Research Article

Techno-Economic Feasibility: Planning an On-Grid Solar Power System for Shrimp Pond Aeration

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Abstract
The rapid growth of the Indonesian shrimp farming industry is accompanied by high production costs, primarily driven by the reliance on fossil fuel-based energy sources that can destabilize the ecosystem. This study investigates the technical, economic, and environmental feasibility of using three energy sources, including photovoltaics (PV), grid, and generator, to supply aeration needs in shrimp ponds. A comparative analysis of three scenarios with on-grid schemes was conducted through optimization using Queen Honey Bee Migration (QHBM) and Grey Wolf Optimization (GWO) algorithms, namely Net Present Cost (NPC), Renewable Fraction (RF), and Carbon Emission (ECO_2). From a technical point of view, a lower electricity tariff is obtained compared to the grid, which is US$ 589,968. The optimization results on the NPC, RF, and ECO_2 parameters show that scenario 1 of the QHBM algorithm is the most optimal. This condition is evidenced by the acquisition of 3 parameters that are closest to the determination of the objective function, yielding an NPC of US$ 230,390.34, RF of 26.01%, and ECO_2 of 1,484KgCO_2e, with 655Wp PV specifications and the number of PV as many as 578pcs. Economically, the investment in a solar power plant for the shrimp pond obtained BEP of 4.2 years with a payback period (PP) obtained in year 5, net cash-flow of US$ 63,317.31, with ROI of 19% and NPV of US$ 775,159.40 in the same year.

Keywords: Aeration, Off-Grid, Photovoltaics, Queen Honey Bee Migration, Scenario, Shrimp Pond

1 Introduction

Indonesia is one of the countries with the largest shrimp export potential in the world. Based on data from the Ministry of Maritime Affairs and Fisheries, in 2022 shrimp production reached 250 million tons with a commodity value of US$ 2.2 billion [1]. The high rate of shrimp production is also followed by the high operational costs of ponds, including the provision of electricity used for pond operations such as aerators [2]. The high operational cost of ponds is inseparable from aeration activities carried out for 24 h which not only increases production costs but is also related to carbon emissions [3]. Regarding technology, shrimp pond production in Indonesia still lags behind other countries. One of the many problems faced in shrimp farming is the increase in electricity prices every year [4]. Of the total aquaculture production, electricity accounts for 15% of operational costs, the third largest after feed and seed costs [5]. Indonesia's dependence on fossil energy sources to generate electricity [6]. Fossil-derived energy sources contribute to (Carbon Dioxide) CO_2 emissions that result in global warming [7]. In overcoming these problems, Indonesia, with its enormous renewable energy potential, offers alternative energy sources, such as solar energy, geothermal, ocean waves, wind, and bioenergy [8]. This condition is also supported by the average solar radiation potential in Indonesia of 4.8 kWh/m^2 [9]. The large potential of solar radiation in Indonesia makes the application of photovoltaic (PV) systems the right solution [10]. In addition, PV systems can help reduce dependence on fossil fuels [11]. To address these challenges, this study proposes an on-grid PV system as an alternative energy source for shrimp pond aeration, focusing on determining the optimal technical capacity of system components. In addition, the (Queen Honey Bee Migration) QHBM algorithm is used with the Python language extension to optimize the minimum value (Net Present Cost) NPC, maximum (Renewable Fraction) RF, and maximum (Carbon Emission) ECO_2. Then the results of the minimum NPC, maximum RF, and maximum ECO_2 will be compared to the QHBM algorithm with (Grey Wolf Optimization) GWO. From an economic perspective, several parameters are used to determine investment feasibility, including Break Event Point (BEP), Cost of Energy (COE), Net Present Value (NPV), Return on Investment (ROI), RF, and payback period (PP).

Previous studies have extensively investigated the techno-economic aspects of solar power plants across diverse geographical locations. A comprehensive analysis [12] of a 50 MW solar power plant at the UENR Nsoatre campus utilized PVsyst software to evaluate three distinct PV technologies, revealing that all technologies demonstrated Cost of Energy (COE) below tariff rates and positive Net Present Value (NPV). Further research [13] on grid-connected solar power installations at a Turkish college employed multiple software tools, resulting in an energy generation of 762 MWh and favorable economic indicators, including a 19.55% Internal Rate of Return (IRR) and an NPV of US$346,085. In Ghana, a study [14] focused on rooftop solar PV systems for educational institutions, employing Google Earth for surface area estimation, which yielded promising economic outcomes (NPV of GHS 15.15 million and IRR of 21%). Additionally, a comprehensive investigation [15] in Turkey utilized HOMER Pro software to design and optimize a hybrid system, comparing various energy penetration ratings and sales limits. This study used advanced algorithms (FHO, GWO, PSO) for optimization, with FHO showing the best computational efficiency. The Turkish study's optimal configuration achieved an NPC of US$52.3 million- and 954-kW PV capacity at full hybrid penetration. These studies collectively demonstrate solar power's economic and technical viability across diverse scales and locations. These studies demonstrate the promising economic potential for solar projects in various locations, with the use of a variety of simulation and optimization tools to design efficient systems.

This study focuses on optimizing on-grid solar power systems for shrimp farms, a key sector of the Indonesian economy. The use of the QHBM algorithm to optimize NPC, RF, and ECO_2 is an innovative approach in this context. This research also compares the performance of the QHBM algorithm with the GWO, providing new insights into the relative effectiveness of the two algorithms in solar power system optimization.

The main novelty of this study lies in the application of the QHBM algorithm for on-grid solar power system optimization in shrimp farms, which has never been done before. The study also combines technical, economic, and environmental analysis in one comprehensive assessment, providing a holistic understanding of the feasibility and sustainability of the system. The use of three different scenarios to evaluate the performance of the system under various operational conditions enhances the robustness of the study results.

A thorough techno-economic analysis, including BEP, COE, NPV, ROI, and PP, provides a complete picture of the financial aspects of the project. The focus on reducing dependence on fossil fuels and lowering electricity operating costs in shrimp farms is an important contribution to the sustainability of the aquaculture industry in Indonesia. Overall, this research makes a significant contribution to optimizing the use of renewable energy in the aquaculture sector, with broad potential applications across a range of other industries and businesses in Indonesia.

This research is expected to provide specific insights for shrimp farmers. Furthermore, it can provide an overview for other industries and businesses to implement renewable energy to reduce dependence on fossil fuels and lower the high electricity operating costs of shrimp farms.

2 Materials and Method

Solar irradiation refers to the total amount of solar energy received by a given surface area over a specified period, typically measured in kilowatt-hours per square meter (kWh/m²) [16]. Understanding solar irradiation is crucial for determining the potential energy production of photovoltaic (PV) systems. Figure 1 provides a comprehensive overview of the research methodology employed in optimizing PV systems for shrimp pond aeration. The process begins with collecting solar irradiation and operational data and applying algorithmic optimization techniques to enhance the system's performance. The final phase involves an investment feasibility assessment to ensure the proposed solution's economic viability, considering factors such as system efficiency, cost of implementation, and long-term financial benefits.

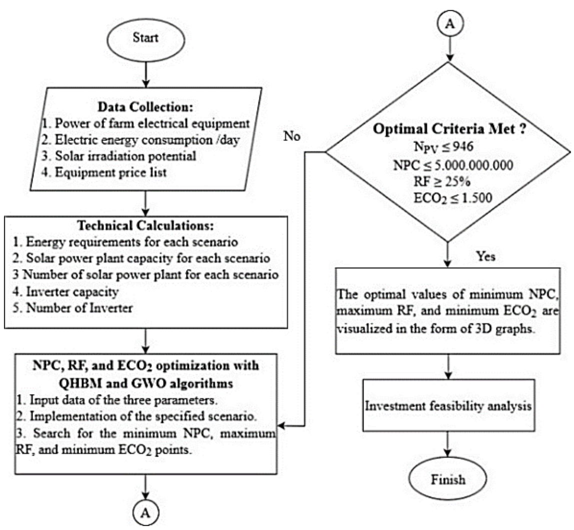

Figure 1: Flowchart of workflow on shrimp pond aeration.

Figure 1 presents the research flow to optimize solar power systems in the agricultural sector. The process begins with data collection related to energy needs and equipment specifications. This is followed by technical calculations and optimization using the QHBM and GWO algorithms to achieve the optimal values of NPC, RF, and ECO_2. The optimization results are then evaluated based on the investment criteria set, and if they are met, an investment feasibility analysis is carried out. Factors that affect the amount of irradiation received include the duration of irradiation, the relief of the earth's surface, the angle of sunlight, and the clarity of the atmosphere [17].

2.1 *Technical Assessment*

To estimate the capacity of the proposed solar power plant, an energy demand calculation is first carried out, taking into account the tolerance of the electrical energy load of 15% – 25% greater than the results of the calculation of energy requirements at the beginning [18]. The Equation (1) used is as follows:

$$W_{supply} = W_{demand} + SF \times W_{demand} \tag{1}$$

with W_{supply}, W_{demand}, SF is energy to be supplied, energy demanded, and tolerance safety factor.

When the calculation of energy demand is known as a whole, the next step is to calculate the peak power generated from the PV. In calculating peak power, there are power losses in the system of the PV itself, with the % of losses ranging from 15% – 25% [19]. The following is Equation (2) to determine the energy demand:

$$P_{spp} = \frac{W_{supply}}{PSH} + (\text{losses} \times \frac{W_{supply}}{PSH}) \tag{2}$$

with P_{spp}, W_{supply}, PSH, losses are power in solar panel, energy to be supplied, peak sun hour, and the number of losses in electrical devices. The losses used in this study were 20% [20].

To find out the number of solar power plants that match the needs, Equation (3) is used as follows:

$$N_{pv} = \frac{P_{spp}\ \text{designed}}{P\ \text{single spp}} \tag{3}$$

with N_{pv}, P_{spp} designed, P single spp is a number of PV's used, total overall power at the solar panel, and power at one solar panel.

In determining the capacity of the inverter, it is assumed that the load value is 25% – 30% greater than the PV watt peak, taking into account the efficiency of the inverter and also the load spikes that can occur at any time [21]. Equation (4) used is as follows:

$$P_{inv} = (P_d \times \eta_{inv}) + (P_d \times tol \times \eta_{inv}) \quad (4)$$

with P_{inv}, P_d, η_{inv}, tol is overall power at the inverter, demand power, inverter efficiency, and safety factor tolerance.

RF is an indicator of how much energy produced by renewable energy sources can supply the load which is characterized by a % value of RF up to 100% [22]. The mathematical calculation to calculate RF can be done using Equation (5), the details of which are as follows:

$$RF = \left(1 - \frac{\sum W_{gen} + \left(\sum P_{pln} \times T_{pln}\right)}{\sum W_{gen} + \left(\sum P_{pln} \times T_{pln}\right) + \sum W_{pv}} \times 100\%\right) \quad (5)$$

with W_{gen}, P_{pln}, T_{pln}, W_{pv} is energy from generator, grid power installed at the study site, duration of grid usage, and energy from PV. The on-grid solar power system is a configuration between solar panels that are directly connected to the on-grid inverter and the PLN power grid [23]. The use of batteries in off-grid systems that can increase maintenance and installation costs is a consideration for choosing an on-grid system [24].

Aeration in shrimp ponds can be inspired as a process of adding oxygen to the water in order to meet the oxygen demand in shrimp ponds with the help of equipment known as aerators [25]. Paddlewheel aerators are widely used in shrimp farming. This preference is due to the paddlewheel aerator's superior aeration mechanism and driving force [26]. In addition, the use of paddle wheel aerators can maintain water circulation in ponds [27]. The adequacy of dissolved oxygen sources greatly affects the success of shrimp ponds in supporting the production process [28]. Therefore, good shrimp farm management is closely related to good water quality [29].

2.2 *Economic evaluation*

BEP could be defined as where an industry or business implementer does not experience profit nor does it experience loss [30]. Equation (6) used to determine BEP is as follows:

$$BEP = \left(\frac{FC}{R - VC}\right) \quad (6)$$

with BEP, FC, R, VC is between the amount of investment and revenue, costs that do not depend on operational aspects, total income in a certain period of time, and costs that depend on operational aspects.

COE can be interpreted as the average cost calculated by Equation (10) with the CRF variable obtained by Equation (7), NPC in Equation (8), and the IC variable in NPC in Equation (9) that users have to pay per unit kWh. [31]. The purpose of this parameter is to compare the cost per kWh through cost analysis such as initial investment costs, operational costs, and component replacement costs [32]. In calculating COE, the formula used is as follows [33]:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (7)$$

$$NPC = IC + O\&M + RC \quad (8)$$

$$IC = (C_{pv} \times N_{pv}) + (C_{inv} \times N_{inv}) + AC \quad (9)$$

$$COE = \frac{NPC \times CRF}{\sum_{d=1}^{365} W_{annual}} \quad (10)$$

with CRF, i, n, NPC, C_{pv}, N_{pv}, C_{inv}, N_{inv}, AC, W_{annual} is the annual amount needed to recover the initial capital investment over the project's lifespan, interest rate, project life period (20–25 years), the cost that covers the overall initial investment, operation and maintenance costs, component/equipment replacement costs, cost of PV, number of PV used, cost of inverter, number of inverter, additional cost, the amount of energy consumption per day in one year.

NPV is defined as the difference between incoming and outgoing cash flows over a given period [34]. If the NPV is positive, then the investment is financially feasible, while if it is negative, it is not financially feasible [35]. Equation (11) for calculating NPV is given below:

$$\sum_{t=1}^{T} \frac{Ct}{(1+r)^t} - C_O \quad (11)$$

with Ct, t=1, r, t, C_o is cash flow in period t (positive inflow, negative outflow), cash flow period in time up to T, interest rate used, time period under analysis, and initial cost of investment at period t = 0.

ROI can be inspired as a measure in evaluating the level of efficiency of an investment which consists of how much effectiveness and profit can be achieved from the investment [36]. Equation (12) can be seen below:

$$ROI = \frac{NP}{C} \text{ x } 100\% \quad (12)$$

with NP, C is the net profit earned in an investment, and the initial cost to start the investment.

PP is an indicator of how long the period of time required in an investment to be able to return the initial investment cost by considering the value of the currency [37].

2.3 *Environmental assessment*

Carbon emissions from fossil fuel use contribute to global warming. Transitioning to renewable energy is crucial to mitigate this. Equation (13) calculates the carbon emission reduction from PV usage [38].

$$ECO_2 = \frac{PV_{wp} \text{ x } PV_{num} \text{ x } PV_D}{1000} \text{ x FE} \quad (13)$$

With PV_{wp}, PV_{num}, PV_D, FE is peak PV watts, number of PV used, length of PV use, and emission factor.

2.4 *Calculation of the operation and maintenance (O&M) cost of solar panels*

Once each cost component is identified, a comprehensive calculation of the operation and maintenance costs of the solar panel system is required. This calculation is critical to understanding the annual investment needed and ensuring the system operates optimally without reducing long-term profitability. Calculating the Annual Cost and Cost per kWh can be seen in Equations (14) and (15).

2.4.1 Annual Cost:

Total Cost = (Cleaning Cost + Inspection Cost + Component Replacement Cost + Insurance Cost + Monitoring Cost + Labor Cost) per year. (14)

2.4.2 Cost Per kWh:

$$\text{Rp/kWh} = \frac{\text{Total Annual Cost}}{\text{Total Energy Production (kWh) per year}} \quad (15)$$

Once each cost component has been identified, a comprehensive calculation of the operation and maintenance costs of the solar panel system is required [39]. This calculation is essential to understand the annual investment needed and ensure that the system continues to operate optimally without reducing long-term profitability [40].

2.5 *QHBM algorithm*

QHBM is an algorithm that adopts the migration process of the queen and scout bees [41]. The queen's journey will be guided by scout bees as illustrated in Figure 2.

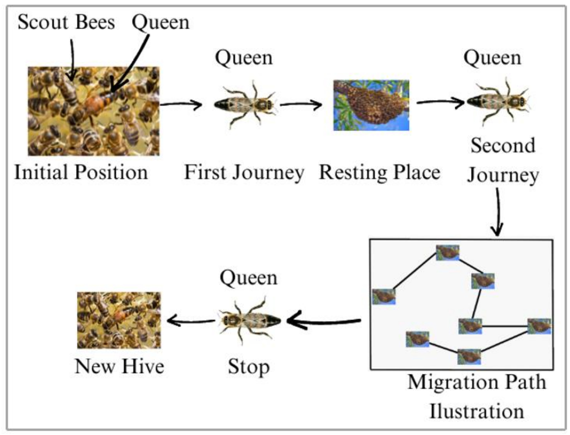

Figure 2: Migration process of queen and scout bees.

The QHBM algorithm begins with initialization, where scout bees are distributed across 8 sectors based on cardinal directions [42]. After being spread into 8 sectors, scout bees perform an excitement dance to signal the queen, who selects the sector with the highest excitement value based on her instincts, acting as the decision maker [43]. Furthermore, to calculate the excitement value of scout bees (C_j) and the probability value of each sector (P_k) [44], Equation (17) with variables using the following Equation (16) can be used:

$$C_j = \frac{1}{n} \sum_{j=1}^{n} e_{r(ij)} \quad (16)$$

$$P_k = \frac{C_j}{\sum_{i=1}^{8} C_j} \quad (17)$$

with n, j, k, $e_{r(ij)}$ is the count of scout bees, the identity of scout bees, sector designations, and the remaining energy for each scout bee.

When all the previous processes have been passed, the next process is the journey. This process is a moment when the queen has decided where to migrate. While migrating, the queen will rest and then continue her journey to a new place according to the decision that has been made. This process will repeat until it finds a suitable place to build a new nest and migration will stop, or in other words, an optimum point is reached. The system scheme is shown in Figure 3, which consists of several components directly connected to the PLN grid.

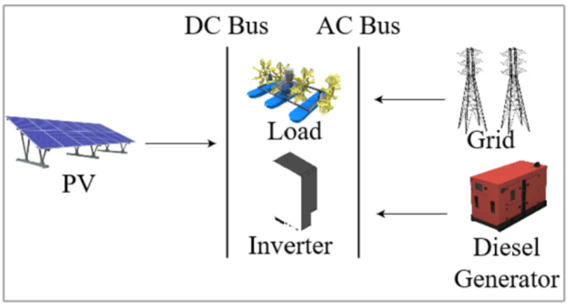

Figure 3: System description.

This study explores energy supply scenarios for a system with solar panels, inverters, paddlewheel aerators, and generators, varying by energy source duration and PV watt-peak. Scenario 1 (sunny): PV supplies 5 h, generator 1 h, and grid 18 h. Scenario 2 (cloudy): PV supplies 3 h, generator 2 h, and grid 19 h. Scenario 3 (cloudy): PV supplies 4 h, generator 1 h, and grid 19 h. The study uses Visual Studio Code with Python to optimize NPC, RF, and ECO_2. The shrimp farm's 4-month-old condition requires the paddlewheel aerator to run continuously for 24 h, with the energy supply distributed as detailed in the energy consumption profile.

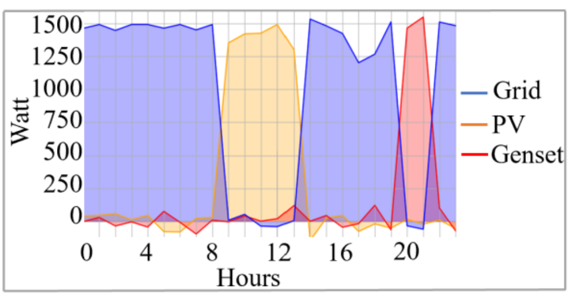

Figure 4: Energy consumption profile.

Figure 4 illustrates the energy consumption profile at the research site, featuring a 2Hp/1491.4W paddlewheel aerator. The energy supply is distributed among three sources: the PLN grid, PV, and generators, represented through different scenarios.

This research utilizes solar power plants, inverters, and MCBs. The specifications of these components are detailed in Table 1.

Table 1: Components specification.

Components	Parameters	Specification		
PV	Watt Peak	655Wp	500Wp	400Wp
	Pmax	655W	500W	400W
	Voc	45.2V	51.5V	37.07V
	Isc	18.43A	12.13A	13.79A
	Vmp	38.1V	43.4V	31.01V
	Imp	17.20A	11.53A	12.9A
	η	21.1%	20.7%	20%
	Price	US$ 331.71	US$ 231.19	US$ 123.40
	Data Source	[45]	[46]	[47]
Inverter	Pin	50,000W		
	Power Factor	0.8		
	η	97.6%		
	Price	US$ 3,658.47		
	Data Source	[48]		
MCB	Rated Current	20A		
	Price	US$ 6.88		
	Data Source	[49]		

2.6 *Objective function*

The primary objective of the optimization function in this comprehensive study is to determine the most advantageous number of solar power plants that can be effectively implemented. This optimization process considers two critical factors: firstly, it aims to identify the solution with the lowest possible investment cost, ensuring economic viability; secondly, it seeks to maximize the percentage of renewable energy in the overall energy mix. By achieving these dual goals, the study strives to significantly reduce carbon emissions typically generated by conventional fossil energy sources. This research repurposes unused space in shrimp ponds for sustainable energy production, addressing clean energy needs while providing shrimp farmers with an additional revenue stream to boost their economic prospects.

Figure 5 in the research paper offers a detailed illustration of the specific research location to provide a clear visual representation of the land available for this ambitious project. This figure showcases the layout and dimensions of the shrimp ponds, giving readers a concrete understanding of the potential scale and impact of the proposed solar power implementation. The visual aid serves to underscore the practical feasibility of the project. It helps stakeholders envision the transformation of these aquaculture sites into dual-purpose facilities that contribute to food production and renewable energy generation.

Figure 5: Research location of solar shrimp farms.

To obtain the optimal planning of shrimp farm solar power based on the parameters of renewable energy ratio, investment cost, and carbon emissions, the planning of shrimp farm solar power must meet three criteria: minimum NPC, maximum RF, and maximum ECO_2. These three criteria form a comprehensive approach to solar integration in shrimp farms. Minimum NPC ensures economic viability, maximum RF encourages the use of clean energy, and maximum ECO_2 demonstrates a commitment to climate change mitigation. This simultaneous optimization aims to create an economically and environmentally balanced solution that contributes to developing renewable energy. Mathematically, the planning of shrimp farm solar power plant has an objective function in Equation (18) as follows:

$$F(x) = W1 \times \left(1 - \frac{\sum W_{gen} + \left(\sum P_{pln} \times T_{pln}\right)}{\sum W_{gen} + \left(\sum P_{pln} \times T_{pln}\right) + \sum W_{pv}} \times 100\%\right) - W2 \times (IC + O\&M + RC) + W3 \times \frac{PV_{wp} \times PV\ Numb \times PV_D}{1000} \times FE \tag{18}$$

with W1, W2, W3, W_{gen}, P_{pln}, T_{pln}, W_{pv}, IC, O&M, RC, PV_{wp}, PV Numb, PV_D, FE are the weights of each function that have a value of 1, energy from generators, PLN electric power installed at the research location, duration of grid use, energy from PV, costs required to start the investment, operational and maintenance costs, equipment replacement costs, PV Watt Peaks, number of PV used, length of PV use, and emission factor. Equation (19) is subject to several variables:

$$\text{Subject to} = \begin{Bmatrix} \text{Npv} \leq 946 \\ \text{NPC} \leq 5{,}000{,}000{,}000 \\ \text{RF} \geq 25\% \\ \text{ECO}_2 \leq 1{,}500 \end{Bmatrix} \tag{19}$$

2.7 *Research data*

The data used in this research includes primary and secondary sources, detailed in Table 2 and Table 3.

Table 2: Type of data and description.

Type of Data	Data	Description
Primary Data	Power of shrimp pond electrical equipment	Description of the power available to the farm equipment at the study site.
	Electric energy consumption in one day (Wh/day)	Total electricity use or consumption per day with the usage pattern.
	Solar irradiation (kWh/m^2)	Solar intensity at the research site obtained from PVsyst V7.3.1 with source data from Metronome 8.1
Secondary Data	Equipment price	List of equipment prices that can be found on e-commerce websites such as Tokopedia.

Table 3: Research variables and description.

Research Variables	Description
Number of PV module (N_{pv})	Number of PV modules used with adjustment to the amount of load.
Number of inverters (N_{inv})	The number of inverters used with adjustment to the amount of load.
PV module price (C_{pv})	Price per unit of each PV module.
Inverter price (C_{inv})	Price per unit of each inverter.

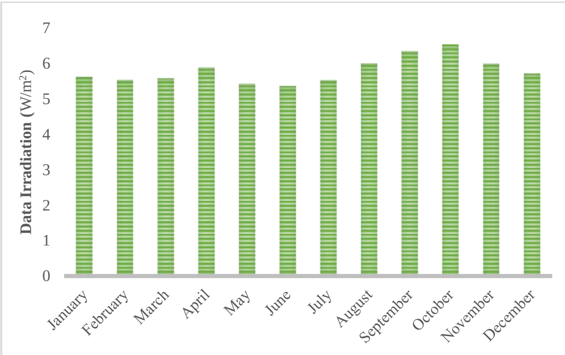

Figure 6: Solar irradiation data of Jabungsisir village, Probolinggo, Jawa Timur.

Considering factors like energy demand, system efficiency, and cost, designing an optimally sized PV system is essential. Achieving the ideal sizing requires a thorough analysis to ensure the system operates efficiently while remaining economically viable over the long term. This careful approach maximizes energy output and ensures cost-effectiveness and sustainability, contributing to the broader goal of reducing reliance on non-renewable energy sources.

3 Result and Discussion

The location of shrimp ponds in this study is in Jabungsisir Village, Paiton, Probolinggo Regency, Jawa Timur with coordinates –7.718022, 113.469735. The shrimp pond consists of 3 pond blocks, namely block E, block D, and block C. Block E comprises 4 ponds, each ranging in area from 2,500 m^2 to 3,000 m^2. Block D comprises 4 ponds spanning an area from 3,600 m^2 – 7,300 m^2. Block C consists of 4 ponds that range in size from 3,100 m^2 – 5,300 m^2.

At the research site, 196 paddlewheel aerators were in operation. The average solar irradiation in Jabungsisir village was recorded at 5.79 kWh/m^2, with the peak sun hours typically occurring between 09:00 and 14:00 WIT. This period represents the time of day when the solar energy potential is at its highest. Figure 6, generated using the PVsyst V7.3.1 software, illustrates these findings in greater detail.

To find out the capacity of the inverter needed to supply the electricity needs of shrimp ponds, the following values are obtained:

P_{demand} = 293W and P_{inv} = 371,758W

Where in obtaining P_{demand} and P_{inv}, the inverter efficiency is used according to the datasheet of 97.6% and considering a safety tolerance of 30%, so that P_{demand} and P_{inv} are obtained as listed. Once known inverter power requirements at the research site, then the next is to determine how many inverters. For the inverter power used, according to Table 1 using a 50,000W with N_{inv} is 8 inverters.

In accordance with the results of the survey of the research site, data collection on energy needs of shrimp ponds per day was carried out with the aim of knowing the planning capacity that would be needed through 3 scenarios. For Scenarios 1, 2, and 3 using a 1491.4 W pump power of 196 pieces and considering a safety factor of 25%, the following is the resulting W_{demand} and W_{supply}.

3.1 *Technical assessment*

Table 4 differentiates the energy demand in each scenario based on the PV, grid, and genset supply duration. Scenario 1 has the highest energy demand with 5 hours of PV supply, 1 hour of genset, and the rest from the grid. Scenario 2 has the lowest requirement with 3 h of PV and 2 h of genset. After determining the energy demand, the next step is to assess the capacity of the solar power plant, taking into account the average solar irradiation of 5.79 kWh/m^2 and the peak solar hours from 09.00–14.00 WIT as in Table 5.

Table 4: Energy needs of each scenario.

Scenario	Component	Quantity (Pcs)	Duration (Hours)	Power (W)	Total Power (W)	Total Energy (Wh)	Amount of Energy SF 25% (Wh)
1	Paddlewheel pump	196	5	1,491.4	292,315	1,461,572	1,826,965
2	Paddlewheel pump	196	3	1,491.4	292,315	876,945	1,096,181
3	Paddlewheel pump	196	4	1,491.4	292,315	1,169,260	1,461,575

Table 5: Solar power plant capacity for each scenario.

Scenario	W_{supply} (Wh)	PSH	Losses	Pspp (Wh)
1	1,826,965	5.79	20%	378,645
2	1,096,181	5.79	20%	227,187
3	1,461,575	5.79	20%	302,917

Concerning the numbers of solar power plants, employing three scenario types with different PV variations, including 655Wp, 500Wp, and 400Wp, the resulting number of solar power plants is listed in Table 6.

Table 6: Numbers of solar power plants for each scenario.

Scenario	Pspp (Wh)	Number of Solar Power Plant		
		655Wp	500Wp	400Wp
1	378,645	578	757	946
2	227,187	347	454	568
3	302,917	462	605	757

For a single 655 Wp PV, an area of 3.11 m^2 is required, while the number needed is 578, requiring an area of about 1797.58 m^2. And for the available area, it is 3 hectares. So, for this planning, it has met the area requirements according to the specifications of the PV.

Based on the technical calculations, the resulting Cost of Energy (COE) for each PV watt-peak level is summarized in Table 7. This table offers an overview of COE values across different PV capacities, enabling an analysis of the impact on economic efficiency. The data provided are crucial to understanding the relationship between PV capacity and system cost-effectiveness.

Table 7: COE for each scenario.

Scenario	Value	COE		
		655Wp	500Wp	400Wp
1	US$	38.13	36.19	28.54
2	US$	43.77	41.82	34.18
3	US$	40.24	38.30	30.66

The study [50] showed that large-capacity PV systems (28.4 kW) resulted in a lower COE of 0.468 $/kWh due to the benefits of economies of scale and efficient energy storage integration. In contrast, small-capacity systems (400Wp to 655Wp) have a higher COE, ranging from 28.54 to 43.77 US$, which may indicate a higher energy cost per kWh. Large systems are more economical and support significant emission reductions, while small ones are less efficient in energy cost optimization.

3.2 *Economic evaluation*

The comprehensive economic parameters offer a detailed summary of financial metrics, facilitating thorough comparison and interpretation and ensuring that all relevant data is accessible for a solid evaluation and discussion of the findings. The results of the economic parameter calculations show that the project has good prospects, with BEP reached in 4.2 years, PP for five years, ROI of 19%, and NPV of US$ 774,634.65, indicating a positive profit and a relatively quick time to break even and return on investment. A study [51] about on-grid PV scenario 6 has a much lower NPV of US$24,402.50, reflecting a low rate of return due to its smaller scale and less aggressive cash flow assumptions, making this study much more financially favorable, although both are viable investments.

3.3 *Optimization results*

The following detailed optimization process involves the values of NPC (Net Present Cost), RF (Renewable Fraction), and ECO_2 (Equivalent CO_2 Emissions). These values are represented in a comprehensive 3D visualization, encompassing six distinct trial scenarios, each designed to explore different potential outcomes and configurations. This 3D representation provides an in-depth view of how the various parameters interact across the other trials, offering valuable insights into the optimization process.

Figure 7 shows the optimization results through the use of 2 compared algorithms, namely QHBM and GWO. Each algorithm has 3 types of scenarios. The QHBM algorithm is shown in the first 3 figures of the top row. The GWO algorithm is shown in the second 3 images of the bottom row. Whether it is the QHBM or GWO algorithm, the acquisition of the best optimization value is indicated by an asterisk. In the process of finding the best optimization value, it is repeated 5 times so that the average results are represented in the following Table 8.

Based on the acquisition of the best values of NPC, RF, and ECO_2 of the QHBM and GWO algorithms above, the best scenario taken must fulfill the objective function previously set, namely min NPC, max RF, and max ECO_2. In this case, the values per scenario will be compared. Scenario 1 QHBM shows a lower NPC value than the NPC value of scenario 1 GWO algorithm. Then the RF and ECO_2 parameters show the same value as the QHBM algorithm. Scenario 2 QHBM shows a lower NPC value compared to the GWO scenario 2 NPC value. Then for the RF parameter, the QHBM algorithm is superior in obtaining the highest RF value. While the ECO_2 parameter, the QHBM algorithm is still also superior. Scenario 3, shows QHBM is lower in obtaining the NPC value. For RF parameters, also QHBM is still superior to GWO. For the ECO_2 value, QHBM also obtained a higher value compared to the GWO algorithm. For the number of PV's used, both the QHBM and GWO algorithms, both methods obtain the most optimal number of PV's is 578pcs. The ECO_2 values in this study represent the cumulative carbon emissions savings, rather than the carbon footprint, and thus a higher ECO_2 value is indicative of a greater environmental benefit, as it corresponds to a larger reduction in greenhouse gas emissions, thereby justifying the conclusion that the PV system with an ECO_2 value of 1484 $KgCO_2e$ is the most environmentally friendly option. If we look at the determination of the objective function, then scenario 1 of the QHBM algorithm is the best scenario.

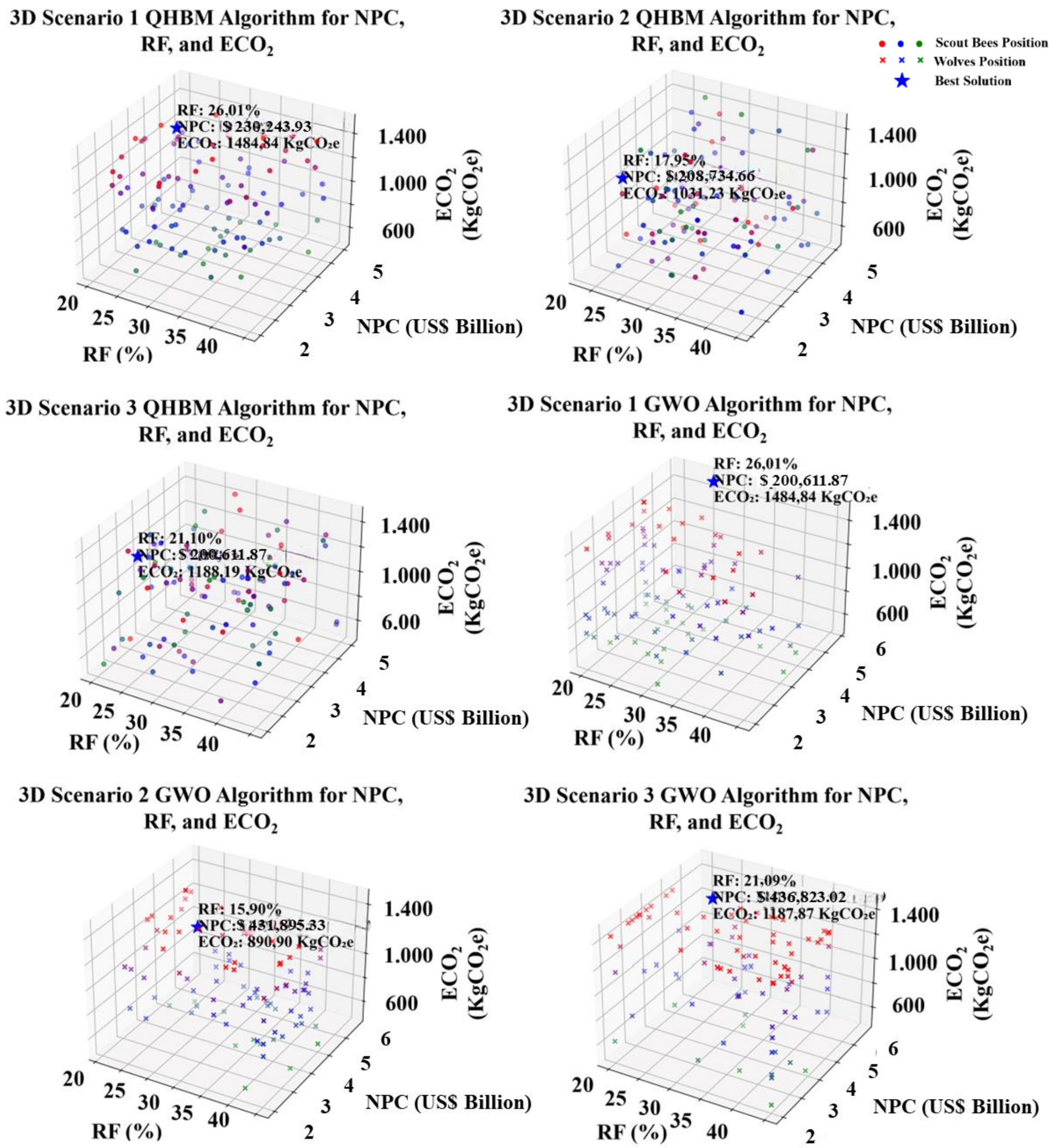

Figure 7: 3D graphics optimization for QHBM and GWO.

Table 8: Best results of NPC, RF, ECO2 QHBM and GWO algorithms.

Scenario	Algorithm	NPC Value (US$)	RF Value	ECO_2 Value	Npv
1	QHBM	230,243.93	26.01%	1,484 $kgCO_2e$	578Pcs
	GWO	440,191.82	26.01%	1,484 $kgCO_2e$	578Pcs
2	QHBM	208,734.66	17.95%	1,031 $kgCO_2e$	578Pcs
	GWO	431,895.33	15.90%	890 $kgCO_2e$	578Pcs
3	QHBM	200,611.87	21.10%	1,188 $kgCO_2e$	578Pcs
	GWO	436,823.02	21.09%	1,187 $kgCO_2e$	578Pcs

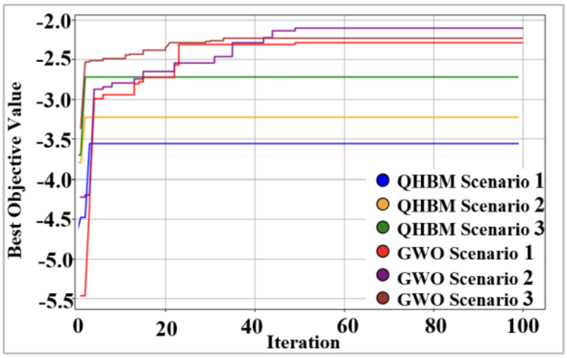

Figure 8: Convergence results of QHBM and GWO algorithm.

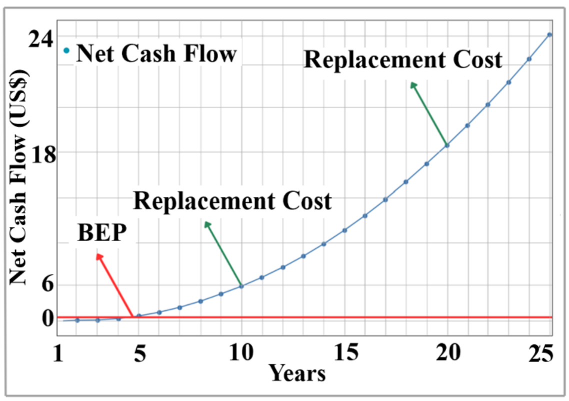

Figure 9: Economic analysis of net cash flow.

3.4 *Convergence results*

Figure 8 presents the speed gain of each algorithm in reaching the convergence point through optimizing the NPC, RF, and ECO_2 parameters. In the resulting graph, there are 3 types of convergence scenarios for each algorithm. For GWO algorithm scenario 1, the convergence point is obtained at the 50th iteration time. Then GWO scenario 2 converges at the same iteration, which is at the 50th iteration time. As for GWO scenario 3, the convergent point is obtained at the 35th iteration.

In scenario 1 QHBM, the convergent point is obtained at the 6th iteration. Scenario 2 QHBM convergent point is obtained at the 4th iteration. And for scenario 3 QHBM the convergent point is obtained at the 3rd iteration, it can be seen in terms of speed, the QHBM algorithm is superior in finding convergent points compared to the GWO algorithm.

In analyzing an investment project, it is necessary to analyze the economic side of the investment. In this study, the value of BEP is obtained for 4.2 years, as shown in Figure 8. The BEP of 4.2 years was calculated by dividing the initial investment costs by the annual cash flow, which was determined by subtracting the total annual expenses from the total annual revenue. The total annual expenses comprised the costs of feed, seeds, chlorine, and labor, which were accounted for in the financial analysis.

The Break-Even Point (BEP) is identified at 4.2 years, with the Payback Period (PP) extending to year 5 (Figure 9). To determine the exact PP in year 5, the Return on Investment (ROI) formula is applied, yielding a 19% ROI based on a cash flow of US$ 63,258.01. Compared to the ROI of the study [52] PV/DG/Battery system configuration (9.40%). This means that the investment calculated by the ROI formula yields a greater return than the PV/DG/Battery system configuration tested in that study. In the study [53], the PP is the period required to recover the difference in investment cost between the system under consideration and the reference system. In this study, the PP for the PV/Battery configuration is about 9 years. Research [40], with a 3-year PP, is more efficient in terms of investment recovery compared to a 5-year PP. However, the longer payback periods of the other projects could be due to factors such as larger scale, higher initial investment, or more conservative financial planning. According to the inverter datasheet, component replacements or maintenance are scheduled every ten years, specifically in years 10 and 20, as part of the system's long-term operational plan. This maintenance ensures the system's continued efficiency and reliability throughout its lifespan.

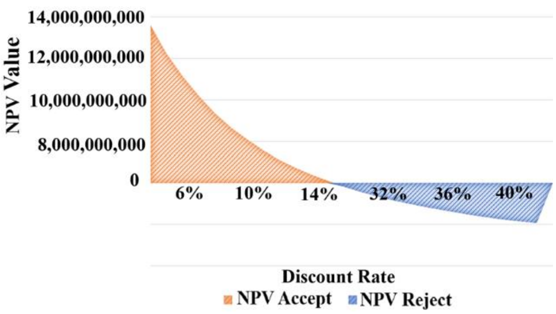

Figure 10: NPV value (INR) and discount rate.

Figure 10 presents the NPV graph, starting from the cash flow in the 1st year until the cash flow in 25th year, using a discount rate or Bank Indonesia interest rate in 2024 of 6% [54], the NPV value of US$ 774,433.49. Therefore, a positive NPV value is crucial to assess the investment feasibility [35].

4 Conclusions

Based on the explanation of the research results above, from a technical point of view, a lower electricity tariff is obtained compared to the grid, which is US$ 38.14. The optimization results on the NPC, RF, and ECO_2 parameters show that scenario 1 of the QHBM algorithm is the best. This condition is evidenced by the acquisition of 3 parameters that are closest to the determination of the objective function, namely NPC of US$ 230,263.27, RF of 26.01%, ECO_2 of 1,484KgCO_2e, with 655Wp solar power plant specifications, and the number of solar power plant as many as 578pcs. Economically, the investment in a solar power plant for the shrimp pond obtained BEP in 4.2 years with a PP obtained in year 5, with the acquisition of net cash flow of US$ 63,282.39 and an ROI value of 19%, with an NPV value of US$ 774,731.87 in the same year.

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Author Contributions

A.: conceptualization, methodology, supervision; A.W.S.A.: data collection, simulation, analysis; M.C.B.: translation, analysis; S.O.: English editing, methodology; G.-J.H.: analysis, supervision. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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