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Comparative Analysis of Electrical Performance of 50 WP Monocrystalline and Polycrystalline Solar Panels in Balikpapan

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ABSTRACT

The increasing demand for electrical energy, coupled with the depletion of fossil fuel resources and environmental concerns, has driven the need for renewable energy development. Solar energy, as one of the most abundant renewable resources in Indonesia, offers significant potential for sustainable electricity generation. This study aims to analyze and compare the electrical performance of 50 WP monocrystalline and polycrystalline solar panels in terms of voltage, current, power output, light intensity, and efficiency. The research was conducted experimentally on the rooftop of Universitas Balikpapan under clear weather conditions. Data were collected every 15 minutes from 09:00 to 13:00 WITA over several days. The measured parameters included solar irradiance, output voltage, output current, and power generation. The efficiency of each panel type was calculated based on the ratio of output power to input solar power. The results indicate that monocrystalline solar panels consistently produce higher efficiency and power output compared to polycrystalline panels under similar conditions. The findings of this study provide useful insights for selecting appropriate solar panel types for optimal energy generation in tropical regions such as Balikpapan.

INTRODUCTION

The increasing global demand for electrical energy and the depletion of fossil fuel resources have accelerated the development of renewable energy technologies. Among various renewable energy sources, solar energy has become one of the most promising alternatives because it is environmentally friendly, sustainable, and widely available. Photovoltaic (PV) technology plays an important role in converting solar radiation into electrical energy and has experienced rapid technological advancement in recent years. Recent studies have shown that improvements in photovoltaic materials and system configurations significantly enhance solar panel efficiency and reliability (Kumari et al., 2024).

Indonesia has considerable solar energy potential due to its geographical location in the tropical region, which receives abundant sunlight throughout the year. This condition provides a strong opportunity for the implementation of photovoltaic systems in residential, industrial, and public sectors. However, the efficiency and performance of solar panels are strongly influenced by environmental conditions such as solar irradiance, temperature, and panel orientation. Therefore, understanding the performance characteristics of different photovoltaic technologies is essential to maximize electrical energy generation (Hariyanto et al., 2024).

Currently, monocrystalline and polycrystalline solar panels are the two most widely used photovoltaic technologies. Monocrystalline panels are manufactured using single-crystal silicon, resulting in higher purity and better electron mobility. Consequently, they generally provide higher conversion efficiency and better performance under varying environmental conditions. In contrast, polycrystalline panels are made from multiple silicon crystal fragments, making them more affordable but slightly less efficient due to energy losses at crystal boundaries (Aedelia & Wijayanto, 2025).

Several previous studies have compared the performance of monocrystalline and polycrystalline photovoltaic modules. Research conducted by Aedelia and Wijayanto (2025) demonstrated that monocrystalline panels exhibited higher efficiency and more stable output power than polycrystalline panels when integrated with a dual-axis solar tracking system. Similarly, comparative experimental research by Kumar et al. (2024) found that monocrystalline panels achieved better electrical efficiency due to their superior crystal structure and reduced recombination losses.

Environmental factors also play a crucial role in determining photovoltaic performance. Solar irradiance directly affects the generated voltage, current, and power output of photovoltaic modules. Higher irradiance increases photon absorption in semiconductor materials, thereby enhancing electron excitation and electrical generation. A study conducted in Indonesia by Hariyanto et al. (2024) confirmed that increasing irradiance significantly improves the output performance of 50 W monocrystalline solar panels under tropical climate conditions.

In addition to efficiency considerations, the development of photovoltaic technology continues to focus on improving material performance and reducing installation costs. Recent technological breakthroughs, such as heterojunction and perovskite-based solar cells, have achieved record conversion efficiencies exceeding conventional silicon-based panels. Reuters (2025) reported that advanced photovoltaic technologies have reached efficiencies above 25%, indicating continuous progress in solar energy systems and highlighting the importance of evaluating existing photovoltaic technologies under real operating conditions.

Despite the growing number of photovoltaic studies, comparative analysis between monocrystalline and polycrystalline solar panels under local environmental conditions in Indonesia remains limited. Differences in weather patterns, irradiance intensity, and ambient temperature may affect the actual performance of photovoltaic modules. Therefore, site-specific experimental analysis is necessary to obtain accurate and practical data regarding solar panel performance in tropical environments.

Additionally, this study offers a practical contribution by evaluating photovoltaic performance under the specific climatic conditions of Balikpapan, Indonesia. Most previous comparative studies were conducted under controlled laboratory environments or in subtropical regions, which may produce different performance characteristics compared to tropical climates. The novelty of this research lies in the direct experimental comparison of 50 WP monocrystalline and polycrystalline solar panels operating under the same local environmental conditions, including identical irradiance exposure and ambient temperature. This approach provides more realistic data regarding the actual operational behavior of photovoltaic modules in tropical regions.

Furthermore, the results of this study are expected to contribute to the development of renewable energy implementation strategies in Indonesia, particularly in selecting suitable photovoltaic technologies for small-scale and household electricity systems. By identifying the differences in voltage, current, power output, and efficiency between both panel types, this research may assist researchers, engineers, and policymakers in optimizing solar energy utilization and improving the effectiveness of sustainable energy systems in tropical environments.

Based on these considerations, this study aims to analyze and compare the electrical performance of 50 WP monocrystalline and polycrystalline solar panels under identical environmental conditions. The observed parameters include solar irradiance, voltage, current, power output, and efficiency. The findings of this study are expected to provide valuable information for selecting suitable photovoltaic technologies and improving the utilization of renewable energy systems in tropical regions.

RESEARCH METHODS

This study employed an experimental quantitative approach to evaluate and compare the electrical performance of 50 WP monocrystalline and polycrystalline solar panels under identical environmental conditions. The experiment was conducted on the rooftop of Universitas Balikpapan, which provides sufficient and unobstructed exposure to solar radiation throughout the testing period. Both photovoltaic panels were installed using the same mounting configuration, including a tilt angle of 20° and an orientation of approximately 66° northeast, to ensure uniform solar energy reception and minimize external influences on the measurement results.

The population of this study consisted of photovoltaic energy conversion systems, while the research samples included two photovoltaic modules, namely one monocrystalline solar panel and one polycrystalline solar panel, each with a rated capacity of 50 WP. The panels were selected using a purposive sampling technique based on similar technical specifications, dimensions, and operational characteristics to obtain a more objective comparison of performance. Both panels were tested simultaneously within the same environmental and operational conditions to maintain experimental consistency.

Data collection was carried out through direct field measurements during clear weather conditions. Observations were conducted at 15-minute intervals from 09:00 to 13:00 WITA to capture variations in solar radiation intensity and electrical output over time. The measured parameters included solar irradiance, output voltage, output current, panel temperature, and generated electrical power. A solar power meter was used to measure solar irradiance, while a digital watt meter and multimeter were utilized to record electrical output data from each solar panel. All instruments were calibrated prior to testing to improve measurement accuracy and reliability.

The experimental procedure began with the installation of both photovoltaic modules on the testing platform according to the predetermined orientation and tilt angle. After installation, the solar panels were connected to the measurement instruments and operated under the same load conditions. Measurements of irradiance, voltage, current, and output power were then recorded simultaneously for both panels at each observation interval. Environmental conditions during testing were also monitored to ensure that the experiment was conducted under stable weather conditions.

To improve the clarity of the research procedure, the study workflow consisted of several sequential stages, including preparation of photovoltaic modules and measuring instruments, installation of solar panels, calibration of instruments, field data collection, and quantitative data analysis. The workflow was designed to ensure that both photovoltaic panels were tested under identical operational and environmental conditions so that the comparison results could be obtained objectively and consistently.

In addition, all measurements were performed simultaneously to reduce the influence of fluctuating environmental parameters such as irradiance intensity and ambient temperature. The collected data were subsequently tabulated and presented in the form of graphs and comparative analyses to evaluate the differences in voltage, current, power output, and efficiency between monocrystalline and polycrystalline solar panels. The research flow diagram is presented to provide a clearer overview of the experimental stages and analytical procedures conducted in this study.

The collected data were analyzed quantitatively to determine the electrical performance and efficiency of each solar panel type. Input power was calculated based on the measured solar irradiance and effective surface area of the panel, while output power was determined from the multiplication of output voltage and current.

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

The efficiency of each photovoltaic module was calculated by comparing the output power to the input solar power received by the panel surface.

$$\eta = \frac{P_{out}}{P_{in}} \times 100\%$$

The analyzed results were subsequently compared to identify differences in electrical characteristics, power generation capability, and energy conversion efficiency between monocrystalline and polycrystalline solar panels under the same operating conditions.

RESULTS AND DISCUSSION

Electrical Characteristics of Photovoltaic Panels

Photovoltaic solar panels convert solar radiation into electrical energy through the photovoltaic effect occurring within semiconductor materials (Afonso et al., 2025; Polymeropoulos et al., 2024; Chala & Alshaikh, 2023). In this process, photons from sunlight excite electrons within the semiconductor layer, generating an electric current that can be utilized as electrical energy. The effectiveness of this conversion process depends on the physical and electrical properties of the photovoltaic material. Consequently, the performance of solar panels is strongly influenced by environmental conditions and material quality. Photovoltaic technology has become increasingly important as a sustainable energy solution due to its ability to generate electricity without producing harmful emissions.

The electrical performance of solar panels is significantly affected by solar irradiance and ambient temperature. Higher irradiance levels generally increase the number of excited electrons, resulting in higher output current and greater electrical power generation. Conversely, unstable irradiance conditions can reduce the consistency of panel output and influence overall system performance. Temperature also affects photovoltaic efficiency because excessive heat can increase internal resistance and reduce voltage output. Therefore, environmental conditions play a critical role in determining photovoltaic efficiency and operational stability under real-world conditions.

Monocrystalline and polycrystalline solar panels are among the most widely used photovoltaic technologies because of their practical implementation and commercial availability. Monocrystalline panels are manufactured using a single-crystal silicon structure that allows more efficient electron movement and lower internal resistance (Benghanem et al., 2023; Faheem et al., 2024). This structure enables monocrystalline panels to achieve higher energy conversion efficiency and more stable performance under varying irradiance conditions. In addition, monocrystalline panels generally have a longer operational lifespan and better space efficiency because they can generate more electrical power within a smaller surface area.

Polycrystalline panels, on the other hand, are composed of multiple silicon crystal fragments formed during the manufacturing process. The presence of crystal boundaries can obstruct electron flow and increase recombination losses, resulting in slightly lower electrical efficiency compared to monocrystalline technology. However, polycrystalline panels remain widely utilized because their manufacturing process is simpler and more cost-effective. These panels are considered suitable for large-scale applications where installation cost is a major consideration. As a result, both panel types continue to be extensively used depending on performance requirements, budget constraints, and operational conditions.

Performance Analysis Under Variable Irradiance Conditions

The performance of photovoltaic modules varies significantly according to changes in solar irradiance throughout the day. Under high irradiance conditions, photovoltaic panels generally absorb more solar energy, resulting in increased electrical output in the form of voltage, current, and power (Massalha et al., 2025; Jereb, 2024; Zhang & Xu, 2020). The relationship between irradiance and electrical output demonstrates that solar radiation is one of the most dominant factors affecting photovoltaic performance. Consequently, peak electrical production typically occurs during periods of maximum sunlight intensity, particularly around midday under clear weather conditions.

Fluctuations in solar irradiance can influence the stability and consistency of photovoltaic output. Rapid changes in irradiance caused by cloud movement, atmospheric conditions, or shading may produce unstable voltage and current values. Panels with higher internal resistance and lower electron mobility are generally more sensitive to irradiance fluctuations, leading to reduced performance stability. Therefore, evaluating photovoltaic systems under varying environmental conditions is essential to determine their operational reliability and practical effectiveness in real-world applications.

Several previous studies have reported that monocrystalline panels demonstrate higher efficiency and more stable electrical performance compared to polycrystalline panels under fluctuating irradiance conditions. This superiority is mainly associated with the uniform crystal structure of monocrystalline silicon, which minimizes recombination losses and improves electron mobility (Machin & Marquez, 2024; Fricano et al., 2025; Maoz et al., 2025). As a result, monocrystalline panels can maintain relatively stable electrical output even when solar irradiance changes significantly. This characteristic makes monocrystalline technology particularly suitable for applications requiring consistent energy generation and high operational efficiency.

In contrast, polycrystalline panels generally exhibit slightly lower electrical efficiency because their heterogeneous crystal structure limits electron movement and increases energy losses during the conversion process. Despite this limitation, polycrystalline technology remains widely used due to its lower production cost and satisfactory operational performance in practical applications (Nur Atikah et al., 2024). In many cases, the affordability of polycrystalline panels makes them an attractive alternative for residential and commercial photovoltaic systems. Therefore, the selection between monocrystalline and polycrystalline panels often depends on the balance between efficiency requirements and economic considerations.

Effect of Solar Irradiance on Electrical Output

The analysis results indicate that solar irradiance has a direct and significant influence on the electrical output of both monocrystalline and polycrystalline solar panels. As the intensity of solar radiation increased during the observation period, both panels exhibited proportional increases in voltage, current, and output power. This confirms that irradiance is a dominant factor in photovoltaic performance, as higher photon energy enhances electron excitation in semiconductor materials (Maulana et al., 2024).

The highest electrical output for both panel types was observed between 10:00 and 12:00 WITA, corresponding to peak irradiance conditions. During this period, both panels reached their maximum power generation, although the monocrystalline panel demonstrated more consistent performance. This observation is consistent with photovoltaic theory, where electrical output is directly proportional to the amount of absorbed solar energy (Purnomo, 2020).

To illustrate this relationship, a summary of irradiance and output power is presented in Table 1. The data show a clear trend of increasing power output with higher irradiance levels for both panel types. Similar findings have also been reported in previous studies, confirming the strong correlation between irradiance and electrical output (Maulana et al., 2024).

Table 1. Relationship Between Solar Irradiance and Output Power

Time (WITA)	Irradiance (W/m²)	Monocrystalline Power (W)	Polycrystalline Power (W)
09:00	~710	25.5	26.9
10:00	~938	39.5	41.0
11:00	~434	14.7	15.9
12:00	~800	31.4	32.9
13:00	~834	31.9	32.8

Comparison of Power Output Between Panel Types

The comparative analysis shows that monocrystalline solar panels generally produce higher and more stable electrical performance compared to polycrystalline panels under similar operating conditions. Although some instantaneous values of polycrystalline output appear comparable, the overall performance consistency of monocrystalline panels is superior, particularly under fluctuating irradiance conditions (Anggara & Saputra, 2023).

This difference can be explained by the structural characteristics of the panels. Monocrystalline panels are made from a single-crystal silicon structure, allowing more efficient electron flow and reducing internal resistance. In contrast, polycrystalline panels contain multiple crystal boundaries that can hinder electron movement and increase energy losses during the conversion process (Purnomo, 2020).

A summary comparison of the electrical performance parameters is shown in Table 2. The table highlights the general trend of higher voltage, current stability, and power output in monocrystalline panels compared to polycrystalline panels. These findings are consistent with previous research that emphasizes the superiority of monocrystalline panels in terms of electrical performance (Anggara & Saputra, 2023).

Table 2. Comparison of Electrical Performance Parameters

Parameter	Monocrystalline	Polycrystalline
Average Voltage (V)	Higher	Slightly Lower
Average Current (A)	Stable	Fluctuating
Average Power (W)	Higher	Lower
Performance Stability	High	Moderate

Voltage Characteristics and Stability of Solar Panels

The voltage characteristics of photovoltaic panels represent an important indicator in evaluating the electrical stability and operational performance of solar energy systems. Output voltage reflects the ability of photovoltaic modules to maintain electrical potential under varying irradiance and environmental conditions. Stable voltage output is essential to ensure efficient energy conversion and reliable operation of photovoltaic systems in practical applications (Massalha et al., 2025; Zhang & Xu, 2020). Therefore, voltage analysis provides valuable information regarding the consistency and electrical behavior of different solar panel technologies.

Based on the experimental observations conducted from 09:00 to 13:00 WITA, both monocrystalline and polycrystalline solar panels exhibited fluctuating voltage values corresponding to changes in solar irradiance intensity throughout the testing period. The fluctuations indicate that photovoltaic voltage output is directly influenced by environmental conditions, particularly irradiance and panel temperature. Under higher irradiance conditions, both panel types generally produced higher voltage values, although slight variations occurred due to differences in semiconductor structure and electrical characteristics (Afonso et al., 2025; Polymeropoulos et al., 2024).

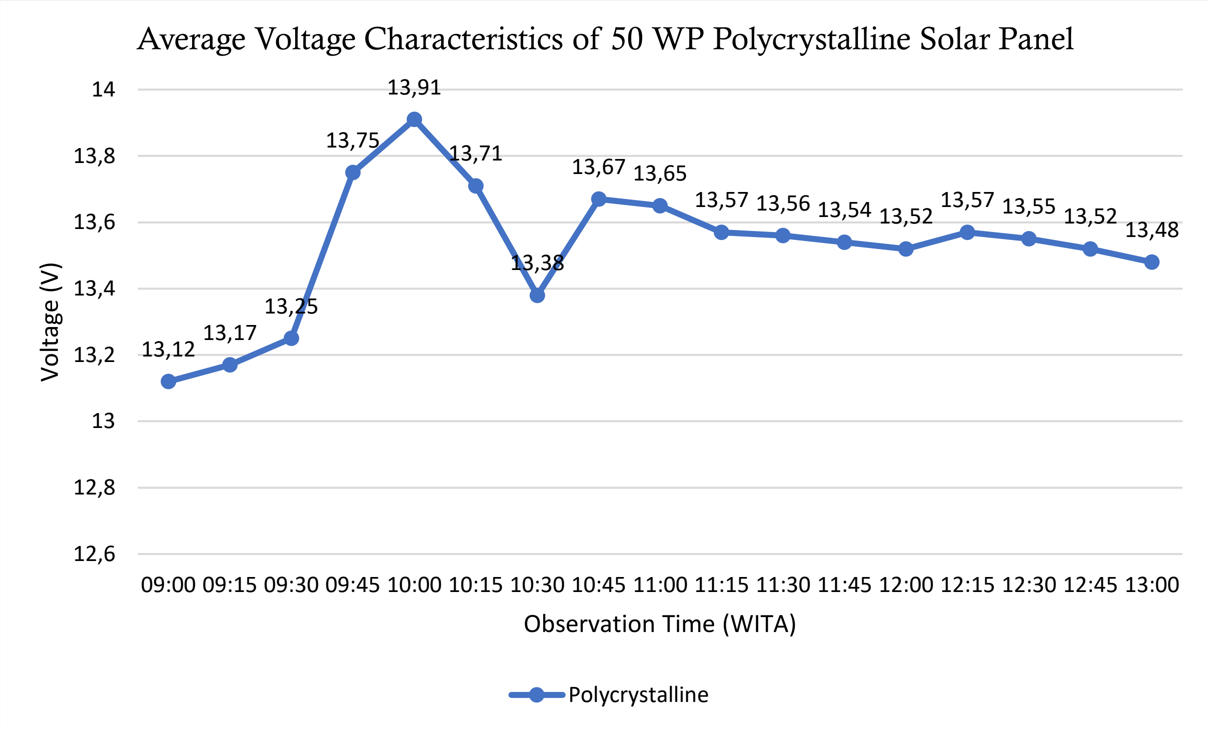

Figure 1. Average Voltage Characteristics of 50 WP Polycrystalline Solar Panel

The comparative results demonstrate that polycrystalline panels produced slightly higher average voltage values during several observation periods. For example, on 30/06/2025, the polycrystalline panel achieved an average voltage of 13.81 V, while the monocrystalline panel recorded an average voltage of 13.44 V. Similarly, on 01/07/2025, the average voltage of the polycrystalline panel was 13.52 V compared to 13.47 V for the monocrystalline panel. These findings indicate that although monocrystalline technology is generally associated with higher efficiency, polycrystalline panels can still produce competitive voltage performance under certain environmental conditions.

The observed differences in voltage characteristics between both panel types are closely related to their semiconductor crystal structures. Monocrystalline panels are composed of a uniform single-crystal silicon structure that supports efficient electron mobility and reduced recombination losses (Benghanem et al., 2023; Faheem et al., 2024). In contrast, polycrystalline panels contain multiple silicon crystal boundaries that may influence electron flow and voltage stability. Nevertheless, the experimental results indicate that polycrystalline panels maintained relatively stable voltage output during the observation period, demonstrating satisfactory operational capability in practical photovoltaic applications.

Overall, the voltage analysis confirms that both monocrystalline and polycrystalline solar panels are capable of producing stable electrical output under fluctuating irradiance conditions. Although the voltage differences between the two technologies were relatively small, variations in stability and peak voltage performance were still observed during different measurement periods. These findings are consistent with previous studies emphasizing that photovoltaic electrical characteristics are strongly influenced by irradiance conditions, semiconductor material quality, and panel structural configuration (Machin & Marquez, 2024; Fricano et al., 2025; Maoz et al., 2025).

Efficiency Analysis of Solar Panels

Efficiency is one of the most important parameters in evaluating the performance of photovoltaic systems because it reflects the ability of solar panels to convert solar radiation into usable electrical energy. Higher efficiency indicates that a greater portion of incoming solar energy can be transformed into electrical output with lower energy losses during the conversion process. The efficiency of photovoltaic modules is strongly influenced by semiconductor material quality, crystal structure, operating temperature, and environmental conditions during operation (Nur Atikah et al., 2024).

The experimental results indicate that monocrystalline solar panels exhibit higher energy conversion efficiency compared to polycrystalline panels under the same environmental conditions. The calculated efficiency values show that monocrystalline panels consistently converted a greater proportion of absorbed solar energy into electrical power throughout the testing period. This superior performance is mainly associated with the uniform single-crystal silicon structure of monocrystalline panels, which supports more efficient electron mobility and minimizes recombination losses within the semiconductor material (Nur Atikah et al., 2024).

In addition to higher efficiency values, monocrystalline panels also demonstrated more stable electrical performance during fluctuations in solar irradiance. Stable efficiency characteristics are important because photovoltaic systems are commonly exposed to continuously changing weather conditions during practical operation. The uniform crystal arrangement in monocrystalline technology allows electrical charge carriers to move more effectively, resulting in improved power conversion capability and reduced internal resistance losses. Consequently, monocrystalline panels are generally considered more suitable for applications requiring high efficiency and stable electrical output.

Polycrystalline panels, on the other hand, exhibited slightly lower efficiency values during the observation period. This condition is primarily caused by the heterogeneous crystal structure and the presence of multiple grain boundaries within the silicon material. These crystal boundaries can obstruct electron flow and increase recombination losses, reducing the overall effectiveness of energy conversion. Nevertheless, polycrystalline panels still demonstrated acceptable operational performance and were capable of producing relatively stable electrical output under fluctuating irradiance conditions (Purnomo, 2020).

Despite having lower efficiency compared to monocrystalline technology, polycrystalline panels remain widely utilized in photovoltaic applications due to their lower manufacturing cost and economic advantages. The simpler production process makes polycrystalline panels more affordable and accessible for large-scale residential and commercial installations. Therefore, the selection between monocrystalline and polycrystalline technology is often determined by the balance between efficiency requirements, installation area, and economic considerations.

A summary of the efficiency comparison is presented in Table 3. The results confirm that monocrystalline panels achieved higher efficiency values than polycrystalline panels under identical operating conditions. These findings are consistent with previous studies reporting that monocrystalline photovoltaic modules generally provide superior energy conversion performance due to their more uniform crystal structure and improved electron transport capability (Nur Atikah et al., 2024).

Table 3. Efficiency Comparison of Solar Panels

Panel Type	Efficiency Range (%)	Average Efficiency
Monocrystalline	13 – 16	Higher
Polycrystalline	10 – 13	Lower

Operational Stability and Practical Application Considerations of Photovoltaic Panels

The operational stability of photovoltaic systems is an important factor in determining their long-term effectiveness and reliability in practical energy applications. Besides efficiency and instantaneous power output, photovoltaic panels must be capable of maintaining stable electrical performance under continuously changing environmental conditions. In tropical regions such as Balikpapan, fluctuations in solar irradiance, ambient temperature, and weather conditions may significantly influence photovoltaic operation throughout the day. Therefore, evaluating the operational stability of solar panels provides additional insight into their suitability for sustainable electricity generation systems.

Based on the experimental observations, monocrystalline solar panels demonstrated relatively more stable electrical performance during irradiance fluctuations compared to polycrystalline panels. The monocrystalline module maintained more consistent current and power output even when solar radiation intensity changed rapidly during several observation periods. This stability is associated with the uniform single-crystal silicon structure, which supports better electron mobility and reduces internal electrical losses. As a result, monocrystalline technology tends to provide more reliable electrical generation under variable environmental conditions.

Polycrystalline panels, although exhibiting slightly lower stability, still showed satisfactory operational capability during the testing period. Variations in output current and power were observed more frequently due to the heterogeneous crystal structure and the presence of grain boundaries that may hinder electron movement. However, the overall electrical performance remained sufficiently stable for practical photovoltaic applications, particularly in systems where installation cost and economic considerations are prioritized. These findings indicate that polycrystalline technology continues to be a feasible alternative for residential and commercial photovoltaic installations.

From a practical perspective, the selection between monocrystalline and polycrystalline photovoltaic technology should consider not only efficiency performance but also operational stability, installation area, and economic feasibility. Monocrystalline panels are more suitable for applications requiring high efficiency and stable energy generation within limited installation space. In contrast, polycrystalline panels may offer a more economical solution for large-scale installations where slightly lower efficiency can be compensated by reduced investment costs. Therefore, both technologies possess distinct advantages depending on operational requirements and implementation priorities.

CONCLUSION

This study analyzed and compared the electrical performance of 50 WP monocrystalline and polycrystalline solar panels under identical environmental conditions in Balikpapan. The experimental results confirmed that solar irradiance has a significant effect on the electrical characteristics of photovoltaic systems. Increases in irradiance intensity were directly followed by increases in voltage, current, and output power for both panel types, demonstrating the strong relationship between solar radiation and photovoltaic energy conversion performance.

The comparative analysis showed that monocrystalline solar panels generally exhibited better electrical performance and operational stability compared to polycrystalline panels. Monocrystalline panels demonstrated higher efficiency, more stable current and power output, and better consistency under fluctuating irradiance conditions. This superior performance is mainly associated with the uniform single-crystal silicon structure, which improves electron mobility and minimizes internal energy losses during the conversion process. In contrast, polycrystalline panels produced slightly lower efficiency due to the presence of multiple crystal boundaries that can increase recombination losses and reduce electrical stability.

Despite their lower efficiency, polycrystalline panels still demonstrated satisfactory operational capability and relatively stable voltage performance throughout the testing period. Their lower manufacturing cost and simpler production process make them a practical and economically attractive option for residential and commercial photovoltaic installations. Therefore, the selection between monocrystalline and polycrystalline technology should consider efficiency requirements, operational stability, installation area, and economic feasibility according to specific application needs.

Overall, the findings of this study provide practical information regarding the performance characteristics of photovoltaic technologies under tropical environmental conditions in Indonesia, particularly in Balikpapan. The results may contribute to the optimization of renewable energy implementation and support the development of more effective photovoltaic systems in tropical regions. Future research is recommended to include longer observation periods, wider environmental variations, and additional parameters such as temperature effects, degradation analysis, and long-term operational performance to obtain more comprehensive photovoltaic evaluation results.

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