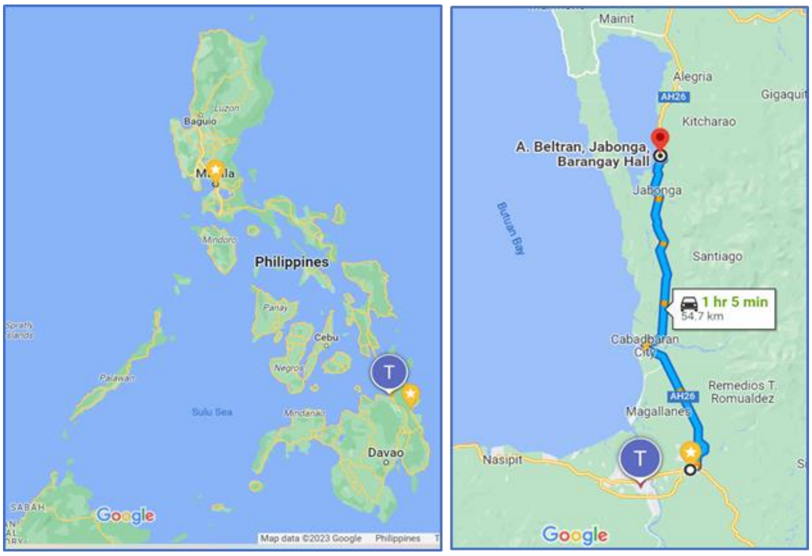

Figure 3. The location of the selected site in southern Philippines (left figure) and the location of the Lake Mainit (right figure).

Source: Google Maps.

For this study, the location of the intended FSPV system shall be at the Lake Mainit in Agusan del Norte Philippines as shown in Figure 3. Lake Mainit, the fourth largest lake in the Philippines, covers a surface area of approximately 149.865 square kilometers and features a coastline of about 50 kilometers. It plays a crucial role in the livelihood of thousands of local community members, primarily through fishing activities. The lake is classified as oligotrophic, indicating low nutrient content which influences its physicochemical properties, natural productivity, optical properties, and morphometric characteristics. Temperature measurements in the lake show that both surface and vertical temperatures range between 26.60 and 30.60 degrees Celsius, providing a stable environment for various aquatic species and supporting the ecosystem required for local fisheries and community livelihoods.

2.1.2 System design or configuration

The design of the solar PV system will be tailored to meet the specific needs of the community using it, drawing on data from resource assessments to determine system requirements. The configuration will utilize available solar panels, floaters, and other necessary materials. Solar photovoltaic (PV) panels, crucial for converting sunlight into electricity, will be selected based on wattage and efficiency ratings. Off-grid power inverters, essential for converting DC from solar panels to AC, will be sized according to the community's energy needs, incorporating technologies for enhanced safety and efficiency. Additionally, a battery storage system will be integrated to store excess energy, thereby ensuring energy availability during periods without sunlight and enhancing grid independence. This system will use batteries suited to the community's usage patterns and budget, providing a reliable and sustainable energy solution.

2.1.3 Defining the Electrical parameters

There are several key electrical parameters that are important for solar PV systems, including voltage, current, power and energy. In most cases, solar panels produce DC voltage, which is then converted to AC voltage using an inverter before being fed into the grid or used to power homes or businesses. But for off-grid systems, there is a flexibility to use the same DC output for direct storage to the battery. The power of a solar PV system refers to the rate at which energy is generated or consumed. Power is typically measured in watts (W) or kilowatts (kW) and is influenced by the voltage and current of the PV system. The energy of a FSPV system refers to the total amount of electricity that is generated or consumed over a period of time. Energy is typically measured in watt-hours (Wh) or kilowatt-hours (kWh) and is influenced by the power and duration of the system.

2.1.4 Defining the simulation tools, parameters and equations

For this simulation, PVsyst is the preferred software to be used. PVsyst is a commonly used tool for simulating the performance of floating solar PV systems, as it provides a comprehensive understanding of the system's performance and helps to ensure that it is both efficient and cost-effective. The information gathered from the risk assessment will be used for the simulations.

Solar irradiance refers to the amount of solar energy received per unit area on the Earth's surface. It is a measure of the intensity of sunlight that reaches a specific location at a given time. The solar irradiance is typically expressed in watts per square meter (W/m²).

The irradiance of the area (Ia) is found out by the formula given as:

$$Ia = \frac{Ins.(ave.)}{Sun\ (ave.)} \qquad (3.1)$$

where Ins.(ave.) is the average insolation of the area and Avg.Sun is the average bright sunshine hours daily. Its unit area is kWh/meter square.

$$Is\ \left(\frac{W}{m2}\right) = irradiance\ (kWh) * (\frac{1000}{hours}) \qquad (3.2)$$

The other parameters of importance used in design and simulation are as follows:

For maximum power:

$$Pmax = Imax * Vmax$$

(3.3)

For PV module efficiency

$$\eta max\ =\ [(Pmax)\ /\ (SI * A)]\ *\ 100$$

(3.4)

For total specific production (TSP):

$$TSP = Total\ Energy\ obtained/Array\ Nominal\ Power \quad (3.5)$$

$$Performance\ Ratio = (Total\ Energy\ recorded\ (kWh))/(Energy\ obtained) \quad (3.6)$$

$$Energy\ obtained = [Total\ Active\ area\ of\ panel\ (m2)] * [Solar\ Irradiance\ at\ Place\ (kWh/\ m2)] \quad (3.7)$$

Array yield for a photovoltaic (PV) solar array, which is a measure of the energy efficiency of a PV system. The formula for calculating Array Yield YA is:

$$YA = EDC\ /\ PPVrated\ (kWh/kWp) \quad (3.8)$$

where *EDC* represents the direct current Energy production in unit of (kWh). While the Final yield (YF) is the AC energy produced via the PV solar system for a specific duration over the nominal (rated) power value of PV solar system. This is the ratio of the usable AC energy output of the PV solar system to the rated power of the system. It factors in energy losses due to system components and conversion from DC to AC. It represents the time at which the system operates in its rated power in unit of kWh/kWp given with the following equation:

$$YF = EAC\ /\ PPVrated\ (kWh/kWp) \quad (3.9)$$

Reference Yield is also given as the ratio of the total available solar energy at a site to the rated power of the PV solar system. It is typically measured in equivalent full sunlight hours. The Reference Yield is given by:

$$YR = HT/HR\ (kWh/kWp) \quad (3.10)$$

All of these yield values can help assess the performance of a PV solar system. System and array energy losses refer to the energy that is not converted into usable electricity due to a variety of factors. Array Losses are losses that occur at the solar panel array level. They include: (1) thermal losses: solar panels are less efficient at higher temperatures, so on hot days or in hot climates, panels produce less electricity per unit of sunlight; (2) mismatch losses can occur when panels in the same array perform differently, due to variations in manufacturing, angles of sunlight incidence, or partial shading of some, but not all, panels; (3) soiling losses includes dust, dirt, bird droppings, snow, or other materials that accumulate on the surface of solar panels can block sunlight and reduce power production. System losses, on the other hand, are losses that occur after the DC electricity has been produced by the solar panels, but before it can be used or sent to the grid. They include: (1) inverter losses; (2) wiring losses; (3) transformer losses; and (4) system availability losses.

Array losses is given by the equation:

$$LA = YR – YA\ (kWh/kWp) \quad 3.11$$

While the System energy losses is given by:

$$LS = YA – YF\ (kWh/kWp) \quad 3.12$$

These losses can occur when parts of the PV system are temporarily out of service due to maintenance, faults, or other issues. PR is a measure of the overall efficiency of the PV system, taking into account all types of losses. The equation for the performance ration is provided by:

$$PR = YF\ /\ YA \quad 3.13$$

A higher PR indicates a more efficient system. The "solar fraction" SF is a term commonly used in solar thermal systems to represent the proportion of the total load that is supplied by solar energy. It is an important parameter that provides a measure of the system's effectiveness at harnessing solar energy to meet the load demand. The solar fraction is calculated by dividing the amount of energy provided by the solar system by the total energy required for a particular use. In mathematical terms:

$$SF = Energy\ supplied\ by\ solar\ /\ Total\ energy\ required \quad 3.14$$

PVsyst is a powerful tool for the design, analysis, and simulation of photovoltaic systems. In addition to the technical parameters, PVsyst also provides several financial parameters to assist with the economic assessment of a PV system. PVsyst uses parameters to calculate key economic indicators, such as the Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period, and Levelized Cost of Energy (LCOE). These indicators can help decision-makers assess the financial viability of a proposed PV system.

The Net Present Value (NPV) is a financial metric that is widely used in capital budgeting and investment planning. NPV measures the profitability of a venture or project by calculating the present values of incoming cash flows and outgoing cash flows. If you have a series of n cash flows, the NPV can be calculated using the following formula:

$$NPV = \sum [(Ct) / (1 + r)t] - C0 \quad 3.15$$

where:

Ct is the net cash inflow during the period t,

r is the discount rate (expressed as a decimal),

t is the number of time periods, and

C0 is the initial investment.

The Internal Rate of Return (IRR) is another important financial metric used in capital budgeting and investment planning. The IRR is the discount rate that makes the Net Present Value (NPV) of a series of cash flows equal to zero. Formally, the IRR can be defined by the following equation:

$$0 = \sum [(Ct) / (1 + IRR)t] - C0 \quad 3.16$$

where:

Ct is the net cash inflow during the period t,

IRR is the internal rate of return,

t is the number of time periods, and

C0 is the initial investment.

The sum component of the formula is calculated for each period from *t =1 to n*, where n is the total number of periods.

The Levelized Cost of Energy (LCOE) is a measure of the average net present cost of producing a unit of electricity over the lifespan of a generating asset. It is often used to compare the cost effectiveness of different energy technologies. The LCOE can be calculated using the following formula:

$$LCOE = [\sum (It + Mt + Ft) / (1 + r)t\ ] / [\sum Et / (1 + r)t] \quad 3.17$$

where:

It is the investment expenditures in the year t,

Mt is the operation and maintenance expenditures in the year t,

Ft is the fuel expenditures in the year t, *r* is the discount rate,

t is the year, and

Et is the electricity generation in the year t.

The sum in both the numerator and the denominator is over the lifespan of the project. In the context of a solar PV project, It would typically be the initial investment for the solar system and any significant maintenance or upgrade costs. Mt would be the ongoing operation and maintenance costs, and Ft is typically zero since there's no fuel cost for solar. Et is the electricity generated each year.

LCOE is often given in cents per kilowatt-hour or dollars/peso per megawatt-hour. A lower LCOE means that the cost of producing electricity is lower, making the technology more economically competitive. The Payback Period is a simple financial metric that measures the time it takes for an investment to recoup its initial cost out of the cash inflows that it generates. It is widely used to estimate the time needed to recover the cost of an investment. The basic formula for the payback period is:

Payback Period = Initial Investment / Annual Cash Inflows 3.18

However, this formula assumes that the cash inflows are constant each year, which might not be the case in reality. For investments where the annual cash inflows are not uniform, the payback period can be calculated by adding up the cash inflows from each period until the initial investment is covered.

3. RESULTS AND DISCUSSIONS

3.1 Calculation for the FSPV System and Battery Storage Size

Every fisherman in Bgy. San Roque uses one (1) 100Ah battery and three (3) 9W-12V direct current (DC) light-emitting diode (LED) bulbs to last overnight. For the 110 fishers, the total battery storage requirement is 2200 AH and 330 pieces of 9 W-12 V DC LED bulbs. These figures are significant in determining the minimum size of the battery storage and charging capacity and the FSPV system. Each day, the FSPV system needs to respond to the requirement of 27 W multiplied by 110 fishers as the capacity required for the solar PV system. The batteries are assumed to be used for 12 hours (from sundown to sunrise) when the fishers go fishing.

A simple mathematical formula was used to obtain the daily energy capacity requirement for the FSPV system:

$$Ct = [bn\ x\ bw] * [fn] * husage \quad 3.19$$

where:

bn is the number of bulbs being used by one fisherman,

bw is the wattage rating of the bulb being used,

fn is the number of fishermen,

husage is the number of hours used

Ct = [3 bulbs * 9W] * [110 fishermen] * 12 hours

Ct = 35,640 Whr

With this figure, the resources needed to put up the FSPV should satisfy the 35,640 Whr daily energy requirement. To calculate for the PV system size, we use the following simple equation:

$$\mathrm{Ss} = \mathrm{Ct} / \mathrm{PVpp} \quad 3.20$$

where:

Ss is the system size needed for the solar PV,

Ct is the capacity requirement

PVpp is the solar photovoltaic power potential

Therefore:

Ss = 35,640 Whr / 3.6 kWhr/kWp

Ss = 9.90 kWp

Using the solar photovoltaic power potential data at 3.6 kWhr/kWp, we can solve the system size, which is 35,640 Whr divided by 3.6 kWhr/kWp as shown above. This would give us an FSPV system size of 9.90 kWp.

Theoretically, a 12V-100AH battery can last 44.44 hours or around three days of use. The requirement to charge the battery based on the consumption of a 27W bulb in 12 hours (6 PM-6 AM) is 324 Wh per day. The total capacity needed from 324 Wh times the number of fishermen gives us a 35,640 Wh energy requirement to be supplied by the FSPV system daily. To calculate for the number of batteries needed in the charging station, a simple formula is also presented as follows:

$$Bs = Ct / Bv \qquad (3.21)$$

where:

Bs is the number of batteries needed for the charging system,

Bv is the battery voltage rating being used by the fishermen,

Ct is the capacity requirement.

Bs = 35,640 Wh / 12V

Bs = 29.7 or 30 units of 12V-100Ah batteries

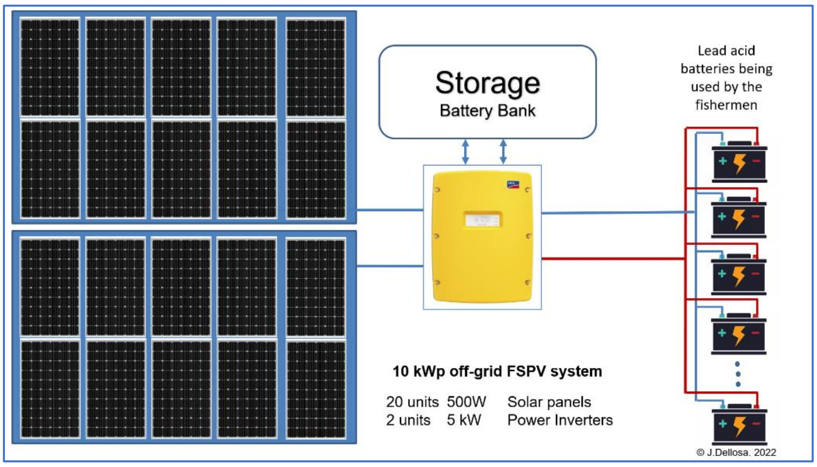

Figure 4. A 10 kWp off-grid system for the local community of fishermen using their rechargeable batteries.

In battery storage, the capacity requirement is 35,640 Wh divided by 12 V gives 2,970 Ah or an equivalent of 29.7 (~30) units of 100 Ah batteries. The resources needed to address the community's needs, the FSPV system size should be at 9.90 kWp and to use 30 units of 100 Ah batteries. The 9.90 kWp system can be rounded off to 10kWp and can be divided into two arrays of 5 kWp. This 10 kWp FSPV system requires two power inverters rated at 5,000 W. For solar panels, there are various sizes in the market available, from 160Wp to 670Wp, as per Trina Solar, one of the largest manufacturers of solar panels in the world. Twenty (20) 500 Wp solar panels are the expected rating for the 10 kWp system, as seen in Figure 4.

3.2 Simulation and Economic Modelling using the PVSyst Tool

The technical and economic simulations were carried out using the PVSyst software. PVsyst is a powerful software tool used for simulating the performance of solar photovoltaic (PV) systems.

3.2.1 Technical and financial paramaters

Table 2 displays important geographical parameters such as meteorological data source, exact coordinates, altitude, and albedo, used in the simulation, which is crucial as PVSyst utilizes various environmental data for accurate simulation runs. The latitude and longitude correspond to the Lake Mainit location in Bgy. A. Beltran, Jabonga.

Table 2 General parameters for a stand-alone FSPV system.

Geographical site	Bgy. A. Beltran, Jabonga, Philippines
Meteo data	NASA-SSE satellite data 1983-2005 – Synthetic
Latitude	9.43degN
Longitude	125.53degE
Altitude	25m
Albedo	0.20

Table 3 provides information on PV field orientation, where tilt and azimuth are set at 15deg and 1deg, respectively, based on the manufacturer's floater design. According to the findings of the resource assessment, the average daily energy requirement for the community of fishermen is 35.7 kWh, and a 10 kWp solar PV system with 20 units of solar panels or modules is needed to satisfy this requirement. The community's preferred battery is a lead-acid battery due to its affordability, and a battery pack comprising 32 units with 48V and a total rating of 1280 Ah is needed to provide for the fishermen's needs. These details are summarized in Table 3.3.

Table 3 System summary for stand-alone system with batteries

A. PV Field Orientation	
Fixed plane	
Tilt/Azimuth	15/1deg
B. Users' needs	
Daily household consumers average	35.7 kWh/day
C. PV System Information	
PV Array	
Number of modules needed	20 units
Power (nominal) total	10 kWp
D. Battery Pack	
Technology	Lead-acid, sealed, Gel
Number of units	32
Voltage	48 V
Capacity	1280 Ah

Table 4 contains the electrical specifications for the solar panels, batteries, and controller used in the 10 kWp FSPV system simulation. The system is configured with two groups of ten solar panels each to produce a total power output of 10 kWp. The required area for the 20 solar panels is calculated to be 47.8 sq.m. The table includes several important electrical specifications, including the maximum power output of the solar panels, the nominal voltage and capacity of the battery, and the maximum charge and discharge current of the controller. These specifications are critical in determining the overall performance and efficiency of the system.

It is worth noting that the specifications listed in Table 3.4 may vary depending on the specific components used in the installation. Factors such as the manufacturer, model, and efficiency rating of the solar panels, batteries, and controller can all affect the system's electrical specifications.

Table 4. PV Array Characteristics

PV Array Characteristics			
PV module		Battery	
Manufacturer	Generic	Manufacturer	Generic
Model	TSM-DE18M-(II)-500	Model	Solar 12V / 160 Ah
(Original PVsyst database)		Technology	Lead-acid, sealed, Gel
Number of PV modules	20 units	Nb. Of units	8 in parallel x 4 in series
Nominal (STC)	10.00 kWp	Discharging min. SOC	17.50%
Modules	10 Strings x 2 In series	Stored energy	50.7 Wh
At operating cond. (50°C)		Battery Pack Characteristics	
Pmpp	9.10 kWp	Voltage	48V
U mpp	78 V	Nominal Capacity	1280 Ah (C10)
I mpp	11.7 A	Temperature	Fixed 20degC
Controller		Battery Management control	
Manufacturer	Generic	Threshold command as	Battery voltage
Model	FLEXmax 80 - 48V	Charging	53.9 / 50.1 V
Nb. Units	2 units	Corresp. SOC	0.90 / 0.75
Technology	MPPT converter	Discharging	46.7 / 48.9 V
Temp coeff.	-5.0 mV/degC/Elem	Corresp. SOC	0.17 / 0.45
Converter			
Maxi and EURO efficiencies	97.5 / 96.6%		
Total PV Power			
Nominal (STC)	10 kWp		
Total	20 modules		
Module Area	47.8 sq.m.		

The electrical specifications provided in Table 3.4 are an essential component of the system design and play a crucial role in determining the performance and efficiency of the floating solar photovoltaic system. Proper consideration of these specifications can help ensure that the system is designed to meet the energy needs of the installation site while maximizing efficiency and minimizing costs.

Table 5 contains cost estimates for a 10 kWp FSPV system. The cost breakdown includes components such as PV modules, batteries, and controllers, as well as environmental studies and installation costs, which include labor, floaters, and anchors. Based from the information provided in the simulation software, the estimated total cost for the 10 kWp FSPV system is Php 1,726,000.00. This suggests that the installation of a floating solar photovoltaic system can be a significant investment, but it can also offer long-term cost savings by generating renewable energy and reducing reliance on traditional power sources.

It is worth noting that while the initial cost of installing a floating solar photovoltaic system may be higher than traditional land-based systems, the long-term cost savings can be significant due to the higher efficiency and reduced maintenance costs. Additionally, installing a renewable energy system like this system can contribute to environmental sustainability by reducing greenhouse gas emissions and dependence on fossil fuels.

Table 5 Cost estimates of the system

Item	Quantity (units)	Cost (Php)	Total (Php)
PV modules TSM-DE18M-(II)-500	20	20000	400,000
Supports for modules	20	1000	20,000
Batteries	32	10000	320,000
Controllers	2	50000	100,000
Other components			
Accessories, fasteners	100	200	20,000
Wiring	100	300	30,000
Combiner box	2	3000	6,000
Monitoring system, display screen	2	10000	20,000
Measurement system, pyranometer	1	10000	10,000
Surge arrester	1	50000	50,000
Studies and analysis			
Environmental studies	1	50000	50,000
Installation			
Transport	1	100000	100,000
Labor / Settings / Floaters / Anchors	1	600000	600,000
Total			1,726,000
Depreciable asset			860,000

Table 6. Operating costs

Operating Costs			
Item	Quantity (units)	Cost (Php)	Total (Php)
Maintenance	-	-	
Repair	-	-	20,000.00
Cleaning	-	-	10,000.00
Insurance	-	-	
Facilities Insurance	-	-	50,000.00
Total (OPEX)	-	-	80,000.00
Including inflation (2.0%)	-	-	97,189.48

Table 7. System Summary

Description	Unit	Amount
Total installation cost	PHP	1,726,000
Operating costs (incl. inflation 2.00%/year)	PHP/year	97,189.50
Excess energy (battery full)	MWh/year	3.40
Used solar energy	MWh/year	12.90
Used energy cost	PHP/kWh	9.2010

Table 6 contains the estimated operating costs for the floating solar photovoltaic system used in the PVsyst simulations. The table includes several cost categories, including repair and maintenance costs, cleaning costs, insurance costs, and inflation costs. The estimated costs for the floaters used in this simulation is Php600,000.00.

It is to emphasize that the structural part was for the floating structure, and not for the solar PV ground components. Note that this cost does not include the photovoltaic panels, inverters, or other components of the solar PV system, but only the structural part required for the system to float on the water.

The repair and maintenance costs listed in the table are an estimate of the ongoing maintenance required to keep the system operating efficiently. This may include routine inspections, replacement of faulty components, and general repairs as needed. The cleaning costs are an estimate of the cost of cleaning the solar panels to maintain maximum efficiency. This may include the cost of labor, equipment, and cleaning solutions. The insurance costs listed in the table are an estimate of the ongoing insurance premiums required to insure the system against potential damage or loss. This may include coverage for damage caused by weather events, theft, or other unexpected incidents. The inflation costs listed in the table are an estimate of the impact of inflation on the overall operating costs of the system over time. This is an important consideration, as inflation can cause the cost of labor, materials, and other expenses to increase over time, leading to higher operating costs.

The estimated operating costs provided in Table 3.6 are an important consideration in the overall cost of the floating solar photovoltaic system. Proper consideration of these costs can help ensure that the system remains efficient and cost-effective over its operational lifetime.

Table 7 provides a summary of the simulation results for the floating solar photovoltaic (FSPV) system. The table includes several key performance metrics, including the total installation cost, operation costs, excess energy when the battery is full, used solar energy, and used energy cost. The total installation cost listed in the table is Php 1,726,000.00, which includes the cost of the photovoltaic (PV) modules, batteries, controllers, and installation costs, such as labor, floaters, and anchors. The operation costs listed in the table are an estimate of the ongoing costs required to keep the system operating efficiently. This includes repair and maintenance costs, cleaning costs, insurance costs, and inflation costs. The total estimated annual operation cost is Php 25,890.00.

The excess energy listed in the table is an estimate of the amount of energy that the system can produce beyond what is required to fill the battery. In this case, the excess energy is expected to be 3.40 MWhr/year. The used solar energy listed in the table is an estimate of the amount of energy that the system is expected to produce and use on-site. In this case, the used solar energy is expected to be 12.90 MWhr/year. The used energy cost listed in the table is an estimate of the cost of the energy produced by the system. In this case, the used energy cost is Php 9.210 per kWhr, which is lower than the current rate in Agusan del Norte at Php 12.00 / kWhr. The simulation results summary provided in Table 7 suggest that the floating solar photovoltaic system is a viable option for generating on-site energy in Agusan del Norte. The system is expected to produce excess energy, reduce energy costs, and operate efficiently over its operational lifetime.

Table 8 provides a summary of key performance metrics for the floating solar photovoltaic (FSPV) system, including available energy, used energy, specific production, performance ratio (PR), and solar fraction (SF). The available energy listed in the table is an estimate of the total amount of energy that the system is capable of producing over the course of a year. In this case, the available energy is expected to be 13,599 kWhr/year.

The used energy listed in the table is an estimate of the amount of energy that the system is expected to produce and use on-site. In this case, the used energy is expected to be 12,940 kWhr/year. The specific production listed in the table is an estimate of the energy production per unit of installed capacity, expressed in kWh/kwp/year. In this case, the specific production is estimated to be 1660 kWh per kWp per annum. The performance ratio (PR) listed in the table is a measure of the efficiency of the system, expressed as a percentage of the available energy that is produced and used. In this case, the performance ratio obtained was 64.22%.

The solar fraction (SF) listed in the table is a measure of the percentage of the energy used by the system that is generated by the solar panels. In this case, the solar fraction is estimated to be 99.40%, indicating that most of the energy used by the system is generated by the solar panels. The results provided in Table 3.8 suggest that the floating solar photovoltaic system is a highly efficient and effective means of generating on-site energy in Agusan del Norte. The system is expected to produce a significant amount of energy, operate efficiently, and deliver a high solar fraction over its operational lifetime.

Table 8. Summary of the results

Available Energy	**16599 kWh/year**
Used Energy	12940 kWh/year
Specific Production	1660 kWh/kWp/year
Performance Ratio (PR)	64.22%
Solar Fraction (SF)	99.40%

Table 9. System Production Results

Available Energy	16599 kWhr/year
Used Energy	12940 kWhr/year
Excess (unused)	3386 kWhr/year
Loss of Load	
Time Fraction	0.7%
Missing Energy	78 kWh/year

Table 9 provides information on the excess (unused) energy and missing energy for the floating solar photovoltaic (FSPV) system. The excess energy listed in the table refers to the amount of energy that is produced by the system but not used on-site. In this case, the excess energy is estimated to be 3,386 kWhr/year, which represents approximately 0.7% of the total energy generated by the system. The missing energy listed in the table refers to the amount of energy that is not produced by the system due to factors such as shading or other environmental conditions. In this case, the missing energy is estimated to be 78 kWh/year.

These figures suggest that the FSPV system is highly effective at generating on-site energy, with only a small fraction of the total energy produced going unused. Additionally, the missing energy is relatively low, indicating that the system is not significantly impacted by shading or other environmental factors that could limit its performance.

3.2.2 Financial Analysis

Table 10 provides important inputs to the economic modeling or simulation using PVsyst for the floating solar photovoltaic (FSPV) system. The simulation period is set at 20 years starting from 2023. The income variation over time is indicated at 2% including inflation, and the discount rate is set at 5%. Regarding financing the deployment of the FSPV system, the required subsidies are estimated to be Php 1.4 million, and using one's own funds is estimated to be Php 326,000.00. With regards to self-consumption, the consumption tariff is set at Php 12.00 / kWhr, and the tariff evolution is set at 2% per year.

The results of the economic modeling provide valuable insights into the financial viability of the FSPV system. The payback period is estimated to be 4.8 years, indicating that the initial investment in the system will be recouped within this time frame. The net present value (NPV) is estimated to be Php 741,732.00, indicating that the project is financially feasible. Finally, the return on investment (ROI) is estimated to be 227.5%, indicating that the project is expected to generate significant returns over its lifetime.

Table 10. Economic modelling parameters and summary of results for ROI.

Simulation period		
Project lifetime	20	years
Start year	2023	
Income variation over time		
Inflation	2	%/year
Discount rate	5	%/year
Financing		
Own funds	326000	PHP

Subsidies	1400000	PHP
Self-consumption		
Consumption tariff	12	PHP/kWh
Tariff evolution	2	%/year
Return on investment		
Payback period	4.8	years
Net present value (NPV)	741,732	PHP
Return on investment (ROI)	227.5	%

These economic modeling results are important for decision-makers and investors who are evaluating the feasibility of deploying an FSPV system. The payback period of 4.8 years is relatively short and suggests that the initial investment in the system is likely to be recouped relatively quickly. The positive net present value (NPV) also indicates that the investment is likely to generate positive returns, and the return on investment (ROI) of 227.5% indicates that the project is expected to generate significant returns over its lifetime.

It is important to note that these economic modeling results are based on several assumptions, including the cost of installation, the cost of operation and maintenance, and the cost of financing. It is important to consider the potential risks associated with these assumptions, such as changes in the cost of materials, fluctuations in energy prices, and changes in government policies and regulations. Additionally, it is important to note that the economic modeling results assume several factors that may vary depending on the specific context of the project. For example, the assumptions about the cost of electricity, inflation rates, and discount rates may be different in different locations or under different economic conditions.

Moreover, the economic modeling results do not consider some potential benefits of an FSPV system that may be difficult to quantify. For example, the system may provide environmental benefits by reducing greenhouse gas emissions and mitigating the impacts of climate change. The system may also provide social benefits by increasing access to electricity for a community of fishermen, improving energy security, and creating jobs as well in the renewable energy sector.

The LCOE can be used to compare the cost of generating electricity from different sources, such as solar, wind, or fossil fuels. In the case of the FSPV system, the LCOE of Php 6.18/kWhr suggests that the cost of generating electricity from this source is competitive with other sources of electricity in the region, such as conventional fossil fuel-based power plants. This is important because it indicates that the FSPV system may be a financially viable option for meeting energy needs in the region over the long term. The results of the economic modeling suggest that an FSPV system may be a financially viable option for meeting energy needs.

Table 11 provides the economic valuation with an investment of Php 1,726,000.00 or at Php 173 per Wp. The computed running cost is at Php 97,189.48 per year with a payback period of 4.8 years. It is important to note that the LCOE (levelized cost of energy) is a metric that reflects the total cost of generating electricity from a particular source over its lifetime, including both capital and operating costs.

Table 11. Economic valuation

Investment	
Global	Php 1,726,000.00 (or USD 31,511.39)
Specific	Php 173 per Wp, (or USD 3.16 / Wp)
Yearly cost	
Run. Costs	Php 97,189.48 / year
Payback period	4.8 years
LCOE	
Energy cost	Php 6.18/kWhr

The first year of operation is expected to generate negative income, as the initial investment costs for the FSPV system are significant. However, over time, the system is expected to generate positive profits as it begins to produce energy and offset the cost of electricity from other sources.

In summary, the investment cost for the FSPV system in Lake Mainit was estimated at Php 173/Wp, with a total cost of Php 1,726,000. The operational costs, including repair, cleaning, insurance, and inflation, were estimated at Php 68,191.00 per year. The system is expected to generate excess energy of 3.40 MWh/year and use 12.90 MWh/year of solar energy, with a cost of Php 9.210/kWh. The FSPV system has an expected available energy of 13,599 kWh/year, a performance ratio of 64.22%, and a solar fraction of 99.40%. The system is expected to generate a negative income in its first year of operation due to initial investments, with positive profits in the following years. The economic modelling estimated a payback period of 4.8 years, a net present value of Php 741,732.00, and a return on investment of 227.5%. The LCOE energy cost was estimated at Php 6.18/kWh.

SUMMARY AND CONCLUSION

The primary objective of this case study was to conduct a simulation and economic modelling of the FSPV system in Lake Mainit in Jabonga, Agusan del Norte, Caraga Region, Philippines. Although FSPV systems are traditionally installed in dams to complement hydroelectric power generation or for electricity grid power generation, the possibility of installing an FSPV system to cater to a community of fishermen was explored in this case.

The simulation and economic modeling of the FSPV system in Lake Mainit showed promising results. Based from the assessment and simulation results, the FSPV system will have a capacity of 10 kWp, consisting of 20 solar panels, and was determined to have an expected available energy of 13,599 kWh/year and an expected used energy of 12,940 kWh/year. The excess energy when the battery is full is expected at 3.40 MWh/year, while the used energy cost is Php 9.210/kWh, lower than the current rate in Agusan del Norte at Php 12.00/kWh.

The FSPV system was also found to have a specific production of 1660 kWh/kWp/year, a PR of 64.22%, and an SF of 99.40%. The unused energy was estimated to be 3,386 kWh/year, with a time fraction of 0.7%, and a missing energy of 78 kWh/year. The economic modeling of the FSPV system showed a payback period of 4.8 years, with a net present value of Php 741,732.00 and a return of investment of 227.5%. The LCOE energy cost was estimated at Php 6.18/kWh, with a running cost of Php 97,189.48/year.

In conclusion, the simulation and economic modeling results suggest that the FSPV system is a viable and cost-effective solution for generating clean energy in Lake Mainit, Agusan del Norte. Based on the findings, the paper concludes that there is a strong motivation to pursue the implementation of the FSPV system in the identified community to address their energy needs. The enormous solar resource potential in Lake Mainit presents a preliminary basis for future renewable energy system implementation, particularly in the form of FSPV, in the area. Overall, the study demonstrates the potential of FSPV systems as a sustainable and cost-effective solution for addressing the energy needs of off-grid communities, particularly those in remote and underserved areas with high solar resource potential.

REFERENCES

[1] J. Weiss, "The economics of climate change in Southeast Asia: a regional review", 2009.

[2] L. Bessa, "Green Governance, Green Peace: A Program of International Exchange in Environmental Governance, Community Resource Management, and Conflict Resolution", 2005.

[3] Inter-government Panel on Climate Change, “Climate Change 2013: The Physical Science Basis”, 2013.

[4] Inter-government Panel on Climate Change, “Climate Change 2014 Synthesis Report, Summary for Policy Makers”, 2014.

[5] International Energy Agency, “South East Asia Energy Outlook, *Special Report*”, 2013.

[6] Y. Kassem, H. Camur, and O. A. M. Abughinda, “Solar Energy Potential and Feasibility Study of a 10MW Grid-connected Solar Plant in Libya”, Eng. Technol. Appl. Sci. Res., vol. 10, no. 4, pp. 5358–5366, Aug. 2020.

[7] R. -A. C. O. Calimpusan, R. Trajano, A. Yungao and J. T. Dellosa, "Water Purification System Powered by a Mini Hydroelectric Power System," 2021 6th International Conference on Development in Renewable Energy Technology (ICDRET), Dhaka, Bangladesh, 2021, pp. 1-6, doi: 10.1109/ICDRET54330.2021.9752679.

[8] I. Takayabu, K. Hibino, H. Sasaki, H. Shiogama, N. Mori, Y. Shibutani, and T. Takemi, "Climate change effects on the worst-case storm surge: A case study of Typhoon Haiyan", *Environmental Research Letters 10, no. 6,* 2015.

[9] I. Stoddard, K. Anderson, S. Capstick, W. Carton, J. Depledge, K. Facer, C. Gough, "Three decades of climate mitigation: why haven't we bent the global emissions curve?", *Annual Review of Environment and Resources 46*: 653-689, 2021.

[10] P. Köppinger, "Climate Report 2014", Energy Security and Climate Change Worldwide, 2014.

[11] Falkner, R. (2016). The Paris Agreement and the new logic of international climate politics. International Affairs, 92(5), 1107-1125.

[12] Van Soest, H. L., den Elzen, M. G., & van Vuuren, D. P. (2021). Net-zero emission targets for major emitting countries consistent with the Paris Agreement. Nature communications, 12(1), 2140.

[13] Seo, S. N. (2017). Beyond the Paris Agreement: Climate change policy negotiations and future directions. Regional Science Policy & Practice, 9(2), 121-140.

[14] Roelfsema, M., Harmsen, M., Olivier, J. J., Hof, A. F., & van Vuuren, D. P. (2018). Integrated assessment of international climate mitigation commitments outside the UNFCCC. Global Environmental Change, 48, 67-75.

[15] Salvia, M., Reckien, D., Pietrapertosa, F., Eckersley, P., Spyridaki, N. A., Krook-Riekkola, A., ... & Heidrich, O. (2021). Will climate mitigation ambitions lead to carbon neutrality? An analysis of the local-level plans of 327 cities in the EU. Renewable and Sustainable Energy Reviews, 135, 110253.

[16] Hafner, M., & Raimondi, P. P. (2020). Priorities and challenges of the EU energy transition: From the European Green Package to the new Green Deal. Russian Journal of Economics, 6(4), 374-389.

[17] Huovila, A., Siikavirta, H., Rozado, C. A., Rökman, J., Tuominen, P., Paiho, S., ... & Ylén, P. (2022). Carbon-neutral cities: Critical review of theory and practice. Journal of Cleaner Production, 130912.

[18] Chen, L., Msigwa, G., Yang, M., Osman, A. I., Fawzy, S., Rooney, D. W., & Yap, P. S. (2022). Strategies to achieve a carbon neutral society: a review. Environmental Chemistry Letters, 20(4), 2277-2310.

[19] Salvia, M., Reckien, D., Pietrapertosa, F., Eckersley, P., Spyridaki, N. A., Krook-Riekkola, A., ... & Heidrich, O. (2021). Will climate mitigation ambitions lead to carbon neutrality? An analysis of the local-level plans of 327 cities in the EU. Renewable and Sustainable Energy Reviews, 135, 110253.

[20] Morgan, J., & Patomäki, H. (2021). Planetary good governance after the Paris Agreement: The case for a global greenhouse gas tax. Journal of Environmental Management, 292, 112753.

[21] Gielen, D., Boshell, F., Saygin, D., Bazilian, M. D., Wagner, N., & Gorini, R. (2019). The role of renewable energy in the global energy transformation. *Energy strategy reviews*, *24,* 38-50.

[22] Mendonça, M. (2012). Feed-in tariffs: accelerating the deployment of renewable energy. Routledge.

[23] Cantarero, M. M. V. (2020). Of renewable energy, energy democracy, and sustainable development: A roadmap to accelerate the energy transition in developing countries. Energy Research & Social Science, 70, 101716.

[24] Kaygusuz, K. (2007). Energy for sustainable development: key issues and challenges. Energy Sources, Part B: Economics, Planning, and Policy, 2(1), 73-83.

[25] Union, E. (2009). Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. Official Journal of the European Union, 5, 2009.

[26] Panwar, N. L., Kaushik, S. C., & Kothari, S. (2011). Role of renewable energy sources in environmental protection: A review. Renewable and sustainable energy reviews, 15(3), 1513-1524.

[27] Hosseinzadeh, A., Zhou, J. L., Li, X., Afsari, M., & Altaee, A. (2022). Techno-economic and environmental impact assessment of hydrogen production processes using bio-waste as renewable energy resource. Renewable and Sustainable Energy Reviews, 156, 111991.

[28] Lowitzsch, J., Hoicka, C. E., & van Tulder, F. J. (2020). Renewable energy communities under the 2019 European Clean Energy Package–Governance model for the energy clusters of the future?. Renewable and Sustainable Energy Reviews, 122, 109489.

[29] Qazi, A., Hussain, F., Rahim, N. A., Hardaker, G., Alghazzawi, D., Shaban, K., & Haruna, K. (2019). Towards sustainable energy: a systematic review of renewable energy sources, technologies, and public opinions. IEEE access, 7, 63837-63851.

[30] Solangi, Y. A., Tan, Q., Mirjat, N. H., & Ali, S. (2019). Evaluating the strategies for sustainable energy planning in Pakistan: An integrated SWOT-AHP and Fuzzy-TOPSIS approach. Journal of Cleaner Production, 236, 117655.

[31] Shimoda, Y., Yamaguchi, Y., Iwafune, Y., Hidaka, K., Meier, A., Yagita, Y., ... & Nishikiori, S. (2020). Energy demand science for a decarbonized society in the context of the residential sector. Renewable and Sustainable Energy Reviews, 132, 110051.

[32] Dagoumas, A. S., & Koltsaklis, N. E. (2019). Review of models for integrating renewable energy in the generation expansion planning. Applied Energy, 242, 1573-1587.

[33] Acharya, M., & Devraj, S. (2019). Floating solar photovoltaic (FSPV): a third pillar to solar PV sector. New Delhi, India: The Energy and Resources Institute.

[34] Fereshtehpour, M., Sabbaghian, R. J., Farrokhi, A., Jovein, E. B., & Sarindizaj, E. E. (2021). Evaluation of factors governing the use of floating solar system: A study on Iran's important water infrastructures. Renewable Energy, 171, 1171-1187.

[35] da Costa, L. C. A., & da Silva, G. D. P. (2021). Save water and energy: A techno-economic analysis of a floating solar photovoltaic system to power a water integration project in the Brazilian semiarid. International Journal of Energy Research, 45(12), 17924-17941.

[36] Lopes, M. P. C., Nogueira, T., Santos, A. J. L., Branco, D. C., & Pouran, H. (2022). Technical potential of floating photovoltaic systems on artificial water bodies in Brazil. Renewable Energy, 181, 1023-1033.

[37] A. Sahu, N. Yadav, and K. Sudhakar, "Floating photovoltaic power plant: A review", Renewable and sustainable energy reviews 66: 815-824, 2016

[38] A.B. Karaveli, U. Soytas, and B. G. Akinoglu, "Comparison of large scale solar PV (photovoltaic) and nuclear power plant investments in an emerging market." Energy 84: 656-665, 2015.

[39] S.R. Ara, S. Paul, and Z. H. Rather, "Two-level planning approach to analyze techno-economic feasibility of hybrid offshore wind-solar pv power plants", Sustainable Energy Technologies and Assessments 47: 101509, 2021.

[40] M.G. Stewart, D. V. Val, E. Bastidas-Arteaga, A. J. O'Connor, and X. Wang, "Climate adaptation engineering and risk-based design and management of infrastructure", pp. 641-684, 2014.

[41] R.D.I. Guerrero, "Philippine lakes: status and strategies for sustainable development", National Academy of Science and Technology 21: 278-86, 1999.

[42] H. Liu, A. Kumar, and T. Reindl, "The dawn of floating solar—technology, benefits, and challenges", In WCFS2019, pp. 373-383. Springer, Singapore, 2020.

[43] H. Rauf, M.S. Gull, and N. Arshad, "Complementing hydroelectric power with floating solar PV for daytime peak electricity demand", Renewable Energy 162: 1227-1242, 2020.

[44] Energy Sector Management Assistance Program, and Solar Energy Research Institute of Singapore, Where Sun Meets Water: Floating Solar Handbook for Practitioners, World Bank, 2019.

[45] H. Liu, A. Kumar, and T. Reindl, "The dawn of floating solar—technology, benefits, and challenges", In WCFS2019, pp. 373-383. Springer, Singapore, 2020.

[46] M.P. C. Lopes, S. de Andrade Neto, D.A.C Branco, M.A. Vasconcelos de Freitas, and N. da Silva Fidelis, "Water-energy nexus: Floating photovoltaic systems promoting water security and energy generation in the semiarid region of Brazil", Journal of Cleaner Production 273: 122010, 2020.

[47] M. Redón-Santafé, P.S. Ferrer-Gisbert, F. Sánchez-Romero, J. B. Torregrosa Soler, J. J. Ferran Gozalvez, and C.M. Ferrer Gisbert, "Implementation of a photovoltaic floating cover for irrigation reservoirs", Journal of cleaner production 66, pp: 568-570, 2014

[48] K. Trapani and D.L. Millar, "Proposing offshore photovoltaic (PV) technology to the energy mix of the Maltese islands", Energy Conversion and Management 67, pp. 18-26, 2013.

[49] J. Song and Y. Choi, "Analysis of the potential for use of floating photovoltaic systems on mine pit lakes: case study at the ssangyong open-pit limestone mine in Korea", Energies 9, no. 2: 102, 2016.

[50] H.M. Pouran, "From collapsed coal mines to floating solar farms, why China's new power stations matter", Energy Policy 123: 414-420, 2018.

[51] K. Trapani and D.L. Millar, "Floating photovoltaic arrays to power the mining industry: A case study for the McFaulds lake (Ring of Fire)", Environmental Progress & Sustainable Energy 35, no. 3: 898-905, 2016.

[52] E. Solomin, E. Sirotkin, E. Cuce, S.P. Selvanathan, and S. Kumarasamy, "Hybrid floating solar plant designs: a review", Energies 14, no. 10: 2751, 2021.

[53] A. Jäger-Waldau, "Snapshot of photovoltaics− March 2021." EPJ Photovoltaics 12: 2, 2021.

[54] Offshore Energy, https://www.offshore-energy.biz/typhoon-proof-floating-solar-plant-marks-operational-milestone-in-the-philippines, Date retrieved January 15, 2021.

[55] E. Solomin, E. Sirotkin, E. Cuce, S.P. Selvanathan, and S. Kumarasamy. "Hybrid floating solar plant designs: a review", Energies 14, no. 10: 2751, 2021.

[56] T.S. Hartzell, "Evaluating potential for floating solar installations on Arizona water management infrastructure", 2016.

[57] R. Cazzaniga, M. Cicu, M. Rosa-Clot, P. Rosa-Clot, G. M. Tina, and C. Ventura, "Floating photovoltaic plants: Performance analysis and design solutions", Renewable and Sustainable Energy Reviews 81: 1730-1741, 2018.

[58] R. Cazzaniga, and M. Rosa-Clot, "The booming of floating PV", Solar Energy 219: 3-10, 2021.

[59] M. AlShabi and M. El Haj Assad, "Artificial Intelligence applications in renewable energy systems", In Design and Performance Optimization of Renewable Energy Systems, pp. 251-295, Academic Press, 2021.

[60] B.K. Bose, "Artificial intelligence applications in renewable energy systems and smart grid–Some novel applications", Power Electronics in Renewable Energy Systems and Smart Grid: Technology and Applications, pp: 625-675, 2019.

[61] A. Mellit, and S. Kalogirou, "Artificial intelligence and internet of things to improve efficacy of diagnosis and remote sensing of solar photovoltaic systems: Challenges, recommendations and future directions", Renewable and Sustainable Energy Reviews 143: 110889, 2021.

[62] T. Lachumanan, R. Singh, M. I. Shapiai, and T. J. S. Anand, “Analysis of a Multilevel Voltage-Based Coordinating Controller for Solar-Wind Energy Generator: A Simulation, Development and Validation Approach”, Eng. Technol. Appl. Sci. Res., vol. 11, no. 6, pp. 7793–7799, Dec. 2021.

[63] Mellino, S., Ripa, M., Zucaro, A., & Ulgiati, S. (2014). An emergy–GIS approach to the evaluation of renewable resource flows: a case study of Campania Region, Italy. Ecological Modelling, 271, 103-112.

[64] Elkadeem, M. R., Wang, S., Sharshir, S. W., & Atia, E. G. (2019). Feasibility analysis and techno-economic design of grid-isolated hybrid renewable energy system for electrification of agriculture and irrigation area: A case study in Dongola, Sudan. Energy Conversion and Management, 196, 1453-1478.

[65] Kowalski, K., Stagl, S., Madlener, R., & Omann, I. (2009). Sustainable energy futures: Methodological challenges in combining scenarios and participatory multi-criteria analysis. European journal of operational research, 197(3), 1063-1074.

[66] Singh, N. K., Goswami, A., & Sadhu, P. K. (2022). Energy economics and environmental assessment of hybrid hydel-floating solar photovoltaic systems for cost-effective low-carbon clean energy generation. Clean Technologies and Environmental Policy, 1-22.

[67] López, M., Soto, F., & Hernández, Z. A. (2022). Assessment of the potential of floating solar photovoltaic panels in bodies of water in mainland Spain. Journal of Cleaner Production, 340, 130752.

[68] Oliveira-Pinto, S., & Stokkermans, J. (2020). Assessment of the potential of different floating solar technologies–Overview and analysis of different case studies. Energy conversion and Management, 211, 112747.

[69] Komrit, S. (2020). Comparative analyses of solar photovoltaic, wind, and hybrid energy systems: case study of Thailand (Doctoral dissertation, California State University, Sacramento).

[70] Kumar, R., Rajoria, C. S., Sharma, A., & Suhag, S. (2021). Design and simulation of standalone solar PV system using PVsyst Software: A case study. Materials Today: Proceedings, 46, 5322-5328.

[71] Yadav, P., Kumar, N., & Chandel, S. S. (2015, April). Simulation and performance analysis of a 1kWp photovoltaic system using PVsyst. In 2015 International Conference on Computation of Power, Energy, Information and Communication (ICCPEIC) (pp. 0358-0363). IEEE.