Jurnal Inovasi Teknologi dan Edukasi Teknik, 4(10), 2024

ECONOMIC, ENVIRONMENTAL AND SOCIAL OPTIMIZATION OF PHOTOVOLTAIC IMPLEMENTATION IN COFFEE SHOP BUSINESSES, MALANG CITY

Febby Ayu Oktiviania, Aripriharta

Universitas Negeri Malang, Jl. Semarang No.5, Sumbersari, Malang 65145 Indonesia
*Corresponding author, email: aripriharta.ft@um.ac.id

doi: 10.17977/um068.v4.i10.2024.3

Keywords
Carbon Emissions
COE
Optimization
PV Hybrid
QHBM

Abstract
This research aims to optimize a hybrid photovoltaic (PV) energy system for a coffee shop business in Malang City by incorporating economic, environmental, and social dimensions. The optimization process employs the Queen Honeybee Migration (QHBM) algorithm, a multi-objective heuristic approach. Key performance indicators include Cost of Energy (COE), Carbon Emissions, Renewable Fraction (RF), and Community Acceptance, which is evaluated using the Technology Acceptance Model (TAM) through a structured questionnaire. The system is designed to meet a daily energy demand of 28.8 kWh, under an average solar irradiation of 3.86 kWh/m^2/day. Simulation and optimization were conducted using Python-based programming. The results demonstrate that the optimal configuration consists of 20 solar panels (550 Wp) and 10 battery units (200 Ah), achieving a COE of IDR 320.04/kWh and an RF of 99.87%. Compared to conventional grid electricity, the proposed system offers significant cost savings and emission reductions. Furthermore, the TAM-based survey yielded an average acceptance score of 3.72, indicating a favorable public perception toward the adoption of hybrid PV systems in small business contexts.

1. Introduction

1.1. Background

The global reliance on fossil fuels has caused a range of serious issues, including rising greenhouse gas emissions, significant climate change, and fluctuating energy prices driven by oil and gas market swings. In response, many nations are speeding up their shift toward cleaner, more sustainable energy systems. The growth of renewable energy sources like solar, wind, and bioenergy has become a key part of global energy plans to reduce environmental damage and improve long-term energy security (World Energy Transitions Outlook 2022: 1.5°C Pathway 2022).

In Indonesia, the government faces a major challenge in reducing fossil fuel consumption, which still dominates the national energy mix. Efforts are being made to expand and utilize New and Renewable Atlas, n.d.-a). Energy (Energi Baru Terbarukan/EBT) in the power sector, while simultaneously ensuring the security of national energy supply (Ahsan, 2021). The Indonesian government has set a renewable energy target of 23% by 2025, rising to 24.8% by 2030, as outlined in the Electricity Supply Business Plan (RUPTL) 2021–2030 (Ahmadi et al., 2023). Indonesia is one of the countries with the world’s largest renewable energy potential, estimated at 3,700 GW. This includes solar, hydro, wind, bioenergy, and geothermal resources (Indonesia’s Prabowo Plans to Retire All Fossil Fuel Plants in 15 Years, but Experts Are Skeptical, 2024). Located along the equator, Indonesia receives an average solar radiation intensity of approximately 4.8 kWh/m^2/day. According to Global Solar Atlas data, Malang City, characterized by daily solar irradiation of around 3.86 kWh/m^2 offers favorable conditions for photovoltaic (PV) system implementation (Global Solar Atlas, n.d.-a)

The abundant renewable energy potential in Indonesia is not only vital for the country's energy security but can also be utilized by small and medium-sized enterprises (SMEs), particularly within the Micro, Small, and Medium Enterprise sector. This sector offers a significant opportunity to implement renewable energy technologies, especially solar PV systems, to improve energy efficiency and promote sustainable business operations (The Sustainable Energy Fund (SEF) Grant Program for Rooftop Solar PV Exceeds the Installed Capacity Target - SMEs and Social Facilities Are the Largest Incentive Recipients, n.d.). UMKM play a strategic role in Indonesia's economy, contributing about 50% to the national GDP over the past five years. One rapidly expanding UMKM subsector is the coffee shop industry. According to the International Coffee Organization (ICO), Indonesia ranks third globally in coffee production, after Brazil and Vietnam. Additionally, the number of coffee shops in the country increased significantly from 1,000 outlets in 2016 to 2,950 outlets in 2019 (Aryani et al 2022).

Despite this growth, UMKM particularly small-scale coffee shops often face challenges in managing energy efficiently due to limited resources and high operating costs. These businesses generally operate with tight profit margins, making energy expenses a considerable burden. Common electrical appliances such as coffee machines, refrigerators, air conditioners, and lighting systems contribute to high electricity consumption, particularly during peak business hours. High electricity bills, coupled with fluctuating PLN tariffs, reduce the competitiveness of these businesses, especially those lacking capital to invest in energy-efficient technologies. Implementing PV systems in coffee shop businesses can offer an innovative solution to improve energy efficiency and operational sustainability. In cities like Malang, where the coffee shop industry is booming, PV system integration can also serve as a branding strategy to attract environmentally conscious customers (Candra Erawan et al., 2023).

Moreover, measuring the environmental impact of coffee shop operations is essential to understand their contribution to carbon emissions and energy consumption. PV system adoption can reduce reliance on fossil-based energy and thereby minimize carbon emissions (Konopatzki et al., 2023). While the initial investment for PV systems is relatively high, such systems offer long-term economic benefits through consistent energy cost savings (Irfani et al., 2021). In addition to environmental and economic aspects, the social implications of PV system adoption should be considered. The deployment of renewable energy technologies in coffee shops can promote energy literacy, strengthen community engagement, and encourage broader acceptance of renewable energy technologies. Community support plays a vital role in advancing the adoption of sustainable energy solutions within this sector (Schulte et al., 2022a).

1.2. Research Gap and Contribution

There have been many studies on the implementation of hybrid photovoltaic (PV) systems, primarily focusing on economic and environmental aspects. (Biswas et al., 2021) assessed the ecological footprint and economic viability of rooftop PV systems using Life Cycle Cost and LCOE approaches, while (Bošnjaković et al., 2023) investigated carbon emissions through a Life Cycle Assessment of PV modules. Conversely, the social perspective on evaluating PV systems still lacks quantitative attention. (Wassie and Adaramola, 2021) reviewed social aspects within rural electrification but did not incorporate them as measurable optimization variables. Additionally, most prior research, such as Christiaanse et al. (2021) and Xue et al. (2024), continue to depend on traditional optimization techniques, such as Genetic Algorithm (GA), RBFopt, or other econometric methods, without exploring natural behavior-inspired heuristic approaches, like Queen Honey Bee Migration (QHBM).

This research fills the gap by offering a multi-objective approach that not only considers economic aspects through the Cost of Energy (COE), but also environmental factors through the Renewable Fraction (RF) and carbon emissions. It also includes social aspects, quantitatively evaluated with the Technology Acceptance Model (TAM), in the form of Community Acceptance. This combination of methods highlights the novelty of using the QHBM algorithm as an optimization tool that mimics queen bee migration to determine the optimal configuration of hybrid PV systems. Additionally, the research's focus on the MSME sector, particularly coffee shop businesses in Malang City, enhances its practical value. Unlike previous studies that tend to focus on large-scale systems or households, this research offers new insights into the application of renewable energy in the small-business sector, which has received less scientific attention. Therefore, this work not only presents a new methodological approach but also broadens the scope of renewable energy deployment in urban microeconomic contexts in Indonesia.

2. METHODS

2.1. Research Description

This research develops a hybrid PV–battery–grid system to reduce the electricity costs for a coffee shop in Malang City. Currently, the location depends on PLN electricity, costing about Rp5,000,000–6,000,000 monthly. The system includes solar panels, batteries, inverters, and a connection to the PLN grid. During the day, solar panels provide the main energy source, while excess energy is stored in batteries for nighttime use or when PV output is low. If PV and batteries cannot supply the load, the system automatically draws power from the PLN grid. All energy flow is managed by a hybrid inverter that controls power conversion and distribution to all electrical equipment in the coffee shop. Figure 1 shows a diagram of the hybrid PV system to be installed, including PV modules, batteries, and the grid/PLN.

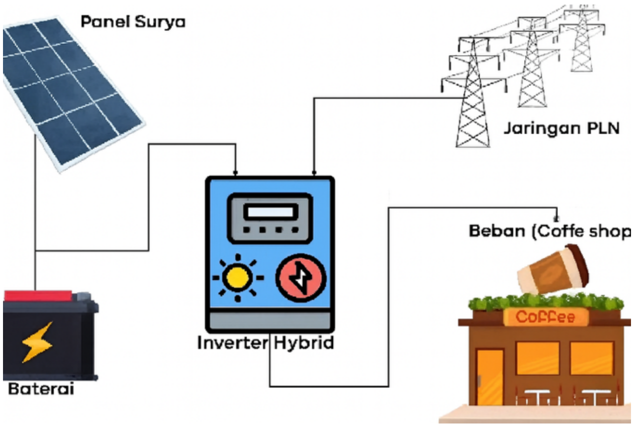


Figure 1. Hybrid Network System

The economic analysis in this research involves calculating the Cost of Energy (COE), which is derived from the Capital Recovery Factor (CRF) and the Net Present Cost (NPC). The environmental aspect is assessed by calculating the Renewable Fraction (RF), which shows the contribution of renewable energy to the total energy supply. For the social analysis, community acceptance of the hybrid PV system is evaluated using the Technology Acceptance Model (TAM). Data were collected through a questionnaire-based simulation, focusing on key TAM variables: Perceived Usefulness (PU), Perceived Ease of Use (PEU), Attitude Toward Using (ATU), and Behavioral Intention (BI). The research location is shown in Figure 2.

Figure 2. Research Location

2.2. Conditions of the Research Location

The average annual solar irradiation in Malang City is 3.86 kWh/m^2/day, with peak sun hours occurring between 10:00 am and 2:30 pm, totaling about 4.5 hours per day. Monthly irradiation data are shown in Figure 3 below, based on the Global Solar Atlas. (n.d.-b).

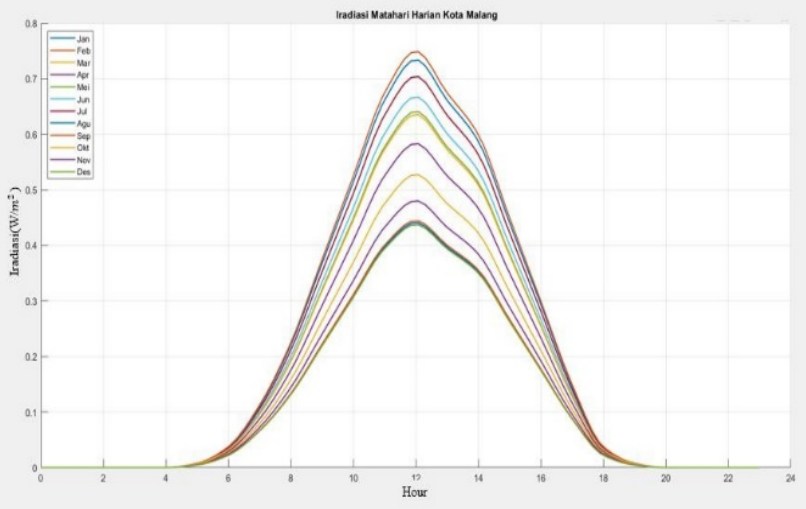


Figure 3. Daily Solar Irradiation of Malang City

The case study was conducted at Es Kopi Bos coffee shop located at Jl. Hamid Rusdi, Bunulrejo, Blimbing Sub-district, Malang City, with coordinates -7.9665° N and 112.6490° East. Based on observations, the total average existing electrical power reaches 28,797 kWh, with a daily energy consumption of 14,304 kWh. The coffee shop relies entirely on PLN electricity, with monthly bills ranging from Rp3,000,000 to Rp6,000,000. The power demand data and daily load profile from the survey results are used as the basis in determining the capacity of the system components to be designed. Table 1 presents details of the power requirements of each electrical equipment in standby condition.

Table 1. Coffee Shop Electrical Equipment Data

Electrical Equipment	Power Consumption (Watt)	Quantity (pieces)
Lights	5	60
AC	1600	2
CCTV	12	16
Computer	12	1
Fan	30	4
Sound	1000	1
Refrigerator	125	5
Freezer	300	2
Coffee Machine	2000	1
Coffee Greender	900	3
Roastery Coffee	330	1
Shocker	1000	1
Sealer	300	1

2.3. Objective Function of Hybrid PV Systems

In hybrid PV systems, the objective function is designed to minimize costs and environmental impacts such as carbon emissions, while maximizing the use of renewable energy based on the following factors:

$$COE = \frac{\left((N_{PV}\ x\ C_{PV}\ ) + (N_{batt}\ x\ C_{batt}) +\ C_{inv}\ +\ C_{O\&M}\ +\ C_{NPC}\right) x\ CRF}{\sum_{t=1}^{365} W_s}$$

Where, COE is the energy cost per kWh, Npv is the number of PV modules used, Cpv is the cost per unit of PV module, $Nbatt$ is the number of batteries used, $Cbatt$ is the cost per unit of battery, $Cinv$ is the total cost of the inverter, $Co\&M$ is the total annual operating and maintenance cost, $Crep$ is the total cost of component replacement over the project's lifespan, CRF is the factor that converts the investment cost into annual payments, and $\sum 365\ wS$ is the total energy production over one year.

Maximizing Renewable Fraction:

$$RF = \frac{(N_{PV}\ x\ P_{PV}\ \ \eta_{PV}) + (N_{batt}\ x\ W_{batt}\ x\ \eta_{batt})}{(N_{PV}\ x\ P_{PV}\ \ \eta_{PV}) + (N_{batt}\ x\ W_{batt}\ x\ \eta_{batt}) + (P_{PLN}\ x\ T_{PLN})}$$

Where, PPV is the required output power of the PV system, ηpv is the efficiency of the PV system, $Nbatt$ is the number of batteries used, $Wbatt$ is the required battery energy capacity, $\eta batt$ is the battery efficiency, $PPLN$ is the electrical power drawn from the utility grid, $TPLN$ is the duration of electricity usage.

Minimizing Carbon Emissions from PLN and Maximizing Community Acceptance can calculate by equations (3) and (4) :

$$ECO^2 = P_{PLN}\ x\ EF_{PLN}$$

$$CA = \frac{\sum_{i=1}^{n} R_i}{n}$$

Where, CA is the average level of public acceptance of the PV system project, Ri is the score or value of respondent i for the project, n is the total number of respondents, $Eco2$ is the carbon dioxide emissions from the use of PLN electricity, and $EFPLN$ is the carbon emission factor from PLN.

Multi-Objective Optimization (MOO) Function is calculated by equation (5):

$$F = \omega_1\ X\ COE + \omega_2\ X\ ECO^2 - \omega_3\ X\ RF - \omega_4\ X\ CA$$

The objective function weighting is determined by distributing direction vectors across solutions, so that each solution has a different weight. This approach uses the Multi-Objective Evolutionary Algorithm based on Decomposition (MOEA/D) method combined with Localized Penalty-Based Boundary Intersection (LPBI). In this method, the weights are not assigned specifically but are represented by evenly distributed direction vectors, resulting in solutions that are balanced across the Pareto front (Ming et al., 2017).

$$Subject: \left\{ \begin{array}{l} 0 \le N_{pv} \le 25 \\ 0 \le N_{batt} \le 20 \\ COE_{PV} \le COE_{PLN} \\ RF_{PV} \ge 80\% \end{array} \right\}$$

2.4. PV Components of Hybrid Systems

The components of the hybrid PV system in this study were selected based on system needs, energy demand, and local availability. The system consists of PV modules as the main energy source, batteries to store excess energy, an inverter to convert DC to AC power, and the power grid as a backup. The following calculation formula (equation 7-9)is used in reference to the selection of system components:

Electrical Energy Requirements (Lubna et al., 2021):

$$W_s = W_d + ((tolerance 25 - 40\%) W_d$$

Where, W_s is the planned electrical energy supply requirement, while W_d is the daily electrical energy required.

PV system energy requirements (Malik et al., 2023):

$$W_{load} = P_{demand} + (P_{demand} \times SF)$$

Where, Wload is the load energy required, Pdemand is the power required by the load, and SF is the safety factor.

Inverter capacity (Adesina et al., 2023):

$$P_{inv} = P_d \times \eta_{inv} + (tolerance\ 25-30\%) \times P_d \times \eta_{inv}$$

Where, Pinv is the required output power of the PV system, Pd is the peak load power, and ηinv is the inverter efficiency. The 25-30% tolerance is an additional margin of inverter capacity to account for potential issues overload.

2.4.1. PV System Specifications

In designing a hybrid PV system for a coffee shop, Trina Solar panels with capacities of 450Wp, 550Wp, and 650Wp are used because their varying power outputs, sizes, and efficiencies can be matched to roof conditions and energy needs. Economically, the 450Wp panels are suitable for limited budgets, the 550Wp panels provide a good balance of capacity and cost, and the 650Wp panels deliver high output with long-term efficiency. The differences in current and voltage between the panels also enable flexible integration with inverters and batteries, thereby improving system performance efficiency.

Table 2. PV System Specifications

Parameters	Specifications		
Brand	Trina Solar 450 Watt	Trina Solar 550 Watt	Trina Solar 650 Watt
Type	Monocrystalline	Monocrystalline	Monocrystalline
Pmax	450 W	550 W	650 W
Isc	11.53 A	18.52 A	18.44 A
Voc	49.6 V	37.9 V	45.3 V
Imp	10.98 A	17.40 A	17.39 A
Vmp	41.0 V	31.6 V	37.4 V
Dimensions (mm)	2102 x 1040 x 35	2384 x 1303 x 35	2384 x 1303 x 35
Weight	24 kg	33.6 kg	33.9 kg
Price	Rp 976.609	Rp. 1.493.000	Rp. 2.986.000

In designing the hybrid PV system for the coffee shop, Trina Solar panels of 450Wp, 550Wp, and 650Wp were used because their range of power ratings and sizes allows for customization to roof conditions and energy requirements. Economically, this combination offers a competitive price per watt-peak: 450Wp fits limited budgets, 550Wp balances capacity and cost, and 650Wp delivers high output for long-term efficiency. The differences in current and voltage among the panels also provide flexibility in integrating with inverters and batteries, improving system performance efficiency.

2.5. Battery Specification

The selection of three battery types-VRLA 200Ah, LiFePo4 200Ah, and another VRLA 200Ah variant-in the design of the hybrid PV system for the coffee shop aims to provide flexibility. Although the capacity and design life are similar, they differ in weight, price, and technology. LiFePo4 is lighter and more efficient for limited space, while VRLA is more economical to keep initial costs down. These three options allow customization based on priorities, whether emphasizing initial cost, spare capacity, or efficiency in installation size and weight. The battery specifications used are listed in Table 2.

Table 3. Battery Specifications

Parameters	Specification		
Type	VRLA	LiFePO4	VRLA
Voltage Nominal	12V	12 V	12 V
Capacity Nominal	200 ah	200 ah	200 ah
Dimensions (mm)	522 x 240 x 219	320 x 170 x 220	533 x 240 x 244
Weight	59 kg	20 kg	65 kg
Design Life	10 years	10 years	10 years
Price	Rp. 4.500.000	Rp. 6.617.518	Rp. 5.600.000

2.6. Inverter Specification

Inverters with these specifications were chosen because they can accept PV inputs of up to 800W, match the capacity of the designed system, and support a wide MPPT voltage range (120-450VDC) to maximize energy production under various solar panel conditions. Equipped with two MPPT trackers, the system can independently manage two panel strings, enhancing efficiency, especially on roofs with different orientations or shading. The inverter used has specifications as listed in Table 3.

Table 4. Inverter Specifications

Max PV Input Power		8000 W	
PV Input (DC)		Battery & Charger	
Nominal DC Volt/Max DC Voltage	360VDC/450VDC	Battery Type Supported	Lead Acid/VRL AVAGM/Deep
Startup Voltage/ Initial Feeding	120 VDC		Cycle/Gel/Flooded/Tubular/Lithium-Ion
MPPT Voltage Range	120-450VDC	Nominal Battery Voltage	48Vdc
No. of MPPT Tracker	2Pcs*18A MPPT Tracker (4000W*2)	Max Solar Charge Current	120A
AC Input (AC)		Max AC Charge Current	120A
AC Start up Voltage	120Vac-140Vac/180Vac	Nominal Output Volt	220Vac/230Vac/240Vac
Acceptable Input Voltage Range	90-280Vac or 170-280Vac	Waveform	Pure sine wave
Max AC Input Current	63A	Efficiency (DC to AC)	93%
Grid Output in Gri-Tie/Hybrid Operation (AC)		Physica	
Nominal Output Volt	220 Vac/230 Vac/240 Vac, Single	Product Dimension (mm)	552 x 422 x 152
	Phase	Product Net Weight (kg)	18.4
Output Voltage Range	184V-265Vac or 195-253V (selectable)	Price	Rp. 11.756.000/unit

2.7. Queen Honey Bee Migration Algorithm (QHBM)

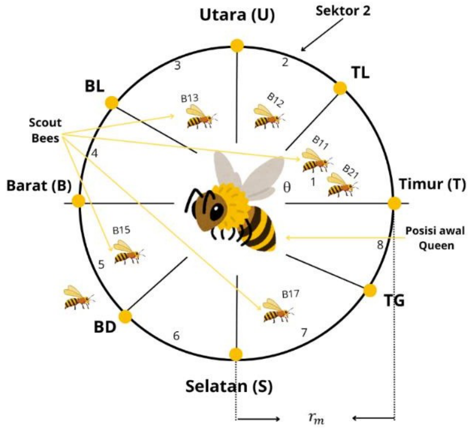


Figure 4. QHBM Algorithm Process

The Queen Honey Bee Migration Algorithm (QHBM) mimics how honey bees migrate to find the best place to build a new hive. In this algorithm, there are two main roles: the queen, which makes decisions, and scout bees that explore eight sectors in the cardinal directions to evaluate potential sites (Aripriharta, Asnarindra, et al., 2023). Based on the reconnaissance results, scout bees communicate with a waggle dance (excitement), and the queen selects the sector with the highest likelihood as the best location for a new hive (Aripriharta, Bayuanggara, et al 2023).

Based on Figure 4, the Queen Honey Bee Migration (QHBM) algorithm features eight sectors and three main stages: scanning, selection, and journey. The first stage, scanning, involves the queen bee performing the initial search, represented by the parameter pair (VPV, PPV). VPV is the output voltage of the solar panel (in volts), while PPV is the output power (in watt-peak). During this stage, the algorithm evaluates various combinations of solar panel voltage and power to determine if they can meet the coffee shop's daily energy needs. After scanning, the scout bees are divided into eight sectors based on cardinal directions. Each scout bee (cj) has a different excitement level, calculated by averaging the excitement within sector j using equation (10):

$$C_j = \frac{1}{n}\sum_{j=1}^{n} e_{ij}$$

Where Cj represents the solution quality in sector j, eij is the excitement score of the i-th scout bee, and n is the number of scout bees in that sector. In this research, excitement reflects the evaluation of the initial setup, such as the number of solar panels and batteries. The second stage involves selection, where the queen bee chooses the sector with the highest probability as the next movement direction. This probability value is calculated by equation (11):

$$P_j = \frac{C_j}{\sum_j^8 C_j}$$

Shows the probability of sector j being selected based on the average excitement (Aripriharta, Bayuanggara, et al., 2023). In this study, the sector with the highest probability value provides the best solution, namely the configuration with the lowest energi cost of ownership (COE) and the highest renewable fraction (RF). The third stage is the journey, where the queen bee moves toward the chosen sector. This movement is modeled through the following equation (12-14):

$$X_m^{(ith+1)} = \mathrm{X}_0 + r_m^{(ith+1)} \times cos\ \theta^{\ (ith+1)}$$

$$Y_m^{(ith+1)} = \mathrm{Y}_0 + r_m^{(ith+1)} \times sin\ \theta^{\ (ith+1)}$$

$$r_m^{(ith+1)} = \left(1 - G_m^{(ith)}\right) x\ r_0$$

Where $X_m^{(ith+1)}$ and $Y_m^{(ith+1)}$are the solution coordinates (number of panels and batteries), $r_m^{(ith+1)}$ is the movement distance, θ is the angle direction, $G_m^{(ith)}$is the distance reduction factor and r_0 is the initial distance. This process iteratively updates the solution until an optimal hybrid PV system configuration is found that balances cost and environmental sustainability.

After reaching a new sector, the queen bee takes a short break before restarting the process at the scanning stage. This cycle continues until the algorithm finds the optimal solution.

2.8. Validity and Reliability Test

The validity test aims to confirm that each questionnaire item effectively measures the theoretical constructs of the TAM model: Perceived Usefulness (PU), Perceived Ease of Use (PEU), Attitude Toward Using (ATU), and Behavioral Intention (BI). In this study, the validity test was performed to evaluate how well the questionnaire captures people's perceptions of the benefits, ease of use, attitudes, and willingness to adopt hybrid PV systems. The two types of validity assessed are convergent validity, which ensures that items within the same construct are highly correlated, and discriminant validity, which confirms that items from different constructs are not overly correlated, allowing for clear differentiation between constructs. The validity test was conducted using item-total correlations, with a Pearson correlation coefficient (r) ≥ 0.3 and a p-value < 0.05, indicating a strong, statistically significant relationship between items and constructs. In addition, the reliability test evaluates the internal consistency among items within a construct, that is, the degree to which items reliably measure the same concept. In the context of TAM, this ensures that items such as PU1-PU4 consistently assess the perceived benefits of hybrid PV systems.

The reliability test was conducted using Cronbach's Alpha, a statistical measure of internal consistency. While Cronbach's Alpha measures reliability rather than validity, it shows how consistently individual items in a survey produce similar responses (Frost, 2022). A high alpha value indicates that the items are measuring the same underlying construct. In this study, the interpretation of Cronbach's Alpha is as follows: values of 0.70 or higher indicate good reliability, 0.60–0.69 indicate fair reliability, and values below 0.60 indicate low reliability. Confirming adequate reliability and validity establishes the questionnaire as a trustworthy tool for measuring public acceptance of hybrid PV systems.

3. RESULTS AND DISCUSSION

3.1. Technical Feasibility Analysis of PV Hybrid

3.1.1. Electrical Energy Needs at the Research Site

The calculation of electrical energy requirements is based on the operating time of 13 hours for some existing electrical equipment. Using this data, Wd is calculated to be 28.798 kWh. Therefore, from equation (7), the energy used, $Wreq$, is calculated as :

$$W_s = 28.798 + ((35\%)\ x\ 28.798 = 38.8773\ kWh$$

3.1.2. PV System Capacity

In Malang City, the average solar irradiation (G) in a year is 3.86Wh/m^2 where the average peak sun hour lasts from 10:00 am to 2:30 pm or for 4.5 hours each day. The peak power of the PV system (P_{PLTS}) using equation (8).

$$W_{spv} = \frac{38.8773}{3.86} + (20\%)\ x\ \frac{38.8773}{3.86} = 12.087\ kWp$$

3.1.3. Battery Capacity

In this study, the battery-autonomous day is 1, the Depth of Discharge (DOD) is 80%, and the battery efficiency ($\eta batt$) is 98%. Then the calculation of battery requirements ($Wbatt$)and battery current capacity ($Icbatt$)is based on equation (9):

$$W_{batt} = \frac{1\ x\ 28.798}{80\%\ x\ 98\%} = 36.722\ kWh$$

$$Ic_{batt} = \frac{36.722}{12\ V} = 3.06\ Ah$$

3.1.4. Inverter Capacity

In this study, the inverter power tolerance is planned to be 30% and the inverter efficiency (ηinv) is 98%. The inverter power capacity is obtained using equation (9) as follows:

$$P_{inv} = 38.8773\ x\ 98\% + (30\%\ x\ 38.8773\ x\ 98\%) = 49.5297\ kWh$$

3.1.5. PV Energy Cost of Conventional Hybrid System

To get the COE value, the calculation of the capital recovery factor, often referred to as CRF, and all operational and operating costs in the development of NPC are used.

$$CRF\% = \frac{0{,}0412\ (1 + 0{,}04125)^{25}}{(1 + 0{,}04125)^{25} - 1} = 0{,}0649$$

It is known that i is the real interest rate (0.0412%), and n represents a 25-year system usage period to obtain a CRF of 0.0649 (6.49%). The net present cost (NPC) can be calculated by adding the initial capital costs (IC), maintenance and operating costs (O&M), and component replacement costs (RC). There are three NPC values derived from each PV specification.

$$Ic = (976.609x27) + (4.500.000x16) + (11.756.000) = Rp\ 110.124.443$$

$$NPC450Wp = \ 110.124.443 + 87.451.500 + 83.765.000 = Rp\ 276.482.000$$

$$Ic = (1.493.000 \text{ x } 22) + \ (4.500.000 \text{ x } 16) + \ (11.756.000) = RRp116.602.000$$

$$NPC550Wp = \ 116.602.000 + \ 87.451.500 + \ 83.765.000 = Rp\ Rp287.809.500$$

$$Ic = (2.986.000 \text{ x } 19) + (4.500.000 \text{ x } 16) + \ (11.756.000) = RRp116.602.000$$

$$NPC650Wp = \ 140.409.000 + \ 87.451.500 + \ 83.765.000 = Rp329.622.500$$

The value of NPC is calculated by adding the IC results to the O&M costs, which are derived from 3% of the initial capital calculation results. The cost of replacing components is based on replacing batteries with a 10-year lifetime within the project period, while the inverter has a 12-year lifetime. The battery components will be replaced twice over the 25-year project duration, and the inverter component will be replaced once during this period. From the NPC calculation results, an equation is derived to determine the COE value as follows:

$$COE450Wp = \frac{276.482.776\ x\ 0{,}0649}{14.189.2245} = Rp1.246,41kWh$$

$$COE550Wp = \frac{287.809.500\ x\ 0{,}0649}{14.189.2245} = Rp1.315{,}87kWh$$

$$COE650Wp = \frac{329.622.500\ x\ 0{,}0649}{14.189.2245} = Rp1.486,55kWh$$

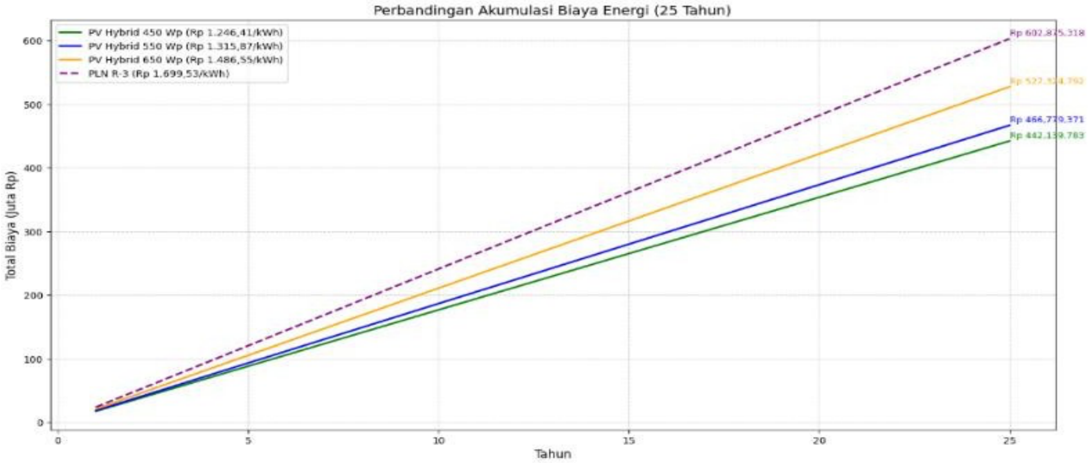


Figure 5. Comparison Chart of Accumulated Costs of Hybrid PV and PLN

A comparison graph in Figure 5 displays the accumulated costs of hybrid PV systems versus PLN R-3 over 25 years. The analysis shows that the 450Wp hybrid PV system costs Rp 1,246.41/kWh, the 550Wp system costs Rp 1,315.87/kWh, and the 650Wp system costs Rp 1,486.55/kWh. By year 25, the 450Wp hybrid PV system has the lowest total cost at IDR 442,139,789, followed by the 550Wp at IDR 466,779.31, and the 650Wp at IDR 527,324,792. The cost difference between the 450Wp hybrid PV system and PLN R-3 is Rp 160,735,535, illustrating the long-term economic benefit of the hybrid PV system run.

3.2. Optimal Hybrid PV System Planning Results

Optimal PV Hybrid System planning, aimed at achieving the best results, is performed in Python to determine the minimum energy cost (COE) by assessing optimal PV and battery sizes. It focuses on maximizing RF renewable energy ratio, reducing carbon emissions ($ECO2$), and increasing community revenue. The study examines two hybrid PV system planning scenarios: 1) conventional hybrid PV system planning; 2) heuristic hybrid PV system planning, which uses two heuristic optimization methods. Figure 6 illustrates the scout and particle search processes used to identify the optimal values for the two algorithms. It shows that the search space for scouts and particles is limited to the RF range of 98.6-100%, COE between Rp. 300.0 and Rp. 600.0, and $ECO2$ from 200 to

1200 kg CO2. These constraints align with the subject's limits. The graph displays three clusters of points, each representing the optimal results for scenario 2 obtained with the QHBM and PSO algorithms. The optimal results for each algorithm are indicated by the color of the clusters: green for QHBM and purple for PSO.

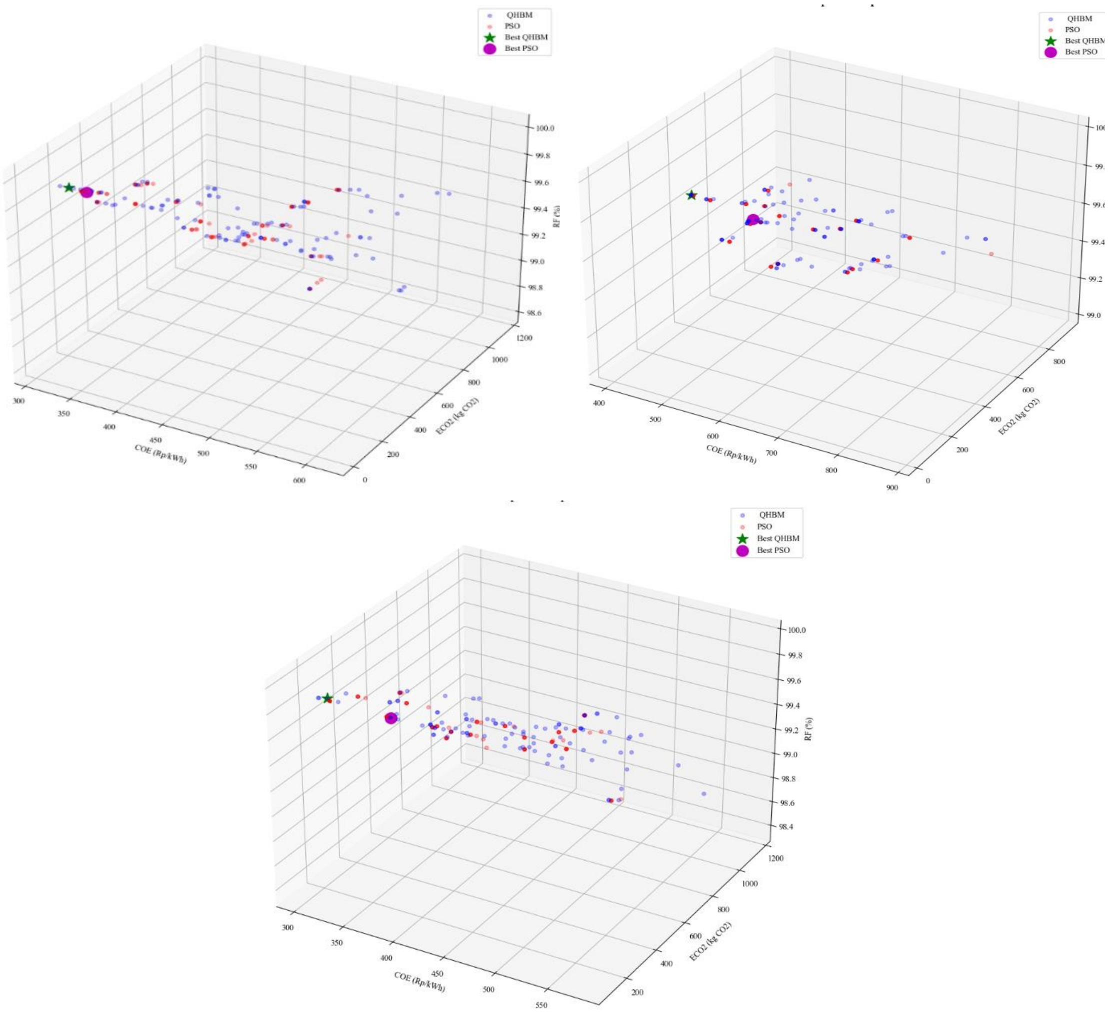


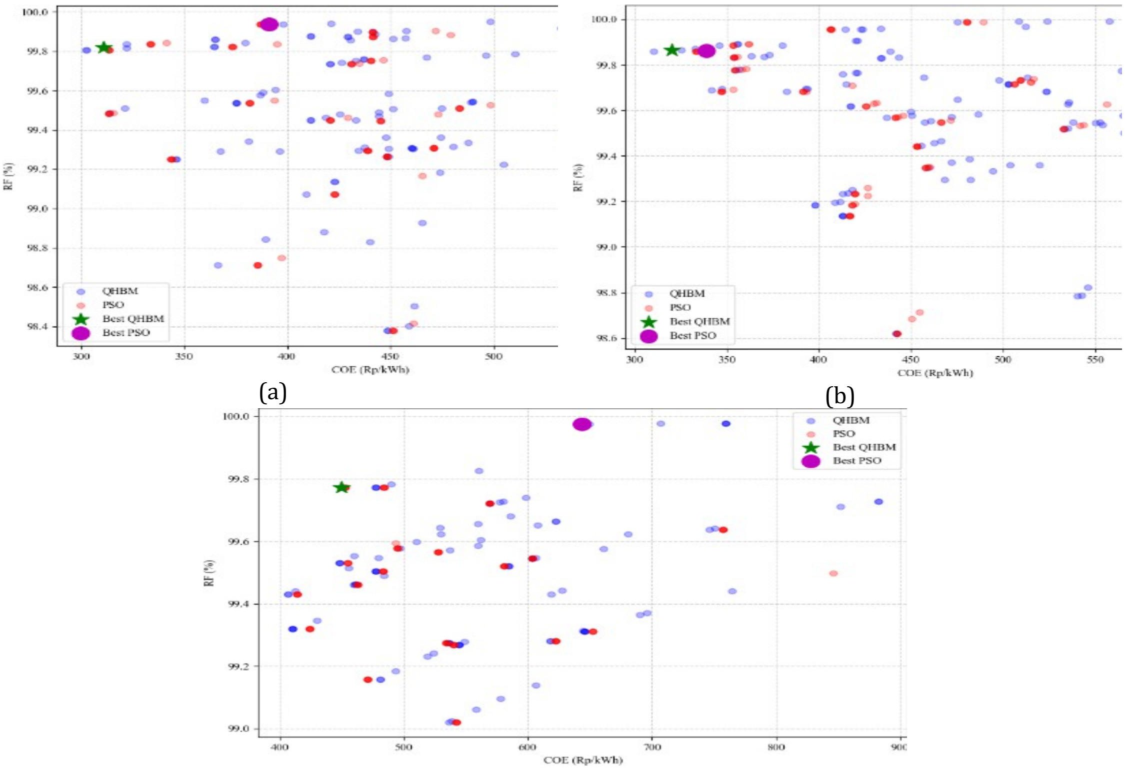
Figure 6. Multi-Objective RF, COE, ECO2

This study will compare the optimization results of the QHBM algorithm and Particle Swarm Optimization (PSO) to evaluate the QHBM algorithm's performance. The simulation results for both algorithms, QHBM and PSO, are shown in Table 5.

Table 5. QHBM and PSO Simulation Results

Maxx Iterasi	P_{Pv} W_P	N_{Pv} (pcs)	Ic_{batt} (Ah)	N_{batt} (pcs)	COE (Rp/kWh)	RF Optimal (%)	ECO_2 (Kg)	CA	*Objective Value*
				Algoritma QHBM					
100	450	23	200	10	311.05	99.82	198.10	3.74	129.76
100	550	20	200	10	320.04	99.87	141.81	3.74	118.58
100	650	19	200	10	449.48	99.77	286.52	3.74	203.44
				Algoritma PSO					
100	450	23	200	10	390.99	99.94	95.15	3.74	133.69
100	550	20	200	10	339.10	99.86	141.81	3.74	126.68
100	650	19	200	10	643.38	99.98	19.11	3.74	204.41

Based on the results of the optimization simulation conducted on the hybrid PV system, Table 5 presents a performance comparison between the two heuristic algorithms. The optimal configurations of the hybrid PV system include 450 Wp PV capacity with 23 panels and 10 12V 200Ah batteries; 550 Wp with 20 panels and 10 12V 200Ah batteries; and 650 Wp with 19 panels and 10 12V 200Ah batteries, generated by both algorithms. Additional evaluations were conducted on several key parameters, including economic, environmental, and social aspects, as well as on the objective function value as an indicator of solution performance. In scenario 2, the QHBM algorithm outperforms the PSO algorithm. Specifically, the QHBM algorithm tracks the minimum hybrid PV system COE, Rp. 320.04/kWh, while the PSO algorithm tracks a minimum of Rp. 339.10/kWh. As shown in Figure 7, the QHBM algorithm can explore a more optimal solution space than the PSO algorithm, especially for minimizing COE without sacrificing the contribution of renewable energy. In the same scenario, the QHBM algorithm achieves an RF of 99.87%, slightly higher than the 99.86% of the PSO algorithm. Although the RF difference between the two algorithms is only 1%, the significantly lower COE value obtained by the QHBM algorithm indicates it is more effective in producing economically efficient solutions while still supporting energy sustainability goals in hybrid PV systems.

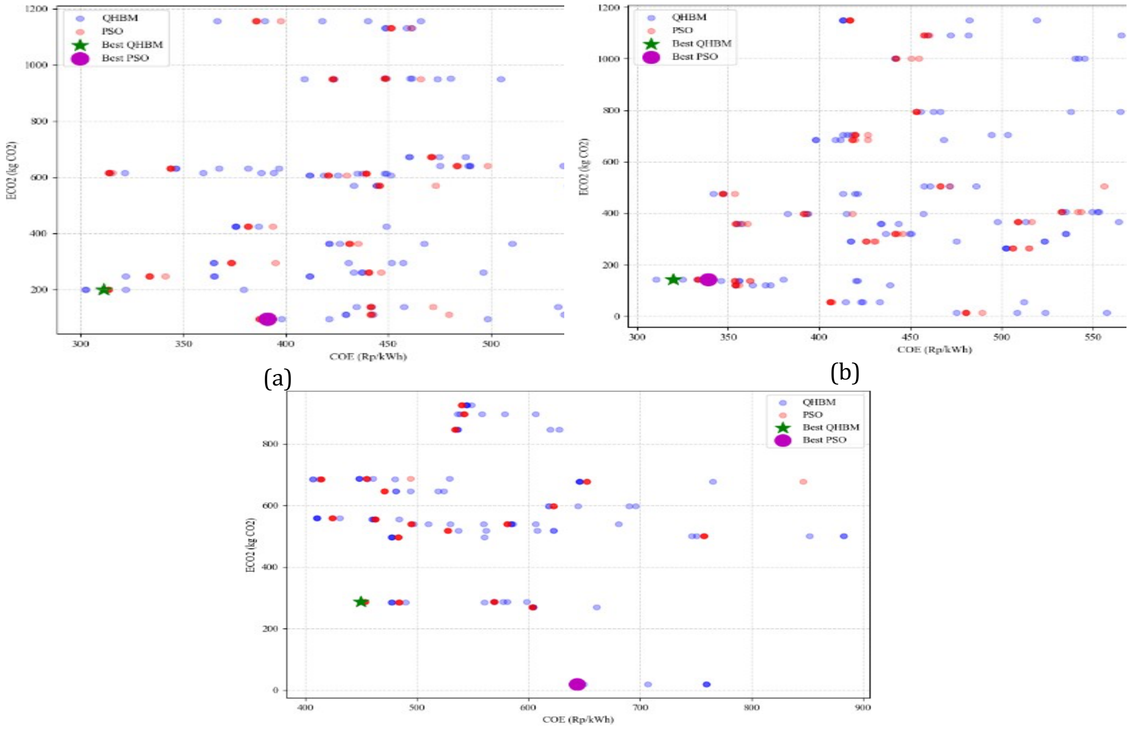


(a)

(b)

Figure 7. Multi Objective COE and RF: (a) 450Wp, (b) 550Wp, (c) 650Wp

Figure 7 illustrates the relationship between COE and carbon emissions ($ECO2$), providing an overview of how effective each algorithm is at generating cost-effective hybrid PV system optimization solutions that also consider environmental sustainability. Based on the simulation data, the QHBM algorithm consistently yields lower COE values than the PSO algorithm, especially for 450Wp and 550Wp PV configurations. At 450Wp, QHBM reduces COE to Rp 311.05/kWh, while PSO results in Rp 390.99/kWh. This notable difference demonstrates better efficiency from QHBM's optimization. A similar trend is observed at 550 Wp, with QHBM achieving Rp 320.04/kWh, compared to PSO's Rp 339.10/kWh. For 650 Wp, PSO results in a COE of Rp 633.38/kWh, whereas QHBM results in Rp 449.48/kWh. This high COE indicates overall inefficiency at this capacity, as costs increase sharply in both algorithms, suggesting that excessive PV capacity does not yield cost benefits. Regarding RF, both algorithms perform very well, with values close to 100% across all configurations. PSO slightly outperforms with RF values ranging from 99.86% to 99.98%, while QHBM produces RF values from 99.77% to 88.87%. The small difference indicates that PSO marginally enhances the integration of renewable energy into the system. However, this minor RF difference does not significantly impact overall system efficiency compared to the energy cost savings from both algorithms. Overall, although PSO has a slight advantage in RF performance, the QHBM algorithm provides a more economical solution without significantly sacrificing sustainability. Therefore, from the perspective of simultaneously optimizing both COE and RF, the QHBM algorithm can be considered superior for generating the optimal hybrid PV system configuration.

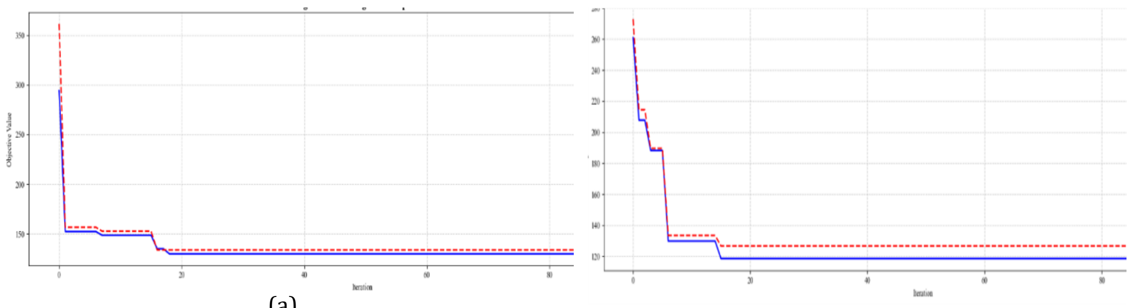


(a) (b)

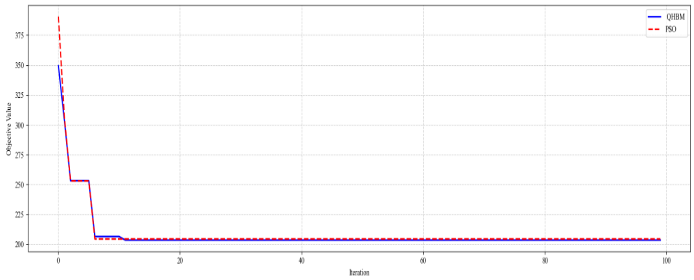
(c)

Figure 8. Multi Objective COE and Carbon Emissions: (a) 450Wp, (b) 550Wp, (c) 650Wp

The convergence comparison algorithms shown in Figures 4.7 to 4.9 present the performance evaluation results of the QHBM and PSO algorithms for optimizing hybrid PV systems, with COE as the economic factor and $ECO2$ as the environmental impact indicator. Regarding $ECO2$, the QHBM algorithm demonstrates more competitive results than PSO. In the 450 Wp configuration, QHBM produces 198.10 kg of emissions, which is higher than PSO, at 95.15 kg. However, in the 550 Wp configuration, both algorithms yield the same emission level of 141.81 kg. In the 650 Wp setup, QHBM results in emissions of 286.52 kg, whereas PSO only emits 19.11 kg. Nonetheless, the very low emission value in the PSO 650 Wp configuration does not align with economic efficiency, as the COE in this setup remains relatively high. This highlights a significant trade-off between economic and environmental factors, with the PSO algorithm, a trade-off that does not appear with the QHBM algorithm. Overall, the QHBM algorithm provides a more balanced approach between cost efficiency and carbon emission reduction, without causing substantial increases in COE as seen with PSO. Therefore, from an energy system sustainability perspective, QHBM can be considered superior because it effectively optimizes energy costs while maintaining competitive carbon emission levels level.



(a) (b)



(c)

Figure 9. Convergence Comparison Algorithm : (a) 450Wp, (b) 550Wp, (c) 650Wp

Figure 9 compares the convergence performance of the QHBM and PSO algorithms in finding the optimal solution for multi-objective optimization of hybrid PV systems. In all three configurations, both algorithms decrease the objective function value within the first 10 to 20 iterations, indicating a strong initial ability to find near-optimal solutions. However, QHBM demonstrates a more stable convergence pattern and reaches a lower final value than PSO, especially in the 450Wp and 550Wp configurations. This suggests that QHBM is more effective at exploring the solution space to identify the best combination of low energy costs and low carbon emissions. For the 450 Wp configuration shown in Figure 9a, the QHBM algorithm achieved a lower objective function value than PSO at around 15 iterations and maintained stability until the 100th iteration. This pattern is similar to the 550Wp configuration in Figure 9b, where both algorithms plateau at nearly the same value after the 20th iteration, with QHBM remaining slightly lower than PSO. In the 650Wp configuration depicted in Figure 9c, both algorithms demonstrate faster and more stable convergence, but the difference in the final value is negligible due to the very high COE caused by the 650Wp setup. This shows that low objective function values do not necessarily equate to cost efficiency in a multi-objective context, so the choice of algorithms and configurations should still consider the balance among indicators. Overall, the QHBM algorithm achieves more optimal, stable objective function values, highlighting its ability to simultaneously minimize energy costs and carbon emissions.

3.3. Analysis of Public Acceptance of Hybrid PV System Implementation

3.3.1. Respondent Characteristics

In Table 6, the characteristics of respondents in this study include two main variables: gender and the latest level of education, along with responses to questionnaire items related to Perceived Usefulness (PU), Perceived Ease of Use (PEU), Attitude Toward Using (ATU), and Behavior Intention (BI). Respondents by gender show that the majority are male (32, 62.7%), and female respondents number 19 (37.3%). Meanwhile, regarding the latest level of education, most respondents have a junior high school background, totaling 1 person (2.0%), followed by high school education with 32 people (62.7%), and a bachelor's degree with 12 people (23.5%). Additionally, 6 people (11.8%) reported their highest level of education as “other”.

Table 6. Respondent Characteristics

Variables	Total
Gender	
Male	32 People
Female	19 People
Education Level	
Junior High	1 Person
High School	32 People
Undergraduate	12 People
Other	6 People

3.3.2. TAM Questionnaire Validity and Reliability Test Results

Validity and reliability tests were conducted to ensure that the TAM questionnaire could accurately and consistently measure public acceptance of hybrid PV systems. The questionnaire consisted of 16 items (4 items each for PU, PEU, ATU, and BI) and was completed by 51 respondents using a 1-5 Likert scale. Validity was tested using corrected item-total correlation (criteria: $r \geq 0.3$; $p < 0.05$), while reliability was tested with Cronbach's Alpha (≥ 0.7 = good; 0.6-0.69 = acceptable; < 0.6 = poor), using Python. The validity test results are shown in Table 7 and indicate that each item has an adequate correlation to the construct being measured.

Table 7. Validity Test Results

Construct	Item	Item-Total Correlation	P-Value	Description
Perceived Usefulness (PU)	PU1	0,618	8,111e-07	Valid
	PU2	0,458	5,597e-04	Valid
	PU3	0,400	2,987e-03	Valid
	PU4	-0,122	3,854e-01	Not Valid
Perceived Ease of Use (PEU)	PEU1	0,719	1,310e-09	Valid
	PEU2	0,822	4,376e-14	Valid
	PEU3	0,773	1,240e-11	Valid
Attitude Toward Using (ATU)	ATU1	0,776	9,095e-12	Valid
	ATU2	0,841	3,065e-15	Valid
	ATU3	0,799	7,209e-13	Valid
Behavior Intention (BI)	BI1	0,483	2,459e-04	Valid
	BI2	0,564	1,111e-05	Valid
	BI3	-0,051	7,184e-01	Not Valid
	BI4	0,449	7,549e-04	Valid

The reliability test evaluates the internal consistency of items within each construct using Cronbach's Alpha. The reliability criteria are: Alpha≥0.7 (good), 0.6-0.69 (acceptable), and <0.6 (poor). The results of the reliability test are shown in Table 8.

Table 8. Reliability Test Results

Construct	Cronbach's Alpha	Description
Perceived Usefulness (PU)	0,455	Poor
Perceived Ease of Use (PEU)	0,882	Good
Attitude Toward Using (ATU)	0,902	Good
Behavioral Intention (BI)	0,464	Poor

The reliability test results show that the PU construct has a Cronbach's Alpha of 0.455 (<0.6), indicating low reliability. This aligns with the validity test results, which reveal that item PU4 is invalid, suggesting low internal consistency for the PU construct, possibly due to differences in respondents' answers or the items' relevance to the coffee shop context. The PEU construct achieved a value of 0.882 (≥ 0.7), indicating high reliability and good consistency among items measuring perceived ease of use. The ATU construct also showed high reliability (0.902; ≥ 0.7), confirming the consistency of its items in assessing respondents' attitudes. Conversely, the BI construct has low reliability (0.464; < 0.6), consistent with the validity results indicating that item BI3 is invalid, thereby contributing to the construct's low internal consistency.

3.4. Analysis of Respondent Results

Based on the analysis of 51 respondents, average scores for the four main variables in TAM were calculated: PU, PEU, ATU, and BI. The PU score was 3.86, suggesting that respondents found the PV system quite useful for coffee shop operations. The PEU score is slightly lower at 3.39, indicating more mixed perceptions of the system's ease of use. The ATU value of 3.86 points to a generally positive attitude toward using the PV system, while the BI score, also at 3.86, reflects a relatively high intention to adopt the system. Overall, these findings indicate a positive public perception of PV systems regarding usability, convenience, attitude, and willingness to adopt renewable energy. The following equation is used to calculate the average value of public acceptance:

$$CA = \frac{14.976}{4} = 3.744$$

Based on the average calculation of the top five respondents' data, a value of 3,744 was obtained. This value is the sum of the average scores of all the main variables, namely PU, PEU, ATU, and BI from each respondent. This result indicates a high level of public acceptance for the implementation of hybrid PV systems, as it is close to the Likert scale number used 5.

3.5. Descriptive Statistical Analysis of Variables

Table 9 presents the average values for each main variable, including PU, ATU, PEU, and BI.

Table 9. Descriptive Statistics of Main Variables

Mean Value of Key Variables	
PU	3.860
PEU	3.392
ATU	3.862
BI	3.862

The results in Table 9 show that the mean values of PU and ATU are in the high category (mean > 4), indicating that most respondents strongly perceive the benefits of using PV systems and hold a positive attitude toward renewable energy. This finding aligns with the TAM framework, where PU is a key factor influencing attitude (ATU) and behavioral intention (BI). Meanwhile, the PEU variable has an average value of 3.39, which is lower than that of the other variables. This reflects respondents' varied perceptions of the system's ease of use, suggesting that *usability* remains a challenge in adopting PV technology. For the BI variable, the average value of 3.86 is similar to ATU, indicating a fairly strong behavioral intention among respondents to adopt or recommend PV systems in the future. Regarding standard deviation, PU has a value of 0.692, showing consistent assessments of system benefits with minimal variation among respondents (a minimum of 1 and a maximum of 5). PEU has the highest standard deviation of 0.837, highlighting differing perceptions of ease of use. Meanwhile, ATU and BI have standard deviations of 0.785 and 0.779, respectively, reflecting differences in experience but still suggesting tendencies toward positive attitudes and intentions to use PV systems.

3.6. Correlation Analysis Between Variables

Based on Table 10, the correlation matrix for the TAM model reveals a varied pattern of relationships among PU, PEU, ATU, and BI. This correlation was calculated using Python to ensure accurate and efficient data analysis. The correlation matrix shows the linear relationships between variables. A value of 1.00 on the main diagonal (PU-PU, PEU-PEU, ATU-ATU, BI-BI) indicates perfect correlation of a variable with itself. This value is standard in correlation matrices and requires no additional interpretation.

Table 10. Correlation Matrix between Variables

Correlation Matrix between Variables				
	PU	PEU	ATU	BI
PU	1.00	0.20	0.23	0.23
PEU	0.20	1.00	0.90	0.92
ATU	0.23	0.90	1.00	0.96
BI	0.23	0.92	0.96	1.00

In Figure 10, the correlation between the PU and PEU variables is 0.20, indicating a positive yet weak relationship. This suggests that perceived ease of use only minimally influences perceived usefulness of technology. In the context of the TAM model, the relationship between PU and PEU should be stronger, since, in theory, easy-to-use technology is usually perceived as more useful. This weak correlation indicates that respondents in this study viewed usability (PU) and ease of use (PEU) as two relatively independent dimensions. That is, although the PV system is easy to use, it may not necessarily be seen as very useful, or conversely, the system may be considered useful even if it is not entirely easy to use.

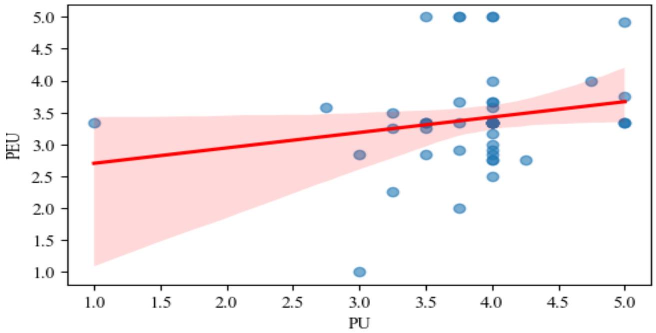


Figure 10. Correlation between PU and PEU Variables

The correlation between PU and ATU in Figure 11 (0.236) indicates a weak-to-moderate positive relationship. This suggests that usability has only a limited influence on technology use. The relatively low correlation suggests that the ease-of-use factor plays a more prominent role in shaping attitudes toward renewable technology.

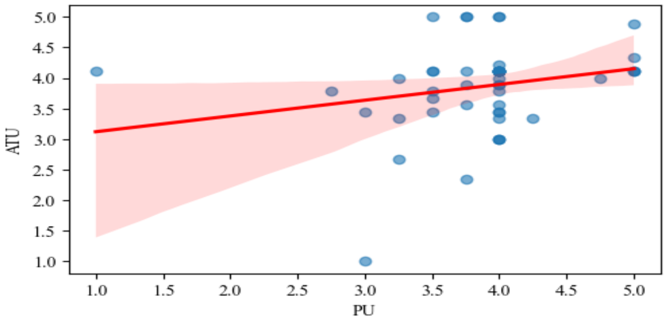


Figure 11. Correlation between PU Variable and ATU

The relationship between PU and BI shows a weak-to-moderate positive correlation, with a value of 0.233, as shown in Figure 12. These results suggest that users' perceptions of their intention to use technology do not significantly impact perceived usefulness. This low correlation indicates that attitudinal factors and ease of use might have a greater influence on users' behavioral decisions intentions.

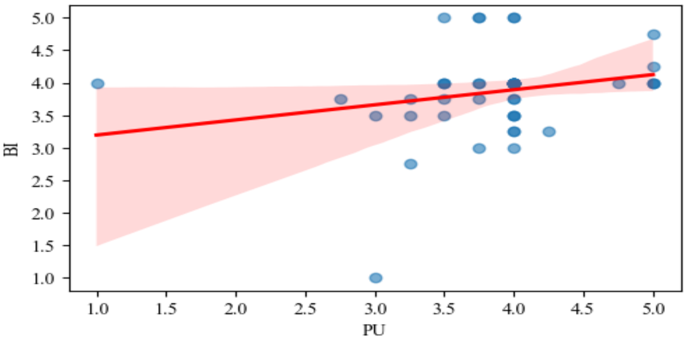


Figure 12. Correlation between PU and BI Variables

Meanwhile, in Figure 13, the relationship between PEU and BI exhibits a very strong correlation of 0.922. This value indicates that the ease of use of renewable energy directly influences users' behavior. In the TAM model, this relationship includes two pathways: the direct effect of PEU on BI and the indirect effect through attitude mediation. This high correlation demonstrates that perceived ease of use significantly impacts user attitudes toward renewable energy technology.

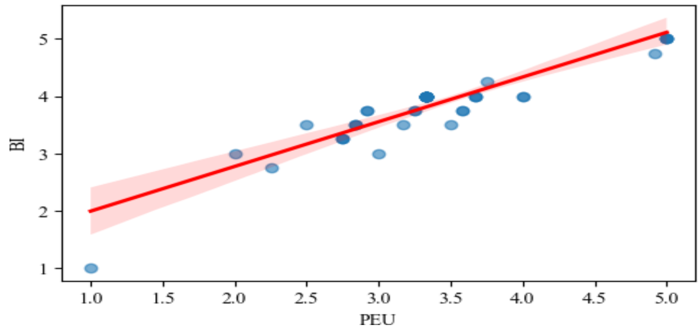


Figure 13. Correlation between PEU and BI Variables

Figure 14 shows the relationship between PEU and ATU, with a value of 0.90. This indicates that the ease of use of technology is a key factor in shaping positive attitudes towards renewable technology systems.

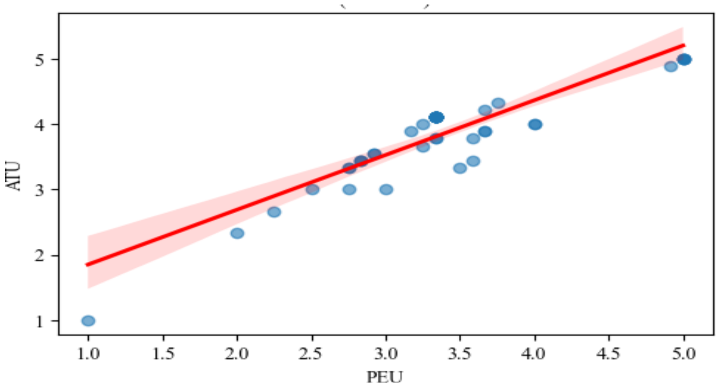


Figure 14. Correlation between PEU and ATU Variables

The relationship between ATU that affects BI in Figure 15 shows a relationship with a value of 0.969. Where the attitude towards behavior indicates that the respondent's positive attitude towards using technology is consistently followed by behavior involving renewable technology. This relationship shows high construct validity and is consistent with the TAM model.

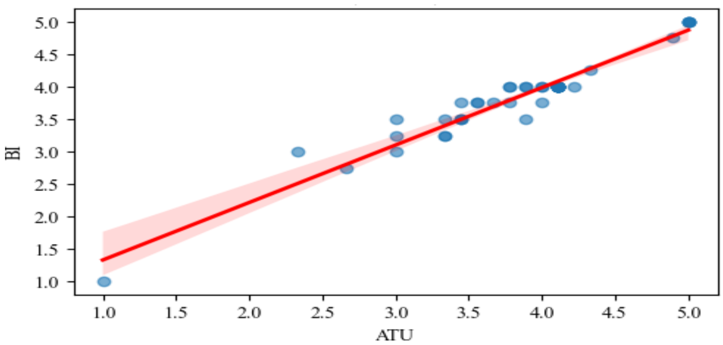


Figure 15. Relationship between ATU and BI Variables

The results of the correlation analysis across variables indicate that the PU variable shows a consistent but weak correlation with the other variables, ranging from 0.20 to 0.24. Meanwhile, the relationships between PEU, ATU, and BI variables show an inverse relationship with the PU variable, with high correlations exceeding 0.90. This pattern indicates that the influence path from PEU to ATU and then to BI is the primary route in the TAM model, while PU's contribution to other variables tends to be limited and insignificant.

4. CONCLUSIONS

This research conducts optimal planning of hybrid PV systems with batteries to achieve minimum electrical energy costs that are environmentally friendly and acceptable to the community.

The optimization process using the Queen Honeybee Migration (QHBM) algorithm yielded the best configuration in the second scenario: 20 units of 550 Wp solar panels and 10 units of 12V 200Ah batteries. This configuration resulted in a Cost of Energy (COE) of Rp320.04/kWh, with potential cost savings of more than Rp340 million compared to conventional electricity. In addition, the Renewable Fraction (RF) reached 99.87%, far exceeding the optimal threshold of 80%, and reduced carbon emissions by 141.8 kgCO$_2$, in line with energy sustainability principles and emission reduction targets. From a social perspective, the survey results indicate that community acceptance of hybrid PV systems is quite high, with an average score of 3.744 on a Likert scale of 1-5. Correlational analysis using the Technology Acceptance Model (TAM) identified the Perceived Ease of Use (PEU), Attitude Toward Using (ATU), and Behavioral Intention (BI) path as the dominant pathway in shaping technology usage intention. These findings indicate that the QHBM-based multi-objective approach that integrates technical, economic, environmental, and social aspects is highly feasible to apply at the MSME scale, especially for coffee shop businesses in Malang City.

REFERENCES

Adesina, L. M., Ogunbiyi, O., & Makinde, K. (2023). Design, implementation, and performance analysis of an off-grid solar-powered system for a Nigerian household. MethodsX,10, 102247. https://doi.org/10.1016/j.mex.2023.102247

Agdas, D., & Barooah, P. (2023a). On the economics of rooftop solar PV adoption. Energy Policy, 178, 113611. https://doi.org/10.1016/j.enpol.2023.113611

Ahmadi, H., Sunitiyoso, Y., & Wicaksono, A. (2023). Scenario Planning of PLN Indonesia Power in 2030: To Be a Leading Green and Sustainable Power Generation Company. European Journal of Business and Management Research, 8(4), 129–139. https://doi.org/10.24018/ejbmr.2023.8.4.2016

Ahsan, M. (2021). Tantangan dan Peluang Pembangunan Proyek Pembangkit Listrik Energi Baru Terbarukan (EBT) di Indonesia. SUTET, 11(2), 81–93. https://doi.org/10.33322/sutet.v11i2.1575

Aripriharta, A., Asnarindra, E., Nibrosoma, A. D., Gumilar, L., & Habibi, M. A. (2023). Pelacakan Daya Maksimum Fotovoltaik dalam Keadaan Transisi Berbayang Menggunakan Algoritma MPPT Queen Honeybee Migration (QHBM). Transmisi: Jurnal Ilmiah Teknik Elektro, 25(3), 85–94. https://doi.org/10.14710/transmisi.25.3.85-94

Aripriharta, A., Bayuanggara, T. W., Fadlika, I., Sujito, S., Afandi, A. N., Mufti, N., Diantoro, M., & Horng, G.-J. (2023). Comparison of queen honeybee colony migration with various MPPTs on a photovoltaic system under shaded conditions. EUREKA: Physics and Engineering, 4, 52–62. https://doi.org/10.21303/2461-4262.2023.002836

Aryani, E., Zanaria, Y., & Kurniawan, A. (2022). ANALISIS PERKEMBANGAN COFFEE SHOP SEBAGAI SALAH SATU PERANAN UMKM DI KOTA METRO. Jurnal Akuntansi AKTIVA, 3(2), 139–145. https://doi.org/10.24127/akuntansi.v3i2.3039

Baiyin, B., Tagawa, K., & Gutierrez, J. (2020). Techno-Economic Feasibility Analysis of a Stand-Alone Photovoltaic System for Combined Aquaponics on Drylands. Sustainability, 12(22), 9556. https://doi.org/10.3390/su12229556

Biswas, A., Husain, D., & Prakash, R. (2021). Life-cycle ecological footprint assessment of grid-connected rooftop solar PV system. International Journal of Sustainable Engineering, 14(3), 529–538. https://doi.org/10.1080/19397038.2020.1783719

Bošnjaković, M., Čikić, A., & Zlatunić, B. (2021). Cost-Benefit Analysis of Small- Scale Rooftop PV Systems: The Case of Dragotin, Croatia. Applied Sciences, 11(19), 9318. https://doi.org/10.3390/app11199318

Bošnjaković, M., Santa, R., Crnac, Z., & Bošnjaković, T. (2023). Environmental Impact of Pv Power Systems. Environmental and Earth Sciences. https://doi.org/10.20944/preprints202306. 1734.v1

Candra Erawan, I. N., Setiawan, I. N., & Sukerayasa, I. W. (2023a). Analisa Mitigasi Emisi Karbon serta Keekonomian Pembangkit Listrik Tenaga Surya (PLTS) Atap On-Grid 463,25 kWp di Perusahaan Farmasi pada Kawasan PT Jakarta Industrial Estate Pulogadung, Jakarta. Jurnal SPEKTRUM, https://doi.org/10.24843/SPEKTRUM.2023.v10.i03.p4

Candra Erawan, I. N., Setiawan, I. N., & Sukerayasa, I. W. (2023b). Analisa Mitigasi Emisi Karbon serta Keekonomian Pembangkit Listrik Tenaga Surya (PLTS) Atap On-Grid 463,25 kWp di Perusahaan Farmasi pada Kawasan PT Jakarta Industrial Estate Pulogadung, Jakarta. Jurnal SPEKTRUM, 10(3), 29. https://doi.org/10.24843/SPEKTRUM.2023.v10.i03.p4

Christiaanse, T. V., Loonen, R. C. G. M., & Evins, R. (2021). Techno-economic optimization for grid-friendly rooftop PV systems – A case study of commercial buildings in British Columbia. Sustainable Energy Technologies and Assessments, 47 , 101320. https://doi.org/10.1016/j.seta.2021.101320

Dwipayana, I. P. G. I., Kumara, I. N. S., & Setiawan, I. N. (2021). Status of Battery in Indonesia to Support Application of Solar PV with Energy Storage. Journal of Electrical, Electronics, and Energy Informatics, 5(1), 29. https://doi.org/10.24843/JEEI.2021.v05.i01.p06

Dyah Ayu Kartika Sari, Fransisco Danang Wijaya, & Husni Rois Ali. (2022). Optimasi Sistem Pembangkit Listrik Tenaga Hybrid di Pulau Enggano. Jurnal Nasional Teknik Elektro dan Teknologi Informasi, 11(2), 154–160. https://doi.org/10.22146/jnteti.v11i2.3849

Effendi, R. (2023). Analisis Penggunaan Energi Surya Fotovoltaik Sebagai Sumber Energi Alternatif. Jurnal Teknik Industri Terintegrasi, 6(4), 1298–1302. https://doi.org/10.31004/jutin.v6i4.20634

Febriani, S. D. A., & Rani, C. T. (2024). Kajian Tekno Ekonomi Sistem On-Grid pada Smart Greenhouse. Jurnal Teknik Terapan, 3(1), 1–9. https://doi.org/10.25047/jteta.v3i1.33

Frost, J. (2022, July 7). Cronbach's Alpha: Definition, Calculations & Example. Statistics By Jim. https://statisticsbyjim.com/basics/cronbachs-alpha/

Global Solar Atlas. (n.d.-a). Retrieved April 19, 2025. https://globalsolaratlas.info/

Global Solar Atlas. (n.d.-b). Retrieved April 9, 2025. https://globalsolaratlas.info/map?c=11.523088,7.998047,3

Harijanto, P. S., & Junus, M. (2021). Kajian PLTS on-grid pada gedung X Politeknik Negeri Malang untuk melayani beban perkantoran menggunakan perangkat *Homer Pro. Jurnal Eltek*, 19(2), 96–104. https://doi.org/10.33795/eltek.v19i2.320

Hilmi, H., Puspitawati, L., & Utari, R. (2020). Pengaruh Kompetisi, Pertumbuhan Laba dan Kinerja Lingkungan terhadap Pengungkapan Informasi Emisi Karbon pada Perusahaan. Owner (Riset dan Jurnal Akuntansi), 4(2), 296. https://doi.org/10.33395/owner.v4i2.232

Hossain, Md. S., Islam, M. R., Das, A., Himel, H. H., Das, B. K., Roy, T. K., & Hasan, Md. S. (2023). An energy-efficient pumping system for sustainable cities and society: Optimization, mathematical modeling, and, impact assessment. Energy Reports, 10, 819–836. https://doi.org/10.1016/j.egyr.2023.07.029

Imad Hazim, H., Azmi Baharin, K., Kim Gan, C., & Sabry, A. H. (2024). Techno-economic optimization of photovoltaic (PV) inverter power sizing ratio for grid-connected PV systems. Results in Engineering, 23, 102580. https://doi.org/10.1016/j.rineng.2024.102580

Indonesia's Prabowo plans to retire all fossil fuel plants in 15 years, but experts are skeptical. (2024, November22). AP News. https://apnews.com/article/indonesia-coal-energy-transition-fossil

Irfani, K. N., Windarta, J., & Handoko, S. (2021). Studi Perancangan Pembangkit Listrik Tenaga Surya pada UMKM Coffee Shop di Kota Semarang Ditenjau dari Analisis Kelayakan Teknis Menggunakan Software PVSYST. Transient: Jurnal Ilmiah Teknik Elektro, 10(4), 643–652. https://doi.org/10.14710/transient.v10i4.643-652

Kadang, J. M., & Windarta, J. (2021). Optimasi Sosial-Ekonomi pada Pemanfaatan PLTS PV untuk Energi Berkelanjutan di Indonesia. Jurnal Energi Baru dan Terbarukan, 2(2), 74–83. https://doi.org/10.14710/jebt.2021.11113

Katche, M. L., Makokha, A. B., Zachary, S. O., & Adaramola, M. S. (2024). Techno-Economic Assessment of Solar–Grid–Battery Hybrid Energy Systems for Grid-Connected University Campuses in Kenya. Electricity, 5(1), 61–74. https://doi.org/10.3390/electricity5010004

Kim, S. H., & Shin, Y.-J. (2023). Optimize the operating range to improve the cycle life of battery energy storage systems under uncertainty by managing the depth of discharge. Journal of Energy Storage, 73, 109144. https://doi.org/10.1016/j.est.2023.109144

Konopatzki, E. A., Oliveira, C. L. D., Marangoni, F., Edwiges, T., & Christ, D. (2023). Photovoltaic plant to supply energy for an electric coffee dryer - energy costs and Compensation. Engenharia Agrícola, 43(spe), e20220150. https://doi.org/10.1590/1809-4430-eng.agric.v43nepe20220150/2023

Lubna, L., Sudarti, S., & Yushardi, Y. (2021). Potensi Energi Surya Fotovoltaik Sebagai Sumber Energi Alternatif. Pelita: Jurnal Penelitian dan Karya Ilmiah, 21(1), 76–79. https://doi.org/10.33592/pelita.v21i1.1269

Lunag, M. N., Tandoc, R. E., Camat, R. K. S., Capito, R. C., Castañeda, L. M. F., Cobarrubias, E. P. P., Dela Cruz, J. J. N., Focasan, J. N. M., Perez, K. I. Q., & Rung, J. T. H. M. (2024). Life cycle analysis of a solar photovoltaic system in a Philippine university. IOP Conference Series: Earth and Environmental Science, 1419(1), 012044. https://doi.org/10.1088/1755-1315/1419/1/012044

Malik, M. I., Adriansyah, A., & Shamsudin, A. U. (2023). Techno-Economic Analysis Utilization of On-Grid Solar Photovoltaic Systems in Improving Energy Efficiency in Manufacturing Industries. Journal of Integrated and Advanced Engineering (JIAE), 3(2), 101–110. https://doi.org/10.51662/jiae.v3i2.96

Ming, M., Wang, R., Zha, Y., & Zhang, T. (2017). Multi-Objective Optimization of Hybrid Renewable Energy System Using an Enhanced Multi-Objective Evolutionary Algorithm. Energies, 10(5), 674. https://doi.org/10.3390/en10050674

Mussi, M., Pellegrino, L., Restelli, M., & Trovò, F. (2021). A voltage dynamic- based state of charge estimation method for batteries storage systems. Journal of Energy Storage, 44, 103309. https://doi.org/10.1016/j.est.2021.103309

Nurtiyanto, W. A., Rosyani, P., Solihin, L., & Prayogo, W. (2022). Analisis Efisiensi Inverter pada Grid-Connected 50 KWp Unpam Viktor. Journal of Computer System and Informatics (JoSYC), 3(4), 348–355. https://doi.org/10.47065/josyc.v3i4.2134

Roddis, P., Roelich, K., Tran, K., Carver, S., Dallimer, M., & Ziv, G. (2020a). What shapes community acceptance of large-scale solar farms? A case study of the UK's first 'nationally significant' solar farm. Solar Energy, 209, 235–244. https://doi.org/10.1016/j.solener.2020.08.065

Schulte, E., Scheller, F., Sloot, D., & Bruckner, T. (2022b). A meta-analysis of residential PV adoption: The important role of perceived benefits, intentions and antecedents in solar energy acceptance. Energy Research & Social Science, 84, 102339. https://doi.org/10.1016/j.erss.2021.102339

The Sustainable Energy Fund (SEF) Grant Program for Rooftop Solar PV Exceeds the Installed Capacity Target—SMEs and Social Facilities are the Largest Recipients of Incentives. (n.d.). UNDP. Retrieved April 19, 2025, https://www.undp.org/indonesia/news/sustainable-energy-fund-sef-grant-program

Usman, M. (2020). Analisis Intensitas Cahaya Terhadap Energi Listrik Yang Dihasilkan Panel Surya. Power Elektronik: Jurnal Orang Elektro, 9(2), 52–57. https://doi.org/10.30591/polektro.v9i2.2047

Venkatesh, Morris, Davis, & Davis. (2003). User Acceptance of Information Technology: Toward a Unified View. MIS Quarterly, 27(3), 425. https://doi.org/10.2307/30036540

Wang, C., Ahmad, S. F., Bani Ahmad Ayassrah, A. Y. A., Awwad, E. M., Irshad, M., Ali, Y. A., Al-Razgan, M., Khan, Y., & Han, H. (2023). An empirical evaluation of the technology acceptance model for Artificial Intelligence in e-commerce. Heliyon, 9(8), e18349. https://doi.org/10.1016/j.heliyon.2023.e18349

Wassie, Y. T., & Adaramola, M. S. (2021). Socio-economic and environmental impacts of rural electrification with Solar Photovoltaic systems: Evidence from southern Ethiopia. Energy for Sustainable Development, 60, 52–66. https://doi.org/10.1016/j.esd.2020.12.002

Wilcox, M. (2024, October 15). For Restaurants Cutting Their Carbon Footprint, Composting Food Scraps Is Just the Beginning. Eater. https://www.eater.com/2024/10/15/24268128/

Xue, L., Liu, J., Lin, X., Li, M., & Kobashi, T. (2024). Assessing urban rooftop PV economics for regional deployment by integrating local socioeconomic, technological, and policy conditions. Applied Energy, 353, 122058. https://doi.org/10.1016/j.apenergy.2023.122058