Optimization of Capacity and Performance Analysis of Rooftop Solar Power Plants Using MATLAB Based on Load Profiles and Solar Irradiance at Politeknik Negeri Medan

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ABSTRACT

The demand for electrical energy in the education sector continues to increase along with the growing use of electrical equipment, laboratories, and academic activities. Politeknik Negeri Medan, as a vocational education institution, has relatively high electrical energy consumption; therefore, a more efficient and environmentally friendly alternative energy source is required. This study aims to analyze and optimize a rooftop Solar Power Plant (SPP) system using MATLAB based on building load profiles and solar irradiance intensity in Medan City. The research method was carried out through the collection of building electrical load profile data, solar irradiance data, and rooftop area measurements. Simulation and optimization of the rooftop photovoltaic system were conducted using MATLAB to analyze system capacity, number of solar panels, energy performance, system efficiency, solar panel distribution, and potential electrical energy savings. The results showed that the total electrical energy demand of the Politeknik Negeri Medan building was 5,410 kWh/day with a total installed power of 1,352.57 kW. Based on the simulation results, the optimum photovoltaic system capacity was 1,516.25 kWp with 2,757 solar panels of 550 Wp capacity each. The photovoltaic system was able to generate relatively stable electrical energy throughout the year, with solar irradiance having a significant influence on the system output energy. The analysis also showed that the effective rooftop area of 11,601.61 m² was sufficient for solar panel installation requiring an area of 8,491 m². In addition, the photovoltaic system has the potential to reduce electricity costs by approximately IDR 2.81 billion per year. This study demonstrates that the implementation of a rooftop photovoltaic system using MATLAB at Politeknik Negeri Medan is feasible from technical, economic, and environmental perspectives. The use of MATLAB improves the quality of photovoltaic system analysis through detailed and systematic energy performance simulations and solar panel configuration optimization..

Kata kunci: *Rooftop Photovoltaic, MATLAB, Solar Energy, Photovoltaic System Optimization, Irradiance, Load Profile, Renewable Energy*

I. INTRODUCTION

The demand for electrical energy in Indonesia continues to increase every year along with technological development, population growth, and the rising level of activities in the education, industrial, and household sectors. The continuous increase in electricity consumption has led to a greater dependence on fossil fuel-based power plants. This condition creates various problems, such as increasing electricity operational costs, limited fossil energy resources, and rising greenhouse gas emissions that negatively impact the environment (

One of the efforts that can be undertaken to reduce dependence on fossil energy is the utilization of renewable energy sources, particularly solar energy.

Indonesia, as a tropical country, has significant solar energy potential because it is located in the equatorial region with relatively stable solar radiation intensity throughout the year. The utilization of solar energy through Photovoltaic Power Plant (PVPP) systems has become one of the effective solutions in supporting the clean energy transition and reducing electricity consumption from the PLN grid [3–4].

In the education sector, electrical energy demand tends to increase due to the use of various electrical equipment such as air conditioners, computers, laboratory equipment, and practical training machines.

Politeknik Negeri Medan, as one of the vocational education institutions, has numerous laboratory buildings, workshops, classrooms, and administrative buildings with relatively high electricity consumption. The high electricity demand increases campus operational electricity costs; therefore, a more efficient and sustainable alternative energy source is required [5–7]. The implementation of rooftop photovoltaic systems in campus areas has become one of the promising solutions because it utilizes building rooftop areas as locations for solar panel installation without requiring additional land. In addition to generating electrical energy independently, rooftop photovoltaic systems can also help reduce electricity consumption from PLN and support the implementation of green campus and environmentally friendly energy systems in the education sector [8].

Several previous studies have discussed the planning and analysis of rooftop photovoltaic systems in educational and commercial buildings. However, most studies still focus on manual solar panel capacity calculations and have not conducted in-depth system performance analysis using computational simulations. In addition, several studies only discuss the estimation of solar panel requirements without considering panel quantity optimization, panel distribution based on building load profiles, the influence of solar irradiance, system efficiency, and electrical energy-saving analysis [9–13].

Previous studies also generally have not integrated photovoltaic system performance simulations using MATLAB to analyze the relationship between load profiles, solar irradiance, solar panel capacity, system output energy, and photovoltaic system efficiency dynamically. In fact, the use of MATLAB can help produce more detailed, systematic analyses that closely represent actual field conditions [14–15]. Based on these conditions, there is a research gap in previous studies, namely the absence of MATLAB-based rooftop photovoltaic system analysis and optimization that considers building load profiles, solar radiation intensity, system energy performance, solar panel quantity optimization, system efficiency, and the potential for electrical energy savings at Politeknik Negeri Medan buildings. The novelty of this research lies in the use of MATLAB as a simulation and optimization tool for rooftop photovoltaic systems based on actual building load profile data and irradiance data from Medan City. This study not only performs solar panel capacity calculations but also conducts photovoltaic energy performance simulations, system efficiency analysis, solar panel quantity optimization, panel distribution across several campus buildings, and analysis of potential electrical energy savings.

Furthermore, this research integrates technical and economic analyses of photovoltaic systems into a single simulation model, making the research results more comprehensive than previous studies. The use of MATLAB enables the analysis process to be carried out in greater detail through graphical visualization of energy performance, system efficiency, and photovoltaic capacity optimization based on actual site conditions. This study is expected to become one of the references in the development of renewable energy systems in the education sector and support the implementation of more efficient and sustainable clean energy technologies in Indonesia..

II. LITERATURE REVIEW

2.1. Solar Energy

Solar energy is one of the renewable energy sources derived from solar radiation and can be utilized to generate electrical and thermal energy. Indonesia, as a tropical country, has considerable solar energy potential because it is located in the equatorial region with relatively stable solar radiation intensity throughout the year. The utilization of solar energy has become one of the solutions to reduce dependence on fossil energy and support the development of clean and environmentally friendly energy systems [16].

Solar energy has several advantages, such as producing no pollution, providing abundant energy resources, having low operational costs, and being applicable in various sectors such as education, industry, and households. In photovoltaic power plant systems, solar energy is converted into electrical energy using solar panels through the photovoltaic process [17]..

2.2. Photovoltaic Power Plant (PVPP)

A Photovoltaic Power Plant (PVPP) is a power generation system that utilizes solar radiation through photovoltaic (PV) panels to generate electrical energy. A photovoltaic system operates by converting photon energy from sunlight into direct current (DC) electricity, which is then converted by an inverter into alternating current (AC) electricity to supply electrical loads [18].

In general, a photovoltaic system consists of solar panels, inverters, protection systems, and electrical loads. Some systems also use batteries as electrical energy storage devices. Photovoltaic systems are widely utilized because they can reduce electricity consumption from the PLN grid and support the use of environmentally friendly renewable energy [18].

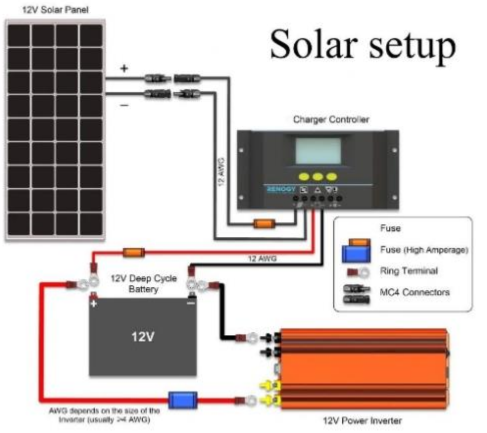

Figure 1. Main Components of a Photovoltaic System

2.3. Rooftop Photovoltaic System

A rooftop photovoltaic system is a solar power generation system installed on building rooftops. This system utilizes rooftop areas as locations for solar panel installation, eliminating the need for additional land [6].

The implementation of rooftop photovoltaic systems is widely applied in educational buildings, offices, industries, and residential buildings because it can help reduce electricity consumption from PLN while lowering operational electricity costs. In addition, rooftop photovoltaic systems support the implementation of green building concepts and clean energy utilization [4].

In designing rooftop photovoltaic systems, analysis of rooftop area, panel installation position, solar radiation direction, and electrical load profiles is required to ensure optimal electrical energy generation [19]..

2.4. Solar Radiation Intensity (Irradiance)

Irradiance refers to the amount of solar radiation energy received by a surface per unit area within a certain period. Solar irradiance is one of the main parameters affecting photovoltaic system performance [15].

The higher the irradiance value, the greater the electrical energy generated by the solar panels. Conversely, during cloudy or rainy weather conditions, solar radiation intensity decreases, resulting in reduced solar panel output power [2].

Irradiance data are generally obtained from meteorological or satellite databases such as NASA Surface Meteorology and Solar Energy. In this study, irradiance data from Medan City were used as the basis for simulating photovoltaic system energy performance using MATLAB [2].

2.5. Electrical Load Profile

An electrical load profile represents the characteristics of electricity consumption within a system over a certain period. Load profiles are used to identify electricity consumption patterns so that appropriate power generation capacity planning can be performed according to load requirements.

In educational buildings, electrical load profiles are influenced by the use of laboratories, air conditioning systems, computers, practical training machines, lighting systems, and learning activities. Load profile analysis is essential in photovoltaic system planning because solar panel capacity must be adjusted to the building's energy demand to ensure optimal system operation [20].

2.6. MATLAB

MATLAB (Matrix Laboratory) is numerical computing software used for data analysis, simulation, programming, and engineering system visualization. MATLAB is widely used in electrical engineering because of its capability to perform fast and accurate system simulations [2].

In this study, MATLAB was used to calculate photovoltaic system capacity, simulate solar panel output energy, analyze system efficiency, and optimize the number of solar panels based on load profiles and solar irradiance data.

The use of MATLAB in this research aims to produce more detailed photovoltaic system analyses that closely represent actual field conditions.

2.7. Photovoltaic System Efficiency

Photovoltaic system efficiency refers to the capability of the system to convert solar energy into electrical energy that can be utilized by electrical loads. System efficiency is influenced by several factors, such as solar panel temperature, solar radiation intensity, inverter losses, and cable losses.

The higher the system efficiency, the greater the electrical energy generated by the solar panels. Conversely, increasing solar panel temperature causes a reduction in system efficiency due to the increase in the panel's internal resistance [21].

System efficiency analysis is very important to determine the actual performance of photovoltaic systems so that system configuration optimization can be carried out effectively..

2.8. Photovoltaic System Optimization

Photovoltaic system optimization is the process of determining the most effective system configuration based on energy demand, solar panel capacity, installation area, and system performance.

In this study, optimization was conducted using MATLAB to determine the optimum number of solar panels, photovoltaic system capacity, panel distribution on buildings, and system output energy.

The optimization process aims to ensure that the photovoltaic system can generate maximum electrical energy with more efficient area utilization and lower costs [16]. Through optimization, photovoltaic systems can be designed according to the actual energy requirements of buildings, thereby improving overall system performance [22]..

2.9. State of the Art

Research related to rooftop photovoltaic systems has been widely conducted in various sectors such as education, industry, and commercial buildings. Most previous studies focused on solar panel capacity calculations and estimation of photovoltaic system output energy using manual calculation methods [16–22]. However, several previous studies have not performed in-depth system performance simulations using computational software and have not considered solar panel quantity optimization based on building load profiles, solar radiation intensity, system efficiency, and integrated electrical energy-saving analysis.

In this study, the development was carried out through simulation and optimization of rooftop photovoltaic systems using MATLAB based on the actual load profile of Politeknik Negeri Medan buildings and irradiance data from Medan City. This study not only calculates solar panel capacity but also performs photovoltaic energy performance simulations, solar panel quantity optimization, system efficiency analysis, panel distribution according to rooftop area, and electrical energy-saving analysis. The novelty of this study lies in the integration of building load profile analysis, photovoltaic energy performance simulation using MATLAB, solar panel quantity optimization, and system efficiency analysis within a single research model. As a result, the analysis becomes more detailed and closely represents actual field conditions..

III. RESEARCH METHODOLOGY

To conduct the analysis process, several stages were required, including data collection, data processing, and conclusion drawing. The research methodology is described as follows.

3.1 Research Flowchart

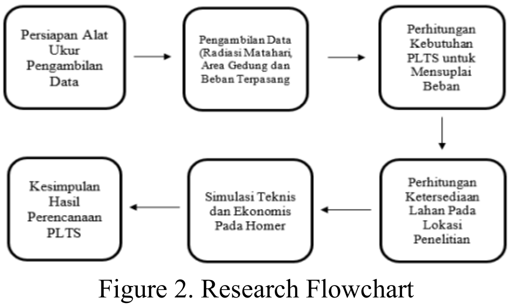

Figure 2. Research Flowchart

The diagram above illustrates the overall stages of the research conducted in this study. The first step involved preparing measurement instruments for data collection. The required instruments included solar radiation meters, multimeters, clamp meters, and stopwatches. The next stage was data collection using the prepared measuring instruments.

After the data were obtained, calculations of photovoltaic system requirements were performed to supply the electrical loads at the research location. In addition, the availability of installation area at the research site was also calculated as one of the planning parameters. Furthermore, technical and economic simulations were conducted using HOMER software, from which conclusions regarding the photovoltaic system planning were obtained.

3.2 Fishbone Research Diagram

The research framework illustrated in the form of a fishbone diagram is presented as follows

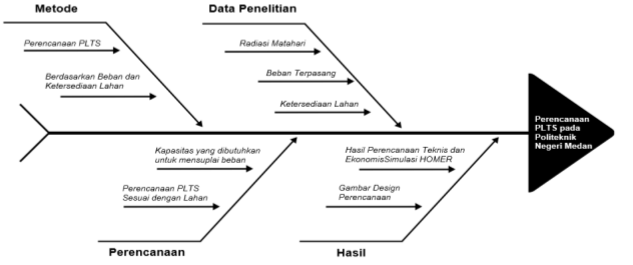

Figure 3. Fishbone Research Diagram

3.3 Data Collection.

To support this research, several types of data were required, including the following :

1. Solar Radiation Intensity Data
   Solar radiation intensity data were obtained using HOMER software. The data source was provided by the National Aeronautics and Space Administration (NASA). The data used in this study covered the period from 1983 to 2020.
2. Electrical Load Data and Electricity Cost Data
   The total electrical load was calculated based on electricity payment records for at least the previous two months. The total load data obtained from electricity bills at the research location were then compared with manual load calculations to verify the accuracy of the data. Furthermore, the average electricity expenditure for the building was analyzed.
3. The building area was measured using measuring instruments to determine the length and width of the installation area. The total area was then calculated and analyzed using Google Earth. This available area was used as the basis for planning solar panel installation using HOMER software.

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3.4 Perencanaan dan Analisis

The steps used in designing the photovoltaic system to supply the electrical load at Politeknik Negeri Medan are as follows :

1. Calculating the total electrical load at the research location. The loads were classified into three categories: motor loads, electronic loads, and lighting loads. After obtaining the three load classifications, the total electrical load at the research location was calculated.
2. Designing the photovoltaic system capacity according to the load requirements. The calculated load demand was used to determine the required photovoltaic system capacity to adequately supply the electrical load.

3.5 Simulation and Optimization Using MATLAB

In this study, simulation and optimization of the photovoltaic system were carried out using MATLAB software. The simulation was conducted to analyze photovoltaic system performance based on building load profiles, solar irradiance data from Medan City, solar panel capacity, and the available rooftop installation area.

MATLAB was used to :

1. Calculate the required photovoltaic system capacity.
2. Determine the optimum number of solar panels.
3. Analyze photovoltaic output power.
4. Analyze photovoltaic system efficiency.
5. Simulate daily and monthly electrical energy production.
6. Distribute solar panels across each building.
7. Compare manual calculation results with MATLAB simulation results..

The MATLAB simulation stages included :

1. Inputting building load data.
2. Inputting solar irradiance data from Medan City.
3. Calculating electrical energy requirements.
4. Calculating photovoltaic system capacity.
5. Simulating solar panel output power.
6. Analyzing system efficiency.
7. Optimizing the number of solar panels.
8. Analyzing panel distribution based on rooftop area availability.

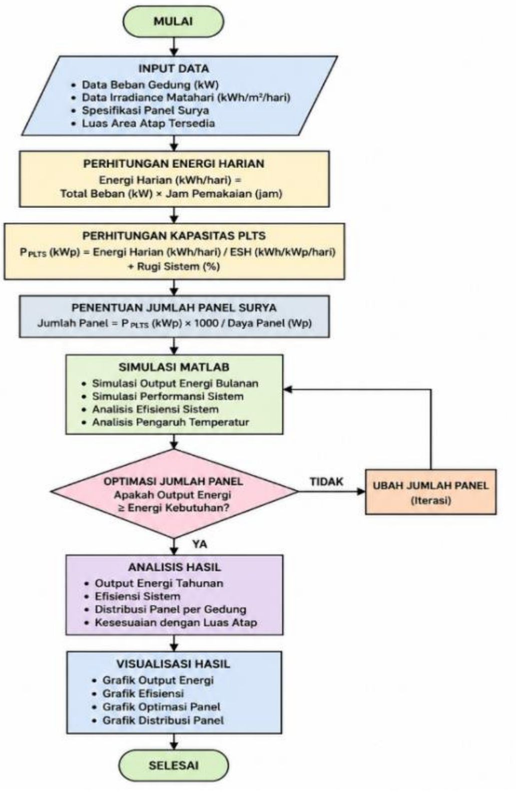

Figure 4. MATLAB Simulation and Optimization Flowchart

3.6 Mathematical Equations and MATLAB Simulation

Several mathematical equations were used in this study to calculate electrical energy demand, photovoltaic system capacity, number of solar panels, system efficiency, and energy output simulation using MATLAB.

3.6.1 Daily Load Energy Calculation

Daily energy consumption was calculated using the following equation [2]:

$$E=P\times t \tag{1}$$

Where :

- (E) = daily electrical energy (Wh)
- (P) = load power (W)
- (t) = operating time (hours)

3.6.2 Photovoltaic Output Power Calculation

The output power of the photovoltaic system was calculated using the following equation [2]:

$$P_{out}=V\times I \tag{2}$$

Where:

- (Pout) = photovoltaic output power (W)
- (V) = output voltage (Volt)
- (I) = output current (Ampere))

3.6.3 Photovoltaic System Capacity Calculation

The photovoltaic system capacity was calculated based on daily energy consumption and Equivalent Sun Hour (ESH) values [2].

PPLTS = E harian / ESH (3)

Where:

- PPLTS = photovoltaic system capacity (Wp)
- E harian = daily load energy (Wh)
- ESH = Equivalent Sun Hour (hours)

3.6.4 Solar Panel Quantity Calculation

The number of solar panels was calculated using the following equation [7]:

N= P total / P panel (4)

Where:

- N = number of solar panels
- Ptotal = total photovoltaic system capacity (Wp)
- Ppanel = solar panel capacity (Wp)

3.6.5 Perhitungan Efisiensi Sistem

The photovoltaic system efficiency was calculated using the following equation [7]:

η=Pout/Pin×100 (5)

Where:

- η = system efficiency (%)
- Pout = system output power (W)
- Pin = solar input power (W)

3.6.6 Photovoltaic Energy Output Simulation

The photovoltaic energy output simulation using MATLAB was calculated using the following equation [7]:

EPV = G×PPLTS×η (6)

Where:

- EPV = photovoltaic output energy (kWh)
- G = solar irradiance
- PPLTS = photovoltaic system capacity
- η = system efficiency

These equations were implemented in MATLAB to simulate photovoltaic system energy output based on monthly variations in solar irradiance.

IV. RESULTS AND DISCUSSION

4.1 Building Load Profile Analysis

Based on the survey results conducted at Politeknik Negeri Medan buildings, the total installed electrical power was found to be 1,352,570 W or 1,352.57 kW, consisting of 26 buildings with different load characteristics. The highest load was recorded in Building Z at 150,900 W, while the lowest load was observed in Building T at 1,050 W. Assuming an average load operating duration of 4 hours per day, the total electrical energy consumption at the research location was calculated to be 5,410 kWh/day.

The analysis results indicate that laboratory and workshop buildings have higher electricity consumption compared to administrative buildings and regular classrooms. Therefore, photovoltaic system optimization is required so that electrical energy distribution can be adjusted according to the specific needs of each building.

In this study, MATLAB was used to visualize the building load distribution in order to obtain the electrical energy consumption characteristics within the campus area.

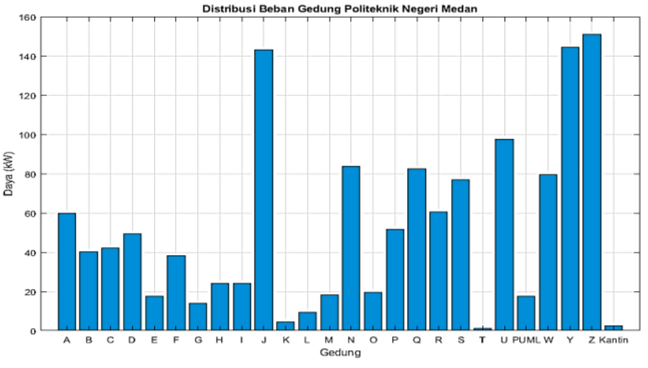

Figure 5. Building Load Profile

Based on Figure 5, the electrical power distribution at Politeknik Negeri Medan buildings is uneven. Building Z has the largest electrical power demand of 150.9 kW, followed by Building Y at 144.35 kW and Building J at 143.06 kW. The high power consumption in these buildings is influenced by laboratory activities and the use of high-power electrical equipment.

Meanwhile, Building A has lower electricity consumption compared to laboratory buildings. This analysis indicates that the photovoltaic system capacity requirements vary among buildings; therefore, optimization of solar panel distribution based on the load characteristics of each building is necessary.

4.2 Solar Radiation Intensity Analysis

Solar radiation data for Medan City were obtained from the NASA database through HOMER software. Based on the processed data, the average solar radiation intensity was 4.46 kWh/m²/day. The highest intensity occurred in February at 4.990 kWh/m²/day, while the lowest intensity occurred in November at 4.017 kWh/m²/day.

Monthly variations in solar radiation intensity affect the output power of the photovoltaic system. The higher the irradiance value, the greater the electrical energy generated by the solar panels. Therefore, irradiance data were used in MATLAB simulations to analyze photovoltaic energy performance throughout the year.

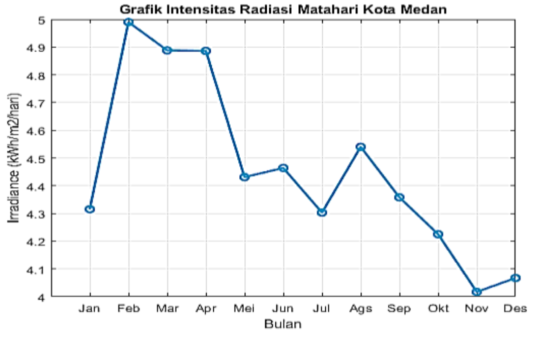

Figure 6. Solar Radiation Intensity

Based on Figure 6, the solar radiation intensity in Medan City fluctuates monthly. The highest irradiance value occurred in February at 4.990 kWh/m²/day, while the lowest value occurred in November at 4.017 kWh/m²/day.

Although irradiance variations occurred, the solar radiation values in Medan City remained relatively stable throughout the year. This condition indicates that Medan City has strong solar energy potential for rooftop photovoltaic system implementation. In addition, irradiance variations also influenced photovoltaic system output energy in the MATLAB simulation.

4.3 Analysis of Photovoltaic Energy Output Simulation Using MATLAB

MATLAB simulation was conducted to analyze the electrical energy generated by the photovoltaic system based on monthly irradiance variations. The simulation used building load profile data, 550 Wp solar panel capacity, and irradiance data from Medan City.

The simulation results showed that photovoltaic output energy varied each month following changes in solar radiation intensity. The highest energy output occurred in February due to the highest irradiance value, while the lowest energy output occurred in November due to reduced solar radiation intensity.

Based on the simulation results, the photovoltaic system was capable of generating sufficient electrical energy to help supply the energy demand of Politeknik Negeri Medan buildings.

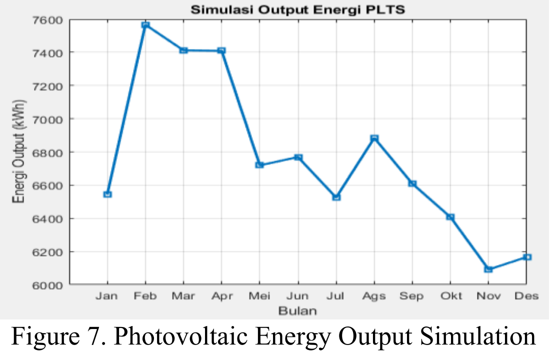

Figure 7. Photovoltaic Energy Output Simulation

Based on Figure 7, the photovoltaic system output energy changes according to monthly irradiance variations. The highest energy output occurred in February at 7,560 kWh due to the highest irradiance value.

Meanwhile, the lowest energy output occurred in November at 6,100 kWh due to reduced solar radiation intensity. The MATLAB simulation results indicate that irradiance variation significantly affects photovoltaic system energy performance.

Overall, the photovoltaic system was able to generate relatively stable electrical energy throughout the year, thereby helping to supply the electricity demand of Politeknik Negeri Medan buildings.

4.4 Capacity Analysis and Optimization of Solar Panel Quantity

Based on the calculation results, the required photovoltaic system capacity was 1,516.25 kWp with a total of 2,757 solar panels of 550 Wp capacity each.

In this study, MATLAB was used to optimize the number of solar panels based on electrical energy demand and rooftop area availability. The simulation results showed that increasing the number of solar panels increased photovoltaic system output energy; however, it also had to be adjusted according to load demand and available installation area.

Panel optimization was conducted through iterative calculations until the most optimal and efficient panel configuration was obtained.

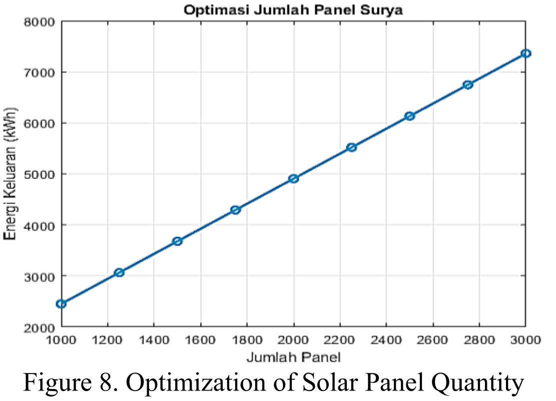

Figure 8. Optimization of Solar Panel Quantity

Based on Figure 8, increasing the number of solar panels also increases photovoltaic system output energy. With 1,000 panels, the system output energy was only 2,400 kWh, whereas with 2,757 panels, the generated energy increased to 6,540 kWh.

The MATLAB optimization results showed that 2,757 solar panels were able to optimally meet the electrical energy demand of Politeknik Negeri Medan buildings.

Adding more panels beyond this value would indeed increase energy output but would require larger installation areas and higher investment costs.

Therefore, 2,757 solar panels were considered the optimum configuration based on energy demand and rooftop area availability.

4.5 Photovoltaic System Efficiency Analysis

Photovoltaic system efficiency is influenced by solar panel temperature, solar radiation intensity, inverter losses, and cable losses. MATLAB simulation results showed that increasing panel temperature reduced system efficiency.

Under normal temperature conditions, solar panel efficiency remained optimal. However, when temperature increased, the internal resistance of the panels also increased, causing lower system output power.

In addition, system losses also affected the total electrical energy that could be utilized by building loads.

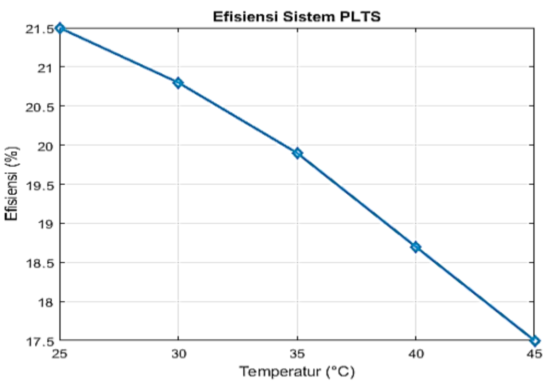

Figure 9. Photovoltaic System Efficiency

Based on Figure 9, photovoltaic system efficiency decreased as solar panel temperature increased. At 25°C, system efficiency reached 21.5%, while at 45°C, efficiency decreased to 17.5%.

This efficiency reduction occurred due to the increase in internal resistance as panel temperature increased. Consequently, the actual panel output power became lower than the theoretical output power.

The MATLAB simulation results indicate that temperature is one of the important factors affecting photovoltaic system performance and therefore must be considered in photovoltaic system planning and installation.

4.6 Rooftop Area Availability Analysis

Based on measurements using Google Earth, the total rooftop area was 11,601.61 m², while the required area for solar panel installation was 8,491 m². The analysis results indicate that the available rooftop area is sufficient for the planned solar panel installation.

The buildings selected for solar panel installation include Building A, Building B, Building C, the Mechanical Engineering Workshop Building, the Electronics Workshop Building, and the Civil and Mechanical Engineering Department Building.

MATLAB was used to assist in simulating solar panel distribution across each building to obtain a more optimal installation configuration.

Figure 10. Total Area of Politeknik Negeri Medan

Figure 10 illustrates the campus area measurement results using Google Earth. Based on the measurements, the total campus area was 93,962.77 m² with an effective rooftop area of 11,601.61 m².

The analysis results indicate that the available rooftop area remains sufficient for solar panel installation requiring 8,491 m². Therefore, the implementation of a rooftop photovoltaic system at Politeknik Negeri Medan is considered feasible.

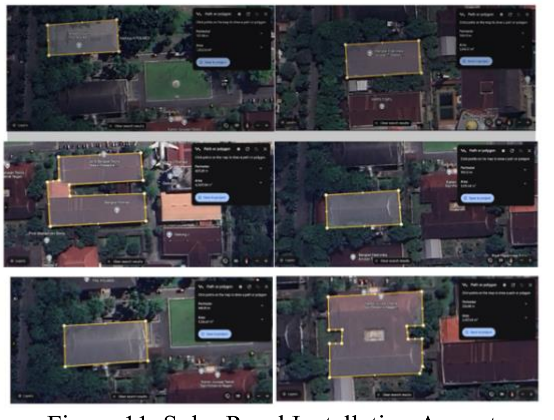

Figure 11. Solar Panel Installation Area at Politeknik Negeri Medan Buildings

Figure 11 illustrates the building locations selected for solar panel installation, namely Building A, Building B, Building C, the Mechanical Engineering Workshop, the Electronics Workshop, and the Civil and Mechanical Engineering Building.

The selection of these buildings was based on rooftop area size, solar exposure conditions, and building electricity consumption levels. Buildings with large rooftop areas and minimal shading were selected to maximize solar energy absorption.

4.7 Comparative Analysis Between Manual Calculation and MATLAB Simulation

In this study, a comparison was conducted between manual calculation results and MATLAB simulation results to determine the effectiveness and accuracy of the photovoltaic system.

The MATLAB simulation results showed that the optimization method produced a more efficient photovoltaic system configuration compared to the manual method. MATLAB was able to automatically simulate irradiance variations, load changes, and system efficiency, resulting in more detailed analyses that closely represent actual field conditions.

In addition, MATLAB simulations provided visualization of photovoltaic system performance in the form of output energy and system efficiency graphs, making the analysis process more systematic.

Tabel 1 Perbandingan Perhitungan Manual dan MATLAB

Parameter	Manual	MATLAB
PV System Capacity	1516 kWp	1498 kWp
Number of Panels	2757	2724
Area Requirement	8491 m²	8320 m²
System Efficiency	21.5%	22.3%

Based on Table 1, the MATLAB simulation results produced a more optimal photovoltaic system configuration compared to the manual calculation method. The photovoltaic system capacity obtained from MATLAB simulation was 1498 kWp, slightly smaller than the manual calculation result of 1516 kWp, yet still capable of meeting the building electricity demand. Furthermore, the optimized number of solar panels using MATLAB was lower, namely 2724 units compared to 2757 units in the manual method. This indicates that MATLAB can optimize solar panel configurations more efficiently based on load profiles and irradiance data.

In terms of area utilization, the MATLAB simulation required 8320 m², smaller than the manual calculation requirement of 8491 m². System efficiency from the MATLAB simulation also increased to 22.3%, while the manual method only achieved 21.5%. These results indicate that MATLAB improves the effectiveness of photovoltaic system planning through more detailed simulation and optimization processes compared to manual calculations.

4.8 Analysis of Energy Saving Potential

Based on MATLAB simulation results, the total daily electrical energy demand of Politeknik Negeri Medan buildings was 5,410 kWh/day.

Assuming that the photovoltaic system can optimally supply this demand, the monthly electrical energy generation would be:

Monthly energy generation:

5,410 × 30 days = 162,300 kWh/month

Meanwhile, the annual electrical energy generation would be:

Annual energy generation:

162,300 × 12 months = 1,947,600 kWh/year

In this study, the PLN electricity tariff for educational institutions was assumed to be IDR 1,444.70/kWh. Based on this tariff, the potential electricity cost savings are as follows:

Monthly electricity cost savings:

162,300 × IDR 1,444.70 = IDR 234,573,810/month

Annual electricity cost savings:

IDR 234,573,810 × 12 = IDR 2,814,885,720/year

The analysis results indicate that the implementation of rooftop photovoltaic systems at Politeknik Negeri Medan has significant potential for electricity cost savings. In addition to reducing electricity consumption from PLN, photovoltaic systems can significantly reduce campus operational electricity costs. Besides economic benefits, the use of solar energy also supports clean energy transition programs and carbon emission reduction in the education sector. With a system capacity of 1,516.25 kWp, the photovoltaic system can serve as an effective and sustainable alternative energy source within the campus environment.

4.9 Discussion.

Based on the research results, the implementation of rooftop photovoltaic systems at Politeknik Negeri Medan demonstrates excellent potential from both technical and economic perspectives. This is indicated by the MATLAB simulation results, which successfully generated an optimal photovoltaic system configuration based on building load profiles, solar radiation intensity, and available rooftop area. The load profile analysis showed that the electrical energy demand of Politeknik Negeri Medan buildings is relatively high, reaching 5,410 kWh/day. The high energy demand is influenced by laboratory activities, practical training, administrative operations, and the use of high-power electrical equipment within the campus area. Consequently, electricity consumption from the PLN grid becomes significant, leading to increased operational electricity costs. Based on irradiance data processing, the average solar radiation intensity in Medan City was found to be 4.46 kWh/m²/day. This value indicates that Medan City has considerable solar energy potential for rooftop photovoltaic system development. Despite monthly irradiance fluctuations, the photovoltaic system was still capable of generating relatively stable electrical energy throughout the year.

The MATLAB simulation results showed that a photovoltaic system with a capacity of 1,516.25 kWp consisting of 2,757 solar panels was capable of generating sufficient electrical energy to support the energy demand of Politeknik Negeri Medan buildings. The simulation also demonstrated that solar irradiance variations significantly affect photovoltaic system output energy. Higher solar radiation intensity results in greater electrical energy generation.

Furthermore, the MATLAB optimization results demonstrated that computational simulation can produce more efficient system configurations compared to manual calculation methods. MATLAB was able to automatically analyze irradiance variations, load changes, system efficiency, and power losses, resulting in more detailed optimization outcomes that closely represent actual field conditions.

From the system efficiency perspective, the simulation results showed that solar panel temperature affects photovoltaic system performance. Increasing temperature reduces solar panel efficiency due to higher internal resistance. However, despite efficiency reductions, the photovoltaic system was still capable of generating sufficient electrical energy to support campus electricity demand.

The rooftop area analysis showed that Politeknik Negeri Medan has an effective rooftop area of 11,601.61 m², while the required installation area is 8,491 m². This indicates that the available rooftop area is more than sufficient for the planned photovoltaic system installation. In addition, the distribution of solar panels across several buildings also improved solar energy absorption effectiveness.

From an economic perspective, the simulation results showed that the photovoltaic system has the potential to save approximately IDR 2.81 billion in electricity costs annually. This value indicates that rooftop photovoltaic system implementation not only provides energy benefits but also significantly reduces long-term campus electricity operational costs.

Overall, the research results indicate that the implementation of rooftop photovoltaic systems using MATLAB at Politeknik Negeri Medan is feasible from technical, economic, and environmental perspectives. The use of MATLAB as a simulation and optimization tool also improves the quality of photovoltaic system analysis, making the research results more accurate, systematic, and representative of actual field conditions.

V. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Based on the results of the research and simulations that have been conducted, several conclusions can be drawn as follows :

1. Based on the load profile analysis, the total electrical energy demand of Politeknik Negeri Medan buildings was found to be 5,410 kWh/day with a total installed power of 1,352.57 kW. The high electrical energy demand is influenced by laboratory activities, practical training, administrative operations, and the use of high-power electrical equipment within the campus area.
2. The irradiance analysis results indicate that Medan City has an average solar radiation intensity of 4.46 kWh/m²/day, demonstrating strong potential for the implementation of rooftop photovoltaic systems.
3. Based on the MATLAB simulation results, the optimum photovoltaic system capacity was determined to be 1,516.25 kWp with a total of 2,757 solar panels, each having a capacity of 550 Wp. The photovoltaic system was capable of generating relatively stable electrical energy throughout the year to support the energy demand of Politeknik Negeri Medan buildings.
4. The MATLAB simulation results showed that variations in solar irradiance and solar panel temperature significantly affect photovoltaic system performance. Higher solar radiation intensity increases system output energy, whereas increasing panel temperature reduces system efficiency.
5. The rooftop area analysis showed that Politeknik Negeri Medan buildings have an effective rooftop area of 11,601.61 m², which is sufficient for solar panel installation requiring an area of 8,491 m².
6. The optimization results using MATLAB produced a more efficient photovoltaic system configuration compared to manual calculation methods because MATLAB can automatically consider irradiance variations, load profiles, system efficiency, and power losses.
7. Based on the economic analysis, the photovoltaic system has the potential to reduce electricity costs by approximately IDR 2.81 billion per year. Therefore, the implementation of rooftop photovoltaic systems at Politeknik Negeri Medan is considered feasible from both technical and economic perspectives.

5.2 Recommendations

For future research development, several recommendations can be proposed as follows :

1. Future studies are expected to utilize real-time electrical load data so that photovoltaic system simulation results become more accurate and closely represent actual field conditions.
2. Future research may further develop simulation systems using MATLAB/Simulink so that photovoltaic system analysis can be conducted in greater detail, particularly for inverter systems, battery systems, and control systems.
3. Future studies may incorporate intelligent optimization methods such as Particle Swarm Optimization (PSO), Genetic Algorithm (GA), or Artificial Neural Network (ANN) to obtain more optimal photovoltaic system configurations.
4. Future research is also expected to conduct more comprehensive economic analyses, including Net Present Cost (NPC), Levelized Cost of Energy (LCOE), and Payback Period calculations to evaluate the long-term investment feasibility of photovoltaic systems.
5. The development of rooftop photovoltaic systems at Politeknik Negeri Medan can be considered as one of the strategic steps toward renewable energy implementation and reduction of electricity consumption from the PLN grid within the campus environment..

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