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Analysis and Design of a Rooftop Photovoltaic (PV) System in Bulaksumur, Yogyakarta Using Archelios Pro

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Abstract
This research focuses on the design and analysis of a rooftop photovoltaic (PV) system in Bulaksumur, Yogyakarta, using the Archelios Pro software. The objective of the study is to evaluate the efficiency and effectiveness of the PV system in terms of energy production and cost savings. The methods used include simulation and analysis with Archelios Pro, which allows for accurate modeling and estimation of energy production. The load profile at the research site was analyzed to determine the annual energy consumption, which reached 8,859 kWh. The designed PV system consists of 15 modules with a total capacity of 6.60 kWp. The results show that the PV system, without battery storage, produces an annual energy output of 10,185 kWh, meeting 115% of the household's annual energy needs. However, without battery storage, only 25.8% of the generated energy is directly usable. In the scenario with battery storage, self-consumption increases from 25.8% to 45.8%, and reliance on the electricity grid decreases from 5,510 hours to 4,179 hours per year. Economic analysis reveals annual cost savings of Rp 3,847,926, although the payback period exceeds 20 years. The use of the PV system also reduces annual carbon emissions by 3,965.25 kg of CO_2, contributing to efforts to achieve net-zero emissions in Indonesia.
Keywords: Photovoltaic; Rooftop; Archelios Pro

Introduction
The development of renewable energy technology has become a primary focus in global efforts to reduce reliance on fossil energy sources and lower greenhouse gas emissions. One of the renewable energy technologies experiencing significant growth is photovoltaic (PV) systems, which harness sunlight to generate electricity. These systems offer an environmentally friendly and sustainable solution to meet the increasing energy demand.

Indonesia, as a country located in the tropics, has great potential for utilizing solar energy (Almanda & Muttaqin, 2020; Hasanah et al., 2019; Sukmajati & Hafidz, 2015). Tropical regions receive more solar radiation compared to subtropical areas. Additionally, the sunlight conditions in tropical regions are more stable in terms of irradiation time throughout the year compared to subtropical regions, where sunlight hours tend to fluctuate more. Thanks to technological advancements, the use of solar energy in Indonesia continues to develop. One application of solar energy is converting it into electricity using solar panels (Anisah & Tarigan, 2023; Irawati et al., 2023). Solar panels can be utilized extensively in solar power plants or at a household scale by installing them on rooftops.

In terms of installation, solar power plants can be integrated with the main grid (on-grid system) (Fuaddin & Daud, 2020; Naim & Wardoyo, 2017; Syahrir, 2024) or can operate independently without connection to the main grid (off-grid/stand-alone system) (Wasono et al., 2024). Installing rooftop PV systems is a practical and efficient implementation to support the transition towards clean energy use (Nurjaman & Purnama, 2022).

In utilizing solar panels as converters of solar energy into electricity, the panels can be installed on the roofs of houses or buildings, commonly referred to as rooftop solar power plants. Rooftop solar power plants represent a future-oriented technology that is environmentally friendly and can provide a solution to the high electricity tariffs currently in place (Rafli et al., 2022; Satria & Syafii, 2018). The use of rooftop solar panels has become a popular alternative energy source, supporting energy needs for both personal use and connection to larger electrical grids.

The research location, Bulaksumur, Yogyakarta, was selected due to its representative and potential characteristics for PV system implementation. Bulaksumur has a relatively high level of solar radiation and supportive infrastructure, making it an ideal location for an in-depth study of the design and performance analysis of rooftop PV systems.

Archelios Pro, a PV simulation and analysis software, was used in this study to design and evaluate the performance of the proposed PV system (Axaopoulos et al., 2014). This software offers various features that enable comprehensive analysis, from 3D modeling to energy production estimation (González-Peña et al., 2021). By utilizing Archelios Pro, this research aims to provide accurate and practical guidance for designing an optimal rooftop PV system.

The goal of this study is to analyze and design an efficient and effective rooftop PV system for the location in Bulaksumur, Yogyakarta, using Archelios software. The results of this research are expected to make a significant contribution to the development and application of PV technology in Indonesia, as well as support global efforts in achieving energy sustainability. A comparison of this research's contributions with previous studies can be seen in Table 1 below.

Table 1. Comparision of Research Contributions

Research Title	Research Focus and Contribution
Simulation of Tilt Angle Changes on Energy Output of 34 Rooftop Solar Power Plants of 100 kWp in Indonesia (Gunawan & Sudiarto, 2021)	Focuses on the impact of tilt angle on the energy output generated by rooftop solar power plants.
Development of the Concept Design of Rooftop Solar Power Plant Practice Tool (Rumokoy et al., 2022)	Focuses on the development of energy distribution system components for rooftop PV systems.
Comparison of Energy Supply from Polycrystalline Solar Panels in On-Grid Solar Power Systems (Sugiarta et al., 2020)	Compares two solar panel configurations in on-grid solar power systems.
Cost Analysis for Solar Power Plant Construction at Taman Markisa in RT 01/RW 08 Mampang, Pancoran Mas, Depok City (Utami et al., 2022)	Analyzes the cost requirements for building a solar power plant in Taman Markisa.
Design and Simulation of On-Grid Rooftop Solar Power Plant (Rooftop PV) System on Office Buildings with a PLN Grid System (Damiri & Lamania, 2023)	Designs and simulates an effective on-grid PV system for office buildings.
Education on the Use of Rooftop Solar Panels for Lighting Systems at the Kuttab Al Firdaus Foundation (Meliala et al., 2021)	Identifies energy needs and designs a rooftop solar panel system for the Kuttab Al Firdaus Foundation.
Analysis and Design of a Rooftop Photovoltaic (PV) System in Bulaksumur, Yogyakarta Using Archelios Pro (Ours)	Analyzes the economic benefits of installing a rooftop PV system, examines the impact of battery storage on energy availability, and assesses carbon (CO2) emission reductions from using rooftop PV systems (Our Study).

Research Method

Location Profile

The simulation for the development of the photovoltaic (PV) system was conducted in Bulaksumur, Caturtunggal, Depok District, Sleman Regency, Special Region of Yogyakarta. As an educational hub known for the presence of Gadjah Mada University (UGM), Bulaksumur offers an ideal geographic location for PV technology development, thanks to its proximity to the equator, which provides high solar intensity year-round. With geographic coordinates at latitude -7.7715616 and longitude 110.3777, and an elevation of 180 meters above sea level, this location has minimal risk of wind and flood damage, supporting the safety and sustainability of the project. Additionally, with a weather station only 3 kilometers away, Bulaksumur allows for accurate weather data collection, which is crucial for PV system performance analysis. The presence of well-developed infrastructure and access to expert resources at UGM make Bulaksumur a strategic location for the implementation and development of renewable energy technologies.

Meteorogical Data

Meteorological data plays a critical role in the design and analysis of photovoltaic (PV) systems. The data used is sourced from Meteonorm Version 8.1, which includes information on global irradiation, direct irradiation, and diffuse irradiation in Bulaksumur, Yogyakarta. Meteonorm Version 8.1 records global irradiation at this location as 1,934 kWh/m²/year, covering the total solar radiation energy reaching the Earth's surface, both direct and scattered. This figure indicates a high potential for PV system development, as it represents the amount of energy that can be received by a horizontal surface per square meter annually. Additionally, the high direct irradiation of 1,027 kWh/m²/year indicates many sunny days, an ideal condition for solar panel efficiency. On the other hand, diffuse irradiation is 907 kWh/m²/year, which, although lower than direct irradiation, is still significant as it contributes to the total energy generated, especially on cloudy days. Graphs and visualizations that show the monthly distribution of solar irradiation and additional data such as wind speed factors, air temperature, and sunshine fraction provide a comprehensive picture of the meteorological conditions in Bulaksumur. Figure 1 below shows the global irradiation, direct irradiation, and diffuse irradiation data at the specified case study location.

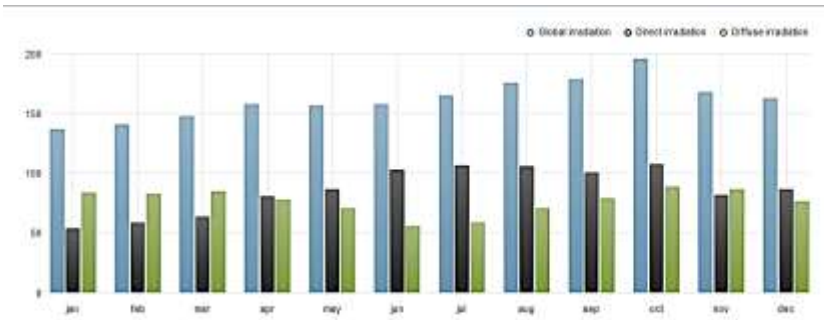


Figure 1. Meteorological Data Profile

Load Profile

The load profile is a quantitative representation of the electrical energy consumption by a system, whether it be a household, commercial building, or industry, over a specific period. In this simulation, the load profile is illustrated in Figure 2 below.


Self-consumption Tutorial ? Online help

List of electrical devices and profiles :

Name	Max power (kW)	Quantity	Total power (kW)	Total consumption (kWh/year)
Desktop computer	0.150	1	0.150	602.250
Incandescent lighting	0.060	17	1.020	2,209.483
LCD TV	0.075	1	0.075	109.500
Refrigerator	0.110	1	0.110	171.039
Heat pump: air extraction, cooling	1.000	1	1.000	5,767.000
Total	**1.395**	**21**	**2.355**	**8,859.272**

Figure 2. Load Profile

To determine the electrical power consumption over 24 hours each day, a graph of electricity usage is created as shown in Figure 3 below.

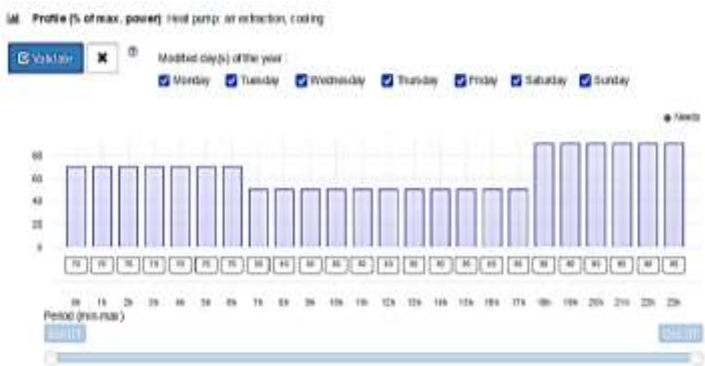


Figure 3. Daily Power Consumption

The analysis of the daily consumption graph shows significant fluctuations in energy usage throughout the day, with peak consumption occurring primarily in the evening. Meanwhile, the period from morning to afternoon shows very low energy usage, which may indicate that the devices are either not in operation or are minimally used during that time. Based on the data presented in Figure 2 and the daily load characteristics shown in Figure 3, the total energy consumption of all listed devices reaches 8,859.272 kWh per year. The maximum power used by the system is 2.355 kW. This analysis shows the distribution and use of energy in households throughout the year, providing a basis for evaluating the effectiveness of the designed photovoltaic system.

PV and Inverter Design

The design of the photovoltaic (PV) system and inverter is a crucial step to achieve optimal energy efficiency and maximize the performance of the installation. The PV panels are oriented facing north with a 0° angle, chosen because of Bulaksumur's proximity to the equator. The location's proximity to the equator allows the panels to receive maximum sunlight exposure throughout the day. The panel tilt is set between 10° and 15°, considered ideal given the almost vertical position of the sun in this region, ensuring the panels can effectively capture sunlight year-round.

This system uses SUNPROPOWER PV modules, type SP410-N108M16, with a total of 15 modules providing an overall capacity of 6.60 kWp. The inverter used is a product from SMA, suitable for household applications. Additionally, the system configuration is designed with optimal spacing between the tables and the implementation of backtracking features to reduce shading that may occur and significantly enhance energy collection efficiency. Once the installation configuration is determined, the configuration is input into Archelios Pro as shown in Figure 4 below.

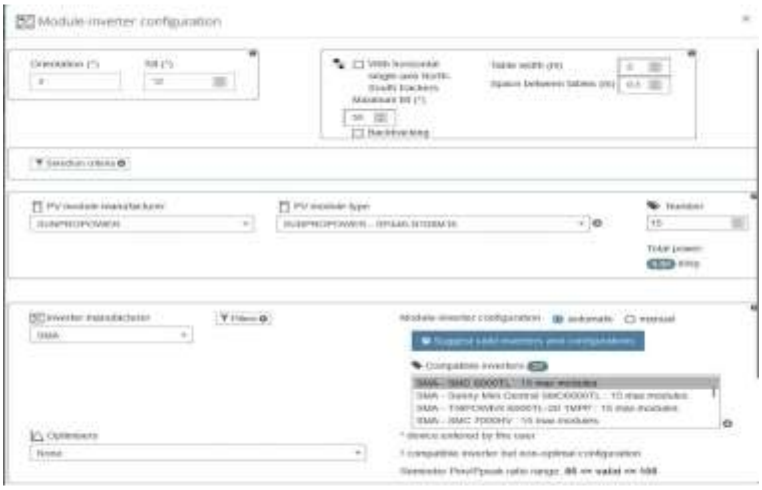


Figure 4. PV Installation Configuration

Cost Estimate

Based on the design discussion in the previous section, the necessary components and requirements for realizing the installation of a rooftop PV system in Bulaksumur, Yogyakarta, are identified. Below is the estimated cost plan needed for the PV installation, as shown in Table 2.

Table 2. Cost Estimate Plan

Description	Quantity	Price (Rp)
Photovoltaic Panels	15 Panels	23.947.554
Inverter	1 Unit	23.808.000
Battery 5.7 kWh	1 Unit	10.000.000
Installation Costs	1 Package	75.435.554

The prices listed in Table 1 are sourced from credible international sources. The displayed prices are the result of converting foreign currency exchange rates into Indonesian currency, resulting in a total cost of Rp. 75,435,554.

Result

Simulate Result without Storage

In the simulation without battery storage, the photovoltaic (PV) system produced an annual energy output of 10,185 kWh. The household's annual energy demand is 8,859 kWh, meaning that the PV system can meet 115% of the annual energy needs. However, of the total energy produced, only 2,626 kWh (25.8%) is consumed directly by the household. This indicates that a large portion of the energy, 7,560 kWh (74.2%), is overproduced and sent back to the power grid due to the absence of storage to save the excess energy. The energy deficit is 6,234 kWh, with the household relying on the grid for 5,510 hours to meet its energy needs when the PV system cannot supply enough power, such as at night or during bad weather. Table 5 and 6 shows the simulation results without storage.

Figure 5. Simulation Results Without Battery Storage

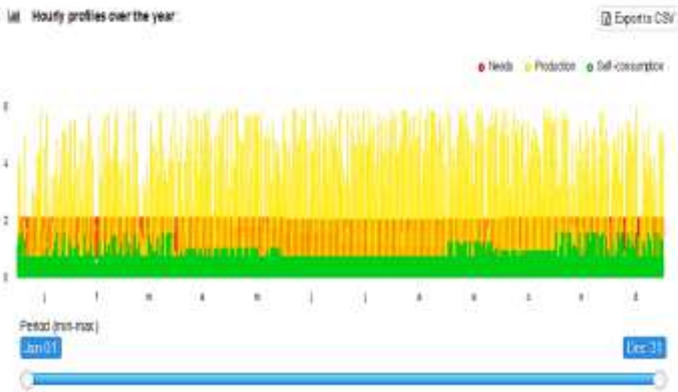


Figure 6. Annual PV Usage Profile Without Battery Storage

The graph indicates significant periods where excess energy is produced and not effectively utilized, as seen from the large yellow area compared to the green area. This underscores the importance of integrating energy storage systems to increase the self-consumption ratio, which in turn can reduce the need to import energy from the grid and optimize the economic and environmental benefits of the PV system. Focusing on improving self-consumption and energy storage will support efforts to achieve higher energy efficiency and greater sustainability of the energy system.

Simulate Result with Battery Storage

In the simulation with battery storage, results show a significant improvement in the utilization of energy produced by the PV system. Total energy production remains the same at 10,185 kWh, and the household's annual energy demand is still 8,859 kWh. However, self-consumption increases to 4,665 kWh, covering 45.8% of total energy production and meeting 52.7% of the energy demand. With battery usage, over-production decreases to 5,342 kWh (52.4%), as some of the energy is stored and used when sunlight is not available. The energy deficit reduces to 4,194 kWh, and dependence on the power grid decreases to 4,179 hours. The battery usage of 2,217 kWh shows a significant contribution in providing additional energy when needed, allowing the household to achieve energy autonomy for 2 hours without sunlight. Figure 7 and 8 show the simulation results with storage.

Figure 7. Simulation Results with Battery Storage

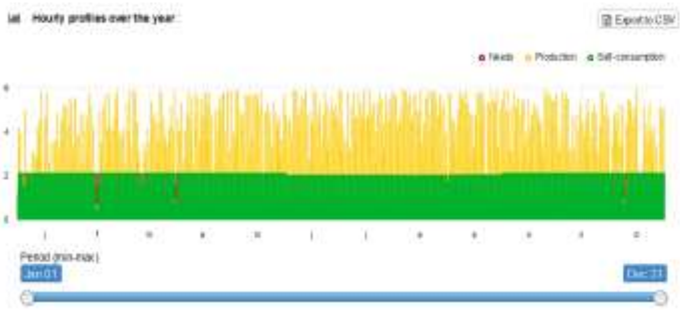


Figure 8. Annual PV Usage Profile with Battery Storage

The graph illustrates the daily profile of energy production and consumption from the PV system throughout the year, with the integration of battery storage. The yellow color represents energy produced by the PV system, which peaks during daylight hours. The green color indicates energy directly consumed from PV production, which occurs throughout the day. The red color marks the load demand, which at certain times, particularly at night or on cloudy days, exceeds PV production, highlighting the importance of battery storage to meet these needs. This shows the effectiveness of the PV system with batteries in managing fluctuations in production and consumption, enhancing the independence and efficiency of renewable energy use.

Comparison of Simulation Results of Rooftop PV System with and Without Energy Storage

The analysis of the simulation results indicates that the PV system with battery storage provides significant benefits compared to the system without storage. Annual energy production is the same for both systems, at 10,185 kWh. However, the use of storage increases self-consumption from 25.8% to 45.8%, reduces over-production from 74.2% to 52.4%, and lowers the energy deficit from 6,234 kWh to 4,194 kWh. Dependence on the power grid is also reduced from 5,510 hours to 4,179 hours per year, with the battery system allowing energy autonomy for 2 hours without sunlight. Although the system with storage requires a larger initial investment, the increased efficiency and energy cost savings indicate that storage can enhance household energy stability and independence in the long term. The comparison can be seen in Table 3.

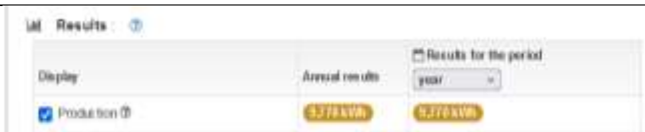
Table 3. Comparison of Photovoltaic Systems without and with Storage

Parameter	Without Storage	With Storage
Energy Production (kWh/year)	10,185	10,185
Energy Demand (kWh/year)	8,859	8,859
Self-Consumption (kWh/year)	2,626 (25.8%)	4,665 (45.8%)
Over-Production (kWh/year)	7,560 (74.2%)	5,342 (52.4%)
Energy Deficit (kWh/year)	6,234	4,194
Dependence on the Grid (hours)	5,510 hours	4,179 hours
Battery Usage (kWh)	0	2,217
Autonomy Without Sunlight (hours)	0	2 hours

Comparison of Tilt and Orientation Selection

Comparing the tilt angle and orientation configurations of the photovoltaic (PV) panels is an important step to optimize energy production and system efficiency. Based on simulations conducted with various combinations of tilt and orientation, it was found that different configurations significantly impact annual energy output. The various configurations of tilt angle and orientation of PV panels can be seen in Table 4.

Table 4. Comparison of Various Configurations of Tilt Angle and Orientation of PV Panels

Parameter	Simulation Results
Tilt 30° with North Orientation (0°)	
Tilt 10° with North Orientation (0°)	
Tilt 20° with North Orientation (0°)	
Tilt 30° with South Orientation (180°)	

Simulations of various tilt and orientation configurations of PV panels show that the 10° tilt configuration with a north orientation (0°) produces the highest energy output of 10,185 kWh per year. This tilt angle is optimal for the location in Yogyakarta, which is near the equator, where sunlight arrives almost vertically throughout the year, allowing for maximum sunlight capture throughout the day. In contrast, a 30° tilt with a north orientation (0°) produces 9,770 kWh per year, and a 20° tilt with a north orientation (0°) produces 10,083 kWh per year. Although lower than the 10° tilt, this configuration is still more efficient than steeper tilts. On the other hand, the 30° tilt with a south orientation (180°) shows the lowest output at 8,380 kWh per year, as this orientation reduces the amount of sunlight received in the southern hemisphere. These results confirm that a 10° tilt with a north orientation is the best configuration to maximize energy output, while other configurations are less efficient at capturing sunlight in the study location.

Cost Estimate and Economic Analysis

To understand the economic feasibility of the photovoltaic (PV) system with and without battery storage, a cost analysis and economic evaluation were conducted. The evaluated system includes a total investment cost of $4,629.79 with annual maintenance costs of $57. The project uses a grid-connected model without subsidies, with an inflation rate of 2% and a bank interest rate of 3.5%. The price of the produced energy is set at $0/kWh since all generated energy is used for self-consumption and not sold back to the power grid. The following economic simulation is shown in Figure 9.

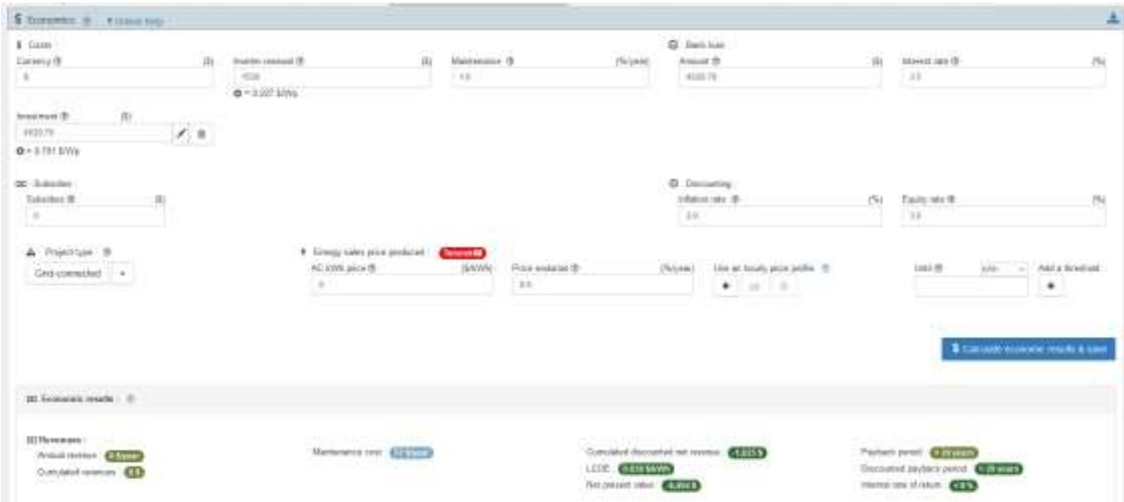


Figure 9. Cost Estimate and Economic Analysis

Based on the above simulation analysis, the Levelized Cost of Energy (LCOE) for the PV system is $0.038/kWh, equivalent to 619.15 IDR. To further examine the comparison between using PV and not using PV, see the following table.

Table 5. Electricity Costs Without Photovoltaic System

Annual Energy Demand (kWh)	Price per kWh	Total (IDR)
8,859	1,444	12,792,396

Table 6. Electricity Costs Using Photovoltaic System

Annual Energy Demand (kWh)	Price per kWh	Total (IDR)
4,665 (PV)	619.15	2,888,334
4,194 (Grid)	1,444	6,056,136
		8,944,470

$$Total\ Savings = C_{Without\ PV} - C_{With\ PV} \quad (1)$$

Where Total Savings is the amount of energy cost savings, C_without PV is the energy cost without using the PV system, and C_with PV is the total energy cost when using the PV system. When comparing the annual energy demand without the PV system, which amounts to 8,859 kWh with the PLN cost of IDR 1,444 per kWh, the total annual energy cost is IDR 12,792,396. On the other hand, with the implementation of the PV system, grid energy usage decreases to 4,194 kWh, and the energy generated from the PV system is 4,665 kWh, making the total annual energy cost IDR 8,944,470. This annual cost difference results in savings of IDR 3,847,926, indicating that even though the payback period is over 20 years and the internal rate of return (IRR) is less than 0%, the PV system still provides significant cost savings in the long term.

Carbon Gas Reduction Estimate

To calculate the reduction in carbon emissions from the use of the photovoltaic (PV) system compared to the scenario without PV, we will compare the carbon emissions generated in both scenarios based on household energy needs and the energy sources used. Without the PV system, the annual energy demand is 8,859 kWh, resulting in carbon emissions of 7,530.15 kg CO_2 per year, based on an average emission factor of 0.85 kg CO_2 per kWh from fossil fuel power plants. With the PV system, energy demand is split between 4,665 kWh from PV and 4,194 kWh from the grid. The carbon emissions from the grid energy amount to 3,564.9 kg CO_2 per year, using the same emission factor.

$$Carbon\ Emissions\ Reduction = Carbon\ Emission\ Without\ PV - \ Carbon\ Emission\ With\ PV \quad (2)$$

Thus, we get: 7,530.15 kg CO_2 − 3,564.9 kg CO_2 = 3,965.25 kg CO_2/year.

Conclusion and Future Work

This research successfully designed and analyzed a rooftop PV system in Bulaksumur, Yogyakarta, using Archelios Pro software. The results from this simulation show that the use of photovoltaic (PV) systems not only provides energy cost savings but also significantly reduces carbon emissions. In the scenario without PV, the annual carbon emissions produced to meet the household energy needs of 8,859 kWh amount to 7,530.15 kg CO_2. With the implementation of the PV system, most of the energy needs are met from the clean energy generated by the PV, with only 4,194 kWh sourced from the grid, resulting in carbon emissions of 3,564.9 kg CO_2 per year. This means that the use of the PV system reduces annual carbon emissions by 3,965.25 kg CO_2, equivalent to avoiding the burning of over 1,580 liters of gasoline. Furthermore, the economic analysis shows annual cost savings of up to Rp 3,847,926, underscoring that the initial investment in the PV system will be recouped through reduced energy costs in the long term. This benefit contributes significantly to reducing the household carbon footprint and supports climate change mitigation efforts, while also demonstrating that adopting renewable energy technology can be both an economical and ecological solution.

Future research should explore the integration of advanced energy management systems to further optimize the use and storage of energy in PV installations. Additionally, expanding the research to various locations with different climate conditions will help validate the findings and enhance the generalization of the results. Research could also investigate the potential integration of PV systems with other renewable energy sources, such as wind or hydro, to provide more comprehensive and resilient energy solutions. Finally, in-depth socio-economic analysis of local community acceptance and willingness to adopt PV technology will be crucial for large-scale implementation.

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