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Utilization of Solar Energy to Enhance Energy Independence in Pematang Serai Village, Langkat Regency

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Abstract
This study aims to evaluate the potential of solar energy in Pematang Serai Village, Tanjung Pura District, Langkat Regency, to support the development of solar power plants (PLTS) as an alternative energy source. This village faces challenges of dependency on fossil energy, which is non-renewable and harmful to the environment. Using qualitative and quantitative research approaches, data collection was conducted through direct observation, interviews, and measurement of sunlight intensity with specialized devices. The results show that the sunlight intensity in this village peaks at 12:00 PM, with an input power of 74.91 W/m² and an average panel efficiency of 15%. The total power produced over six hours reaches 922.38 Wh, providing a significant opportunity to create an energy-independent community through renewable energy utilization. This study suggests the application of PLTS at both household and commercial levels as a practical solution to decrease reliance on fossil energy.

***Keywords**: Solar energy, Pematang Serai village, solar power plants, renewable energy, energy independence*

1. Introduction

The global energy crisis and environmental impacts caused by fossil energy usage are critical issues driving the development of renewable energy sources (RES) (1). Solar energy is one of the most promising RES, especially in tropical countries like Indonesia. With an average solar radiation of 4.8 kWh/m²/day (2). Indonesia has significant potential to develop this clean and eco-friendly energy source (3).

Pematang Serai Village, located in Tanjung Pura District, Langkat Regency, features geographical and climatic conditions favorable for utilizing solar energy. The village is characterized by consistently warm weather throughout the year (4). However, its residents remain heavily reliant on environmentally harmful fossil energy. Moreover, the lack of renewable energy infrastructure poses a barrier to transitioning toward more sustainable energy sources (5).

This study aims to evaluate the potential of solar energy in the village to support the establishment of PLTS and promote an energy-independent community. By optimizing solar energy utilization, this village can serve as a model for sustainable clean energy practices at the local level (6).

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Research Questions, What is the potential of solar energy in Pematang Serai Village to support the development of PLTS, How much electrical power can be generated from the village's solar energy potential and What are the challenges faced in implementing PLTS in Pematang Serai Village. This research aims to analyze the potential of sunlight in Pematang Serai Village as an energy source, calculate the electrical power generated through solar panels and provide policy recommendations for PLTS development in the village.

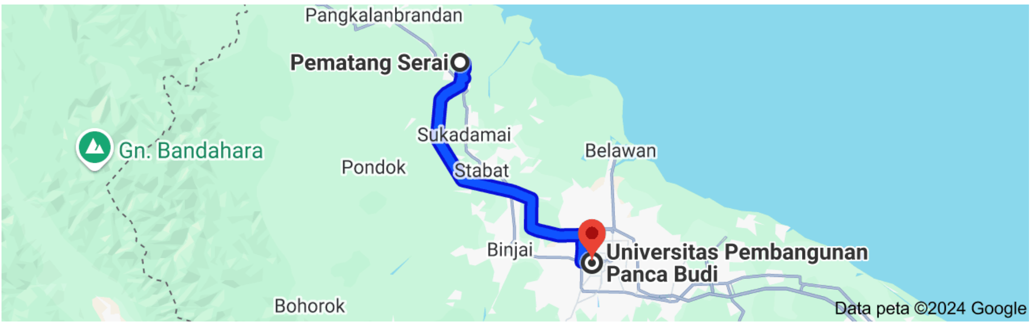

Figure 1. Pematang serai map

2. Methods

This study employs a descriptive qualitative approach to analyze solar energy potential and a quantitative approach to calculating solar panel efficiency and electrical power generated (7). The study was conducted in Pematang Serai Village, Tanjung Pura District, Langkat Regency. This location was selected based on its geographic and climatic suitability for solar energy development.

2.1. Data Sources

The data for this study were obtained from both primary and secondary sources. Primary data were collected through interviews with village officials, direct observations of sunlight intensity, and measurements using radiation measurement tools to ensure accurate and reliable results. Secondary data were derived from various sources, including scientific literature, academic journals, government reports, and statistical data provided by the Central Bureau of Statistics (BPS), offering a broader context and supporting the analysis of solar energy potential in the study area.

2.2. Data Collection Techniques

The data collection techniques employed in this study included direct observation, interviews, and quantitative analysis. Direct observation involved measuring sunlight intensity at 10-minute intervals between 10:00 AM and 4:00 PM to capture variations in solar radiation throughout the day. Interviews were conducted with community members to explore their perspectives on the potential of renewable energy and the challenges associated with its implementation. Quantitative analysis was performed to calculate key parameters such as input power, output power, and panel efficiency, providing a detailed assessment of the solar energy potential in the study area.

2.3. Data Reduction

In this process, researchers record the data that has been collected through interviews, observation and documentation. Then summarize the data that is considered the main topic of discussion in the research, namely data relating to the potential of the sun as a source of electrical energy in Pematang Serai Village.

2.4. Display Data

After the data has been reduced, the next step is to present it. The analyzed data will be presented descriptively in accordance with the problem formulation.

2.5. Conclusion and Verification

After the data has been successfully reduced and presented in the form of descriptive text, the next step is to conclude. At this stage, researchers systematically compile the data that has been presented about the potential of the sun as a source of electrical energy.

3. Results and Discussion

From these observations, the following results were obtained:

Table 1. Intensity measurement

Time	Intensity (W/m^2)	Voltage (V)	Current (A)
10.40	97,128	18,90	0,59
10.50	110,033	19,72	0,59
11.00	110,055	19,78	0,58
11.10	109,916	19,26	0,56
11.20	109,938	11,27	0,56
11.30	109,888	19,13	0,55
11.40	109,994	19,52	0,57
11.50	109,944	19,40	0,51
12.00	110,094	19,80	0,58
12.10	100,096	19,86	0,58

The highest voltage measured was 19.86 Volts, when the intensity of sunlight was 100.096 W/m^2, namely at 12.10, while the measured current was 0.58 Ampere. The above conditions were obtained when there was no load, then testing was carried out under loaded conditions. The efficiency of a solar panel is obtained from the electrical power that comes out in watts compared to its surface area. Currently, the efficiency of solar cells on the market is around 14 - 17% (8,9). This means that a solar panel can only convert around 14 – 17% of all the solar energy received by the solar cell, and the rest will be reflected in the air (10). Based on the table above, the amount of intensity received by the solar module in the form of photon energy is not completely absorbed, some is reflected depending on the amount of energy and frequency of photons needed to release electrons from their bonds (11,12).

Table 2. Load solar cell measurement

Time	Intensity (W/m²)	Solar Module				μ (%)
		Voltage (V)	Current (V)	Pin (W)	Pout (W)	
11.00	110,055	18,87	0,58	74,881	10,94	14 %
11.20	110,091	19,36	0,57	74,905	11,03	14 %
11.40	110,061	19,27	0,56	74,885	10,79	14 %
12.00	110,094	19,80	0,58	74,907	11,484	15 %
12.20	110,055	19,72	0,56	74,881	11,04	14 %
12.40	110,067	19,76	0,58	74,889	11,46	15 %
13.00	101,698	19,30	0,56	69,195	10,808	15 %
13.20	100,642	18,84	0,55	68,476	10,36	15 %
13.40	100,363	18,46	0,56	68,286	10,33	15 %
14.00	97,234	18,50	0,57	66,158	10,54	15 %
14.20	82,804	18,38	0,55	56,339	10,10	17 %
14.40	76,044	18,18	0,53	51,740	9,63	18 %
15.00	80,703	18,02	0,52	54,910	9,37	17 %

3.1. Solar Energy Potential in Pematang Serai Village

The measurements reveal a peak sunlight intensity of 110.094 W/m² at 12:00 PM. With a solar panel area of 0.68 m², the input power received was 74.91 W. The total power generated over six hours amounted to 922.38 Wh, equivalent to an average of 153.73 Wh per hour. The aim of calculating the efficiency value is to determine the percentage of sunlight energy that the solar module can absorb (13,14). Following are several equations to determine the input and output power.

$$P_{in} = \text{Solar intensity} \times \text{Module area} \ldots\ldots\ldots (1)\ (15)$$

$$= 110{,}094\ W/m^2 \times (63\ cm \times 54\ cm) + (63\ cm\ \times 54\ cm)$$

$$= 110{,}094\ W/m^2 \times 0{,}6804\ m^2$$

$$= 74{,}907 \text{ Watt}$$

Meanwhile, the maximum output power of the solar module is calculated using the following equation:

$$P_{out} = V_{oc} \times I_{sc} \times FF \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)\ (10)$$

$$= V_{oc} \times I_{sc} \times \frac{V_{mp} \times I_{mp}}{V_{oc} \times I_{sc}}$$

$$= V_{mp} \times I_{mp} = 19{,}80 \times 0{,}58$$

$$= 11{,}484\ Watt$$

3.2. Solar Panel Efficiency

The average efficiency of the solar panels was 15%, which aligns with the standard for commercially available solar panels (16,17) Although this efficiency is not the highest, the power generated is sufficient to meet small-scale electricity needs (18) such as household lighting and charging electronic devices. So efficiency is obtained using the following equation:

$$\mu = \frac{P_{out}}{P_{in}} \times 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3)\ (19)$$

$$= \frac{11{,}484}{74{,}907} \times 100\%$$

$$= 15{,}33\ \%$$

3.3. Inverter Testing

Inverter testing aims to understand the working principle and determine the efficiency and frequency output produced (20). When the inverter is loaded, is the inverter considered suitable by the 50/60 Hz frequency standard? The inverter test circuit is shown in the following figure:

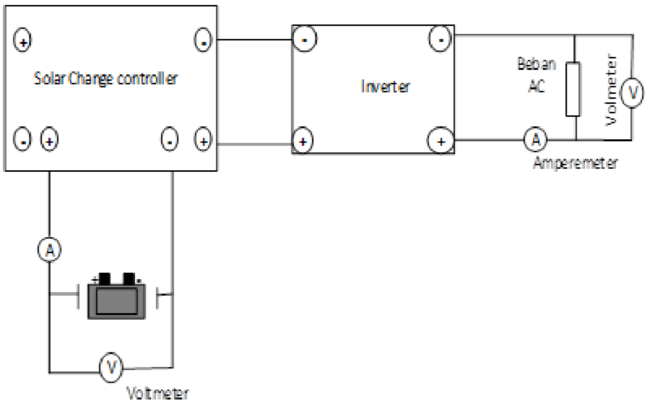

Figure 2. Inverter test circuit

Table 3. Inverter testing with various loads

Load	Input		Output		
	Voltage (V)	Current (A)	Voltage (V)	Current (A)	Frequency (Hz)
Lamp 5 W	13,6	100	224,6	4,93	49,9 Hz
Lamp12 W	13,52	100	223,4	4,97	49,9 Hz
Lamp 17 W	13,50	100	224,1	5,043	49,9 Hz
Lamp 20 W	13,49	100	224,0	5,023	49,9 Hz
Fan 50 W	13,42	100	226,0	5,063	49,9 Hz

Based on table 3, the output voltage on the inverter with a 5-watt light load is measured at 224.6 Volt AC and the current flowing is measured at 4.94 Amperes with a measured frequency of 49.9 Hz. The battery input voltage decreases as the load tested increases. The inverter voltage output for each load has almost the same AC load output, an average of 224 AC Volts, and a Frequency output of 49.9 Hz. The condition of inverter functions well after being tested because the stability of the voltage provided is per the PLN standard of 230 VAC and the Indonesian frequency standard of 50 Hz (21).

3.4. Challenges and Barriers

The main obstacle to implementing PLTS is the lack of community knowledge about renewable energy technologies (22). Additionally, the initial installation cost of solar panels is still perceived as high by most residents (23).

3.5. Development Opportunities

The village has significant potential to serve as a pilot area for local solar energy development (24,25). With government support and training programs, residents can be encouraged to adopt solar energy on a broader scale (26).

Conclusions

The weather conditions in Pematang Serai Village are predominantly hot, which results in high sunlight intensity, making it suitable for solar energy generation. The solar modules in the area produce voltage and current that meet the standards for New Renewable Energy use. Over six hours, a solar power system can generate 922.38 Wh, with an average of 153.73 watts per hour, which is sufficient to meet the basic electricity needs of the community. This demonstrates the potential for Pematang Serai Village to become an Energy Independent Village through the utilization of solar energy. The study concludes that the sunlight intensity is adequate to support the development of solar power plants (PLTS), the electrical power generated from the solar panels is sufficient for basic needs, and successful implementation of PLTS requires technical support and policy backing from the government to ensure sustainability. Based on these findings, it is recommended that the local government provide technical training for residents on the installation and maintenance of PLTS, offer financial subsidies or incentives to reduce the initial installation costs and foster collaboration between academics, the government, and the private sector to develop renewable energy infrastructure.

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Conflict of Interest

The authors declare no competing interests

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