Jurnal Polimesin
Department of Mechanical Engineering
State Polytechnic of Lhokseumawe
http://e-jurnal.pnl.ac.id/polimesin

e-ISSN	: 2549-1999	No.	: 6	Month	: December
p-ISSN	: 1693-5462	Volume	: 23	Year	: 2025

Processing dates: received on 2025-08-27, reviewed on 2025-10-31, accepted on 2025-11-06 and online availability on 2025-12-31

Technical feasibility study of floating solar power for water hyacinth removal in Limboto Lake, Gorontalo

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Abstract

Limboto Lake in Gorontalo Province has experienced a decline in ecosystem quality due to the massive growth of water hyacinth (Eichhornia crassipes). The presence of water hyacinth reduces lake productivity and disrupts fishing activities. Common control efforts has been mechanical removal of water hyacinth with high cost due to fuel consumption. This study aims to assess the feasibility of utilizing a floating Solar Power Plant (PLTS) as an alternative energy source to power the water hyacinth lifting machine. The methods used in the study include a literature review, field surveys, calculations of engine energy requirements, design of a floating PLTS system, and technical feasibility analysis. The water hyacinth lifting machine requires 12–18 kWh of energy per day, which a floating PLTS system can meet with a capacity of 5 kWp. The findings demonstrate that the proposed floating solar power system is technically feasible for implementation. In addition to supporting the sustainable operation of water hyacinth-lifting machines, this technology also reduces evaporation from lakes and increases the use of renewable energy in Gorontalo.

Keywords:
Floating Photovoltaic (FPV), water hyacinth, lifting machine, feasibility study, renewable energy

1 Introduction

In the global effort to achieve sustainable use of renewable energy, solar energy has emerged as a primary solution due to its abundant availability and environmental benefits. Between 2020 and 2040, worldwide energy consumption is projected to increase by 48% [1], creating an urgent need for renewable energy Development to reduce fossil fuel dependency and mitigate climate change impacts [2].

In Indonesia, energy demand continues to rise every year [3], driven by population growth, industrial Development, and increasing electrification. Therefore, the Development and deployment of renewable energy sources are essential to meet national energy demands and reduce fossil fuel consumption, which contributes to global warming and greenhouse gas emissions [4]. Electricity generated by solar energy offers environmental benefits and helps mitigate the adverse effects of global warming [5].

However, the constraint of limited land availability for solar panel installation, especially in densely populated regions, has led to the innovation of Floating solar Photovoltaic (FPV) systems, an emerging technology that offers higher efficiency than conventional land-based solar panels [6]. Moreover, by integrating multiple renewable energy sources, hybrid renewable systems enhance the diversity and stability of power generation [7]. FPV systems also provide additional environmental benefits, such as natural cooling from water bodies, reduced water evaporation, and inhibition of algal growth, which can affect water quality [8].

At the local level, the implementation of FPV technology in Lake Limboto, in Gorontalo Regency, offers an opportunity to optimize solar energy use without competing with land for other socioeconomic activities. As of 2015, Lake Limboto covered an area of approximately 2,537 hectares [9]. However, the lake has experienced a decline in both water quality and quantity due to excessive sedimentation and the uncontrolled growth of aquatic weeds, particularly water hyacinths.

Despite the growing global and national interest in FPV systems, previous studies have focused mainly on the technical performance and efficiency of FPV for energy generation, with limited attention to their direct application in supporting local ecological management [10], [11]. This knowledge gap highlights the need to assess the technical feasibility of FPV systems as an energy source for operating mechanical devices that contribute to environmental restoration [12]. Therefore, this research aims to evaluate the technical feasibility of a floating solar power system to support water hyacinth lifting operations in Lake Limboto, optimizing system design for on-grid connection to maximize energy production and reduce the environmental impact associated with land-based installations [13].

Although research on FPV systems has rapidly progressed in recent years, most studies have concentrated on the technical aspects of power generation, such as energy conversion efficiency, cooling effects, and environmental impacts on aquatic ecosystems [14]. However, the application of FPV-generated energy to operate specific mechanical devices, such as water hyacinth lifting machines, has not been sufficiently explored. In addition, studies on solar energy utilization in Lake Limboto remain limited to general assessments of renewable potential without addressing local ecological challenges, particularly the excessive growth of water hyacinths that degrade water capacity and quality. To date, no comprehensive feasibility study has evaluated the technical, economic, and sustainability aspects of integrating FPV systems as an energy source for lake-cleaning operations. This research, therefore, aims to fill this gap by assessing the feasibility of implementing FPV technology to power water hyacinth lifting machines in Lake Limboto (Fig. 1).

Fig. 1. Location of the project site
Sumber: Google Earth 2025

2 Research methodology

This research uses a technical feasibility study approach with the following stages:

1. Survey and initial data collection, including solar irradiation data, lake topography, meteorological data, and technical specifications for the water hyacinth lifting machine;
2. Analysis of the energy requirements of the water hyacinth lifting machine to determine the required capacity of the floating solar power plant; and

3. Design of the floating Solar Power Plant (PLTS) system, including solar panel selection, floating structure design, and electrical system configuration.

This research aims to develop a framework for evaluating FPV standards based on PVyst Version 7.8. The methodology used in this research is located at Lake Limboto, Gorontalo. To achieve this research objective, the following data were collected on the PV system configuration at Lake Limboto: (1) Global Horizontal Irradiation, temperature, Horizontal Diffuse Irradiation, linkage turbidity, wind velocity, and relative humidity. This data was sourced from the Global Solar Atlas and the Indonesian Meteorology, Climatology, and Geophysics Agency. In this study, PVSyst software version 7.8 was used to analyze the electricity generation potential of solar power plants. Fig. 2 shows a simulation flow diagram. PVSyst is used to measure and analyze solar power systems connected to the PLN electricity grid (on-grid). PVSyst offers comprehensive simulation capabilities and includes an extensive meteorological database.

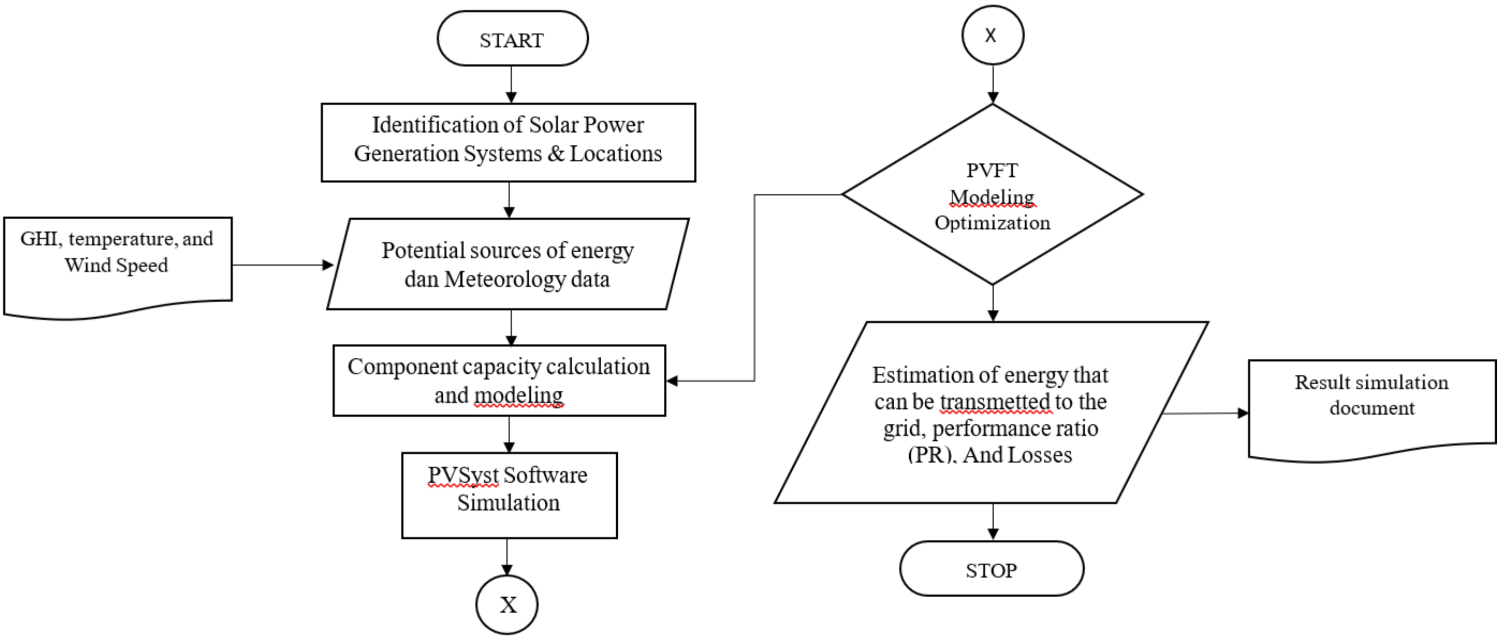

Fig. 2. Modeling and simulation method capacity

Steps for modeling and simulating floating solar panels on Lake Limboto, Gorontalo:

1. Determine the location and relevant parameters of the solar energy system, including longitude, latitude, altitude, and weather data (Fig. 3).

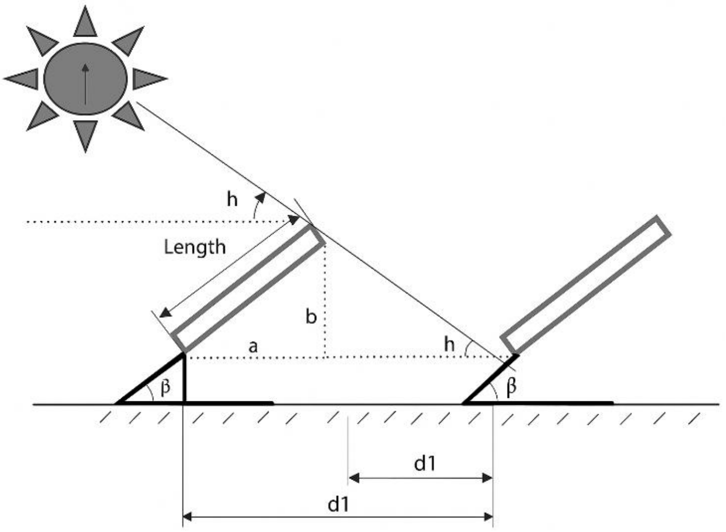

Fig. 3. Shading angle diagram [15] [16]

2. Determine the required system configuration, including the number and type of PV modules, the kind of inverter, and the type of mounting structure.

The technical specifications presented in Table 1 and

Several factors affect the performance of a floating solar power system, including the efficiency of the solar panels [16]. This efficiency refers to the amount of solar energy that can be captured and converted by the PV panel into electricity with Eq. (1) [18].

Table 2 were determined based on the system's power requirements obtained from PVsyst simulation results and validated through relevant manufacturer datasheets and literature references. The selection process considered the system's energy demand, site conditions, and efficiency parameters to ensure optimal system performance.

Table 1. Technical specifications for PV module JW-HD144N-400 [17]

Parameter	Variable	Value
Cell Type	-	158,75×*79,375*
Testing Condition	-	
Number of cells	-	144 pcs(12×12)
Dimensions [mm]	*L×W×H*	2016×*996×30*
Weight [kg]	-	31
Peak power [W]	*Pmax*	400
MPP Voltage [V]	*Vmp*	41,5
MPP Current [A]	*Imp*	9,64
Open circuit voltage [V]	*Voc*	49,8
Short circuit voltage [A]	*Isc*	10,14
Module efficiency [%]	-	19,92
Operating temperature [°C]	-	-40°C ± 85°C
Maximum system voltage [V]	-	1500V (IEC)
Maximum series fuse rating [A]	-	20
Power tolerance	-	0±5W
Bifacialty	-	80%
Temperature coefficient of Pmax	-	-0,32%/°C
Temperature coefficient of Voc	-	-0,26%/°C
Temperature coefficient of Isc	-	+0,046%/°C
Nominal Operating Cell Temperature	-	42±2°C

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Table 2. Technical Inverter specifications [19] [20]

Technical data	Parameters
Brand/type	Sunny Central, SMA/2660 UP-US
MPP voltage range V_{DC}, 35°C/50°C	880 to 1325 V / 1100 V
Min. input voltage $V_{DC,\ min}$/Start Voltage V_{DC}, Start	849 V / 1030 V
Max. input voltage $V_{DC,\ max}$	1500 V
Max. input current $I_{DC,\ max}$/ with DC coupling	3200 A / 4800 A
Max. short-curcuit current $I_{DC,SC}$	6400 A
AC Power frequency/range	50 Hz / 47 Hz to 53 Hz 60 Hz / 57 Hz to 63 Hz
Nominal AC voltage/nominal AC voltage range	600 V/480 V to 720 V
Max. Efficiency (%)	98,7 %

$$\eta = \frac{P_{max}}{A\ (PV) \times I_{rr}} \times 100\ \% \tag{1}$$

In this simulation, the PV panel capacity is calculated using Eq. (2), which describes the method for determining the number of PV panels, where N denotes the total number of units or sections required [21].

$$N_{PV} = \frac{PV\ Cap\_tot\ (Wp)}{Wp/PV} \tag{2}$$

The calculation of space for PV panel placement considers only the area required for the panel itself, without accounting for space for ease of installation and maintenance, or for the area needed for the power plant and other buildings. The required data include the PV panel efficiency, obtained from the specified panel specifications, by using Eq. (3).

$$Area\ (m^2) = N_{PV_{panel}} \times Size_{PV_{panel}} \tag{3}$$

The inverter capacity calculation is adjusted to account for the required power. Using Eq. (4) for its application.

$$N_{inv} = \frac{AC_{power}(kW)}{Cap_{inv}(kW)} \tag{4}$$

The DC: AC ratio in a Photovoltaic (PV) system is the ratio between the maximum power that can be generated by the solar panel (DC) and the maximum power that can be processed by the inverter (AC). This ratio is crucial to ensure that the system operates efficiently and minimizes power losses. The DC: AC ratio is calculated using the solar panel's power output under standard test conditions, which is approximately 1,000 W/m² at 25 °C. The inverter's capacity also constrains the solar panel's power output. The DC: AC ratio compares the size of the solar panels to the inverter. Usually, the ratio is around 1.25, but it can range from 1.15 to 1.4 depending on the solar panels used [20]. For this calculation, Eq. (5) is used.

$$DC : AC_{ratio} = \frac{PV_{Power}(kW)}{Cap_{inv}(kW)} \tag{5}$$

The Performance Ratio (PR) calculation shows how efficient a PV panel is. It is found by comparing the amount of energy the panel produces in a year with the amount of energy it would produce under ideal conditions. is operating at maximum capacity [22]. The PV PR is calculated using Eq. (6).

$$PR = YF/YR \tag{6}$$

The voltage of the PV panel is set according to the voltage listed in the technical data (Table 1 and

Several factors affect the performance of a floating solar power system, including the efficiency of the solar panels [16]. This efficiency refers to the amount of solar energy that can be captured and converted by the PV panel into electricity with Eq. (1) [18].

Table 2), and this voltage is used as the inverter input. The inverter can handle voltages between 849 VDC and up to 1030 VDC. The system voltage is calculated using the given Eq. (7).

$$Volt.Syst_{PV} = PV_{volt} \times Serial\ Circuit_{PV} \tag{7}$$

The voltage of the PV panel system is calculated and set to the optimal number of PV panels that matches the inverter's input voltage [23]. The normal current from the PV panels must be figured out because it connects to the whole PV panel setup, which is worked out along with the system's wiring. The current estimate is based on how much current flows through the inverter, compared to the inverter's voltage and power capacity, as explained in Eq. (8). It also uses the maximum current the inverter can take from the array, as mentioned in Eq. (9).

$$Input\ Current_{Inv} = \frac{Power_{inv}}{Input\ Volt_{inv}} \tag{8}$$

$$Imax_{inv} = I_{PV} \times N_{-PV_{Parallel}} \tag{9}$$

3. Determine electrical parameters such as DC cables, AC cables, and transformer configuration.

When PV panels are connected in parallel, the total current from all the panels is added, while the voltage remains the same as that of a single panel. This configuration allows the system to increase the output current, which is useful for meeting higher power requirements [24]. However, when PV panels are connected in series, the voltage from each panel is added, while the current remains constant. This allows the system to achieve a higher voltage, which is necessary for compatibility with an inverter. The calculation uses Eq. (10).

$$N_{PV/inv} = \frac{N_{total}\ PV}{N_{inv}} \tag{10}$$

4. Use the input data to create a simulation that shows how well the solar energy system is performing. This includes calculating the energy produced, the performance ratio, and the overall efficiency of the system.
5. Boundary conditions and assumptions

In this study, several boundary conditions and assumptions were established to ensure the accuracy and consistency of the simulation results. The average daily solar irradiance at the Limboto Lake area was assumed to be 4.8–5.2 kWh/m²/day, based on meteorological data from BMKG Gorontalo Station for the last five years. The ambient temperature was supposed to range from 25°C to 34°C, with an average relative humidity of 75%. System losses considered in the simulation included temperature loss (5%), wiring and inverter loss (4%), and soiling loss (2%). The weather variation was modeled based on monthly average values, assuming no extreme shading or reflection effects on the water surface. These boundary conditions were incorporated into the PVsyst simulation to represent the real environmental conditions of Lake Limboto as closely as possible.

3 Results and discussion

3.1 Energy requirements of lifting machines

This energy requirement calculation is essential to accurately dimension the required capacity of the FPV system, including the number of solar panels and battery storage capacity, to ensure the effective and efficient operation of the water hyacinth cleaning machine at all times. The total energy requirement per day reaches around 12–18 kWh. Based on the identification results, the water hyacinth lifting machine requires an average power of around 2–3 kW with an effective operating time of 6 hours per day.

3.2 Solar energy potential in Lake Limboto

The solar energy potential in Lake Limboto is significant, given its location in a tropical region with high solar radiation intensity throughout the year. Average daily solar irradiance in the region ranges from 4.5 to 5.5 kWh/m²/day, making Lake Limboto an ideal location for FPV applications. The lake's large surface area also enables large-scale deployment of solar panels without sacrificing agricultural or residential land. A technical feasibility study indicates that Lake Limboto has strong potential for implementing a large-capacity FPV system, which would not only support the energy needs of water hyacinth cleaning machines but also contribute to the local electricity supply, reducing the burden on the conventional electricity grid and increasing regional energy independence.

3.3 Floating solar power plant design

The design of this floating solar power plant accounts for several key parameters, including solar panel efficiency in humid environments, the stability of the floating structure against wave loads, and the integration of an anchorage system that accommodates fluctuations in lake water level. Selecting corrosion- and UV-resistant floating materials is crucial to ensure the system's long lifespan in freshwater environments. Required PLTS capacity: 5 kWp, Number of solar panels: ± 15 units (capacity 330 Wp/panel), Battery capacity: 20 kWh to ensure night/cloudy day operation, Inverter: 5 kW This off-grid hybrid is designed considering the integration of a bidirectional inverter to facilitate the injection of surplus power into the local grid, as well as a remote monitoring system for performance optimization and predictive maintenance, The system is installed on a sturdy floating platform with mooring to stabilize it on the lake surface. Thus, this design not only meets the operational energy needs of the water hyacinth lifting machine but also has the potential to make a significant contribution to the stability of the regional electricity grid, in line to increase the renewable energy mix in Indonesia, in addition, this project has the potential to open new opportunities for the local manufacturing industry in the production of FPV system components.

3.4 Discussion

The analysis results indicate that the floating solar power plant is capable of supplying sufficient energy to sustainably power a water hyacinth lifting machine. Furthermore, the floating solar power plant offers additional benefits, including reducing evaporation from the lake's surface and providing habitat for specific aquatic biota beneath the solar panels. Optimization of this system could involve implementing advanced energy storage technologies and adaptive load management strategies to ensure a stable power supply, particularly during periods of low solar irradiance. Further studies on the long-term ecological impacts of the floating solar power plant on the lake ecosystem, including changes in water temperature and fish migration patterns, would provide important insights for the Development of similar projects in the future. This Development could also include a feasibility study on integrating micro-hydro or diesel power plants into a hybrid system to improve energy supply reliability, particularly in remote areas not yet covered by PLN electricity.

The graph in Fig. 4 shows the PR value of a solar power plant system over the course of one year, from January to December. PR is an essential parameter for evaluating the performance of a solar power plant because it reflects the system's actual efficiency relative to ideal conditions. The PR value is calculated by comparing the system's actual energy output (Yf) with the theoretical energy output (Yr) expected from the intensity of solar radiation incident on the modules. The graph shows an annual average PR value of 0.842. This value indicates that the solar power plant system is performing well, with a system efficiency of approximately 84.2% under ideal conditions. Generally, a well-designed solar power plant has a PR in the range of 0.75–0.85, indicating a good to excellent performance. Meanwhile, the Monthly PR Distribution, the PR value each month looks relatively stable with a range of 0.83 - 0.85, there is no significant fluctuation between the rainy season and the dry season, which indicates that this PLTS system is quite reliable in dealing with climate variations. This PR stability shows that system loss factors such as shading, dirt on the module (soiling), high temperature, and inverter losses are relatively controlled throughout the year.

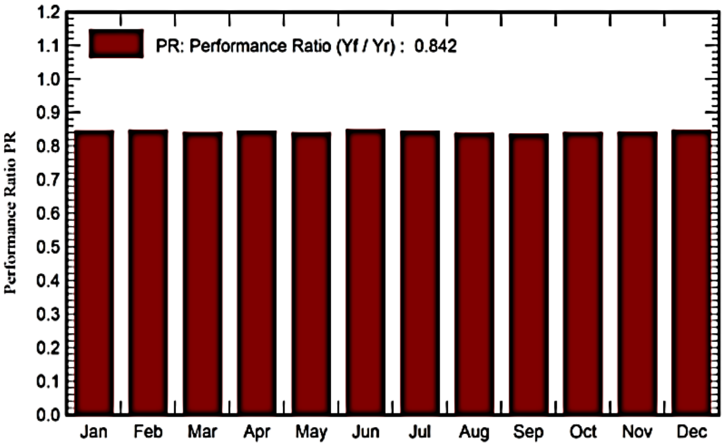
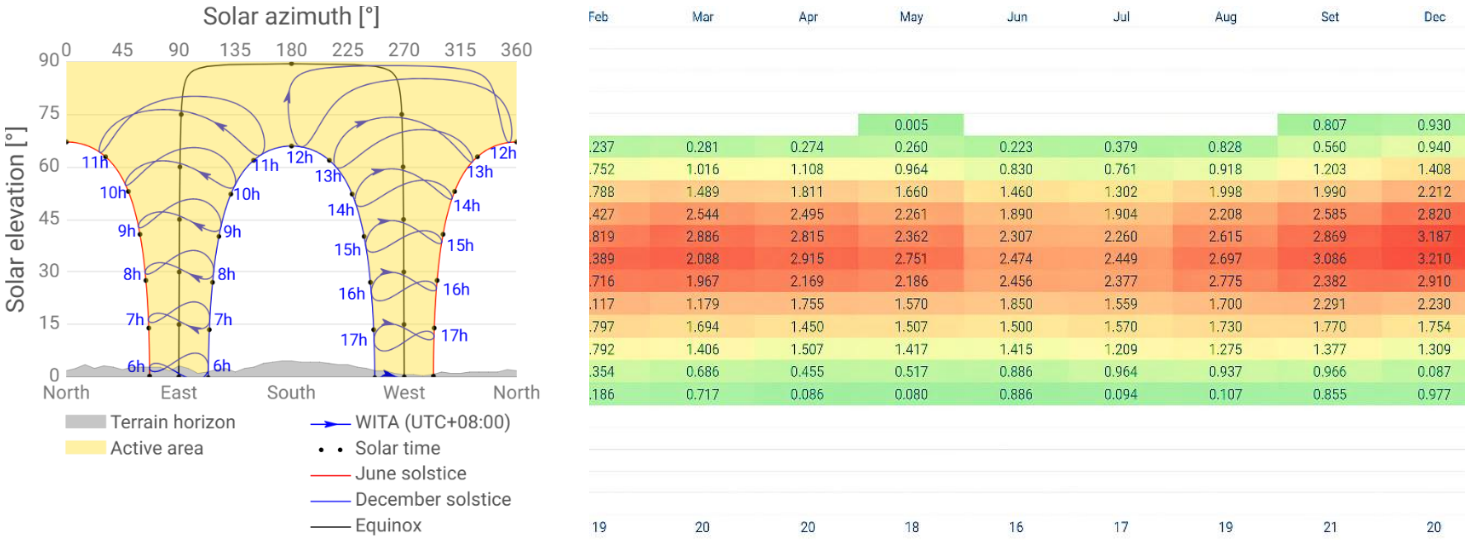


Fig. 4. PR

Solar Panel Orientation Optimization is used to determine the orientation (facing direction) and tilt angle of the solar modules to receive maximum radiation throughout the year. At Lake Limboto, a southerly direction (180° azimuth) is optimal, with the panel tilt angle determined based on the average elevation during the day. Variations in the sun's path (between solstices and equinoxes) cause differences in the intensity of radiation received by the modules, making this diagram important in annual energy simulation calculations. Fig. 5.



Feb	Mar	Apr	May	Jun	Jul	Aug	Set	Dec
			0.005				0.807	0.930
.237	0.281	0.274	0.260	0.223	0.379	0.828	0.560	0.940
.752	1.016	1.108	0.964	0.830	0.761	0.918	1.203	1.408
.788	1.489	1.811	1.660	1.460	1.302	1.998	1.990	2.212
.427	2.544	2.495	2.261	1.890	1.904	2.208	2.585	2.820
.819	2.886	2.815	2.362	2.307	2.260	2.615	2.869	3.187
.389	2.088	2.915	2.751	2.474	2.449	2.697	3.086	3.210
.716	1.967	2.169	2.186	2.456	2.377	2.775	2.382	2.910
.117	1.179	1.755	1.570	1.850	1.559	1.700	2.291	2.230
.797	1.694	1.450	1.507	1.500	1.570	1.730	1.770	1.754
.792	1.406	1.507	1.417	1.415	1.209	1.275	1.377	1.309
.354	0.686	0.455	0.517	0.886	0.964	0.937	0.966	0.087
.186	0.717	0.086	0.080	0.886	0.094	0.107	0.855	0.977
19	20	20	18	16	17	19	21	20

Fig. 5. Solar elevation

Solar Panel Orientation Optimization is used to determine the orientation (facing direction) and tilt angle of solar modules to maximize annual radiation. At Lake Limboto, a southerly direction (180° azimuth) is optimal, with the panel tilt angle determined by the average diurnal elevation. Variations in the sun's path (between solstices and equinoxes) cause differences in the intensity of radiation received by the modules, making this diagram important in annual energy simulation calculations.

The findings of this study demonstrate significant advances over prior research on FPV systems. Earlier studies, such as [18], generally focused on the technical performance of FPV systems, including energy conversion efficiency, temperature effects, and environmental impacts on aquatic ecosystems. However, those studies did not examine the direct use of FPV-generated energy to operate specific mechanical devices in aquatic environments.

In contrast, this study integrates technical, economic, and environmental feasibility analyses of utilizing energy produced by FPV systems to power a water hyacinth lifting machine in Lake Limboto. Simulation results using PVsyst software, along with mechanical power requirement estimations, indicate that the proposed system can reliably meet the energy demand of the lifting mechanism throughout the year. This integrated approach highlights the practical potential of FPV systems not only as renewable energy generators but also as effective tools for ecological restoration efforts.

Therefore, compared with prior research, this study makes a novel contribution by demonstrating the applicability and sustainability of FPV technology for local environmental management, particularly for controlling excessive water hyacinth growth in tropical lake ecosystems such as Lake Limboto.

4 Conclusions

This study shows that the application of a floating solar power plant not only ensures the sustainable operation of water hyacinth removal machine but also contributes to reducing dependence on fossil fuels and minimizing surface water evaporation in tropical regions. The results demonstrate that the daily energy demand of the water hyacinth lifting machine in Limboto Lake, estimated at 12–18 kWh/day, can be reliably supplied by a floating solar power plant with a capacity of 5 kWp. The solar energy potential in Gorontalo, with an average daily solar radiation of approximately 4.8 kWh/m², strongly supports the technical feasibility of implementing FPV systems in the lake environment. However, this study is limited to technical and energy performance assessments and does not address economic feasibility or detailed environmental impacts. Future research should therefore include comprehensive financial, operational and ecological analysis.

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