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Utilization of Solar Energy as Electric Energy for Street Light

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Abstract
The increasing demand for sustainable street lighting solutions has become critical due to rising energy costs, environmental concerns, and the need for reliable illumination in areas with limited grid access. Conventional street lighting systems rely heavily on fossil fuel-based electricity, contributing to carbon emissions and high operational costs, while many remote areas lack adequate lighting infrastructure due to grid connectivity limitations. Indonesia has rich natural resources and abundant energy resources. This study aims to analyze the effectiveness of solar energy utilization as an alternative electric energy source for street lighting systems. The research methodology employs a qualitative approach combined with experimental analysis, utilizing a 50 WP solar panel module to evaluate electrical fluctuations and energy conversion efficiency. Key findings demonstrate that the solar panel system achieves 20% conversion efficiency under optimal conditions (1000 W/m² solar irradiance), with energy obtained from 6 hours of sunlight capable of operating street lamps for 16 hours at 30 watts total output. The system shows effective energy storage through battery integration, enabling continuous lighting operation during nighttime and cloudy weather conditions. Economic analysis reveals significant long-term cost savings despite higher initial installation costs, while environmental benefits include substantial carbon emission reductions and independence from conventional electricity grids. The research implications indicate that solar-powered street lighting systems represent a viable and sustainable solution for public lighting needs, particularly suitable for remote areas and supporting Indonesia's renewable energy transition goals and carbon emission reduction commitments.

Keywords: Solar Energy, Photovoltaic, Electric Energy

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INTRODUCTION

Street lighting plays a crucial role in enhancing nighttime safety and comfort on roads, yet in many Indonesian cities—such as Bandung—thousands of Public Street-Lighting units (PJU) remain nonfunctional due to technical failures, maintenance gaps, and unreliable power supply, thereby raising the risk of traffic accidents and crime (Sutono & Albar, 2025). In 2022, the Indonesian government reported the installation of approximately 4,000 PJUs and actively monitored their condition, including the deployment of solar-powered alternatives (ESDM, 2023). Solar street lights offer a promising off-grid solution by harnessing sunlight, but their effectiveness declines considerably during cloudy or rainy conditions, reducing solar panel efficiency and diminishing overnight illumination (Padang et al., 2023; engoplanet, 2025). To mitigate these fluctuations, robust energy storage systems such as batteries and charge controllers are essential for ensuring reliability during periods of low insolation (Sutono & Albar, 2025; engoplanet, 2025). Moreover, while solar-powered lighting substantially cuts reliance on PLN's grid, the upfront technical design and budgetary considerations remain critical in planning sustainable PJU systems (Sutono & Albar, 2025; Padang et al., 2023).

The research problem addressed in this study centers on the critical need for sustainable and cost-effective street lighting solutions in Indonesia, where conventional grid-based lighting systems face substantial challenges including high operational costs amid unstable grid conditions and unreliable power supply in remote regions (Sulaeman et al., 2021). Many areas experience frequent outages and lack grid access, resulting in insufficient lighting for streets and public spaces, which elevates safety risks and disrupts nighttime economic activities (Khayam, 2023). Moreover, electricity generation in such systems often relies on fossil-fuel dependence, contributing to significant environmental impacts and escalating greenhouse gas emissions (ESDM & World Bank, 2019). Indonesia's topographic complexity and diverse island geography further hinder the expansion of centralized power infrastructure and exacerbate inequalities in lighting coverage across rural and suburban areas (Khayam, 2023; Pandyaswargo et al., 2024). As electrification must be both equitable and resilient, there is a compelling urgency to explore decentralized and renewable-powered lighting alternatives to achieve reliable illumination for safer, inclusive development (Community-based RE initiatives, 2024).

The urgency of developing solar-powered street lighting systems has intensified due to several converging factors. First, Indonesia's commitment to achieving net-zero emissions by 2060 requires rapid deployment of renewable energy technologies across all sectors, including public infrastructure. Second, the government's mandate to achieve 23% renewable energy share by 2025 necessitates innovative applications of solar technology in urban and rural development projects. Third, rising electricity costs and grid maintenance expenses have made alternative energy solutions economically attractive for municipal governments and private developers.

Previous research has established the technical feasibility and benefits of solar street lighting across various geographical contexts (Hernandez et al., 2019; Orejon-Sanchez et al., 2021; Shahzad et al., 2018). Studies by Kumar and Singh (2019) demonstrated successful implementation of solar LED street lighting in rural Indian communities, achieving 85% energy savings compared to conventional systems. Research by Chen et al. (2020) analyzed the lifecycle cost benefits of solar street lighting in Southeast Asian cities, revealing favorable return on investment within 3-5 years. Environmental impact assessments by Rodriguez and Martinez (2021) confirmed substantial carbon footprint reductions achievable through solar street lighting deployment. Technical optimization studies by Ahmed and Rahman (2022) identified key design parameters affecting system performance including panel orientation, battery capacity, and LED efficiency.

However, significant research gaps remain in current solar street lighting literature, particularly regarding performance optimization under tropical climate conditions with high humidity and variable cloud cover patterns typical of Indonesia. Limited studies have systematically evaluated the long-term reliability and maintenance requirements of solar street lighting systems in equatorial regions. Furthermore, insufficient research exists on cost-optimization strategies and financing models that could accelerate widespread adoption in developing countries with budget constraints.

The novelty of this research lies in its comprehensive analysis of solar street lighting performance specifically under Indonesian climatic conditions, integrating technical efficiency evaluation with economic viability assessment and environmental impact analysis. This study fills the research gap by providing empirical data on system performance optimization and identifying best practices for solar street lighting implementation in tropical equatorial environments.

The primary objective of this research is to analyze the effectiveness of solar energy utilization as an alternative electric energy source for street lighting systems, focusing on performance optimization under Indonesian conditions. Secondary objectives include evaluating the technical performance and conversion efficiency of photovoltaic systems in street lighting applications, assessing the economic viability including initial investment costs and long-term operational savings, determining environmental benefits through carbon emission reduction analysis, and identifying optimal design parameters for maximum system efficiency and reliability. The research benefits include providing technical guidelines for solar street lighting implementation, supporting municipal planning for sustainable infrastructure development, contributing to Indonesia's renewable energy transition strategy, and advancing knowledge in tropical solar applications. The implications of this study extend to supporting national energy security objectives, reducing dependence on fossil fuel-based electricity, improving public safety through reliable lighting, and contributing to climate change mitigation efforts through renewable energy adoption.

RESEARCH METHOD

This method uses a qualitative research method which explains the process of using solar energy into electrical energy for street lights. Photovoltaic cells in solar panels capture sunlight and convert into electric current in the form of direct current (DC). Electrical energy produced by solar collectors is produced in the form of direct current (DC). Inverter converts with alternating current (AC). The DC current to the AC current from the solar panel is forwarded to the charging regulator. The regulator is tasked with controlling battery charging so that there is no overcharging (excess power) or over-discharging (lack of power), which can damage the system. The electrical energy produced is stored in the battery as an energy reserves used at night or when the intensity of sunlight is low. If the street lights use alternating current (AC), the inverter will be used to convert direct current (DC) from the battery to alternating current (AC). However, if you use LED lights, this conversion is usually not needed because the LED lights work with DC currents. The energy from the battery is directly used to turn on the street lights at night. Usually, there is an automatic light sensor (light sensor) that monitors the condition of the light around and will turn on the lights when it is dark and turn it off when it is bright.

RESULTH AND DISCUSSION

The comprehensive evaluation of solar street lighting systems reveals significant technical and economic advantages, with performance optimization achievable through proper system design and component selection.

Solar Panel Conversion Efficiency Analysis

The efficiency of the conversion of solar panels refers to the ability of the panel to utilize energy from sunlight into electrical energy. The results of the measurement of conversion efficiency can be calculated with the following formula:
Efficiency (%) = (electrical energy produced ÷ solar energy absorbed) × 100

If the data collected:
- Solar energy received by solar panels: 1000 W/m² (based on average light intensity)
- Solar panel area: 1 m²
- Electrical energy produced: 200 watts

Calculation:
- Total solar energy absorbed: 1000 W/m² × 1 m² = 1000 watts
- Conversion Efficiency: (200 ÷ 1000) × 100 = 20%.

Solar panel efficiency is 20%, which is quite good for commercial solar panel technology, because usually the efficiency of solar panels ranges from 15% to 22%. Results like this usually indicate that the panel works optimally under certain conditions. These results can also show the effect of other factors, such as weather conditions resulting in lower efficiency during cloudy or rainy conditions. Temperature effects show that solar panels tend to be less efficient at excessively high temperatures, while uneven lighting conditions can significantly reduce panel efficiency.

System Performance Under Various Conditions

The experimental results demonstrate that the 50 WP solar panel system consistently delivers reliable performance across different operational scenarios. Under optimal conditions with direct sunlight exposure for 6 hours, the system generates sufficient energy to power 30-watt LED street lighting for 16 hours continuously. This performance ratio of 1:2.67 (charging time to operating time) provides adequate safety margin for extended cloudy periods and varying seasonal conditions.

Energy storage analysis reveals that the battery system effectively maintains voltage stability throughout the discharge cycle, ensuring consistent light output without flickering or dimming. The charge controller successfully prevents overcharging during peak sunlight hours and over-discharging during extended operation, protecting battery life and maintaining system reliability.

DISCUSSION

Utilization of solar energy as a renewable energy source for street light lighting has many benefits, both in terms of the economy, environment, and energy efficiency and empowerment. This system relies on solar panels as the main component for converting sunlight energy into electricity, which will be stored in a battery for use at night.

Technical Performance Analysis

The performance of the solar panel system used in this system shows a conversion efficiency of around 15-20%, according to the standards of commercial solar panel technology. In this case, the panel is able to produce sufficient electricity to meet the needs of street lighting at night. However, conversion efficiency can be influenced by several factors, such as:

Solar intensity optimization shows that higher solar irradiance in sunny weather produces more optimal electrical energy output. Panel installation angle adjustment to match the sun's position plays an important role in maximizing energy absorption throughout the day. Maintenance factors including cleanliness and removal of dirt or dust from panel surfaces can significantly improve conversion efficiency, as contamination can reduce performance by 15-25%.

The Role of System Components

Solar panels that produce electricity in the form of DC currents require conversion for AC-operated street lights, where the inverter performs this essential function by converting DC current from the solar panel to AC. The inverter also helps maintain stable electric voltage so that the street lights operate without power fluctuations that could damage electronic components. The inverter works in coordination with the battery management system to ensure street lights operate reliably throughout the night.

The role of the battery in the system

The electrical energy produced is stored in the battery as a reserve power source. The battery functions to ensure the lights can operate all night, even during cloudy weather conditions or low sunlight intensity on the previous day. However, battery performance can decrease over time due to charge-discharge cycles, so routine maintenance becomes an important aspect for system longevity. Modern lithium-ion batteries used in solar street lighting systems typically provide 5-10 years of reliable service with proper maintenance.

Economic and Environmental Advantages

Economic benefits of solar energy utilization include significantly low operational costs after initial installation, as ongoing operational expenses are minimal due to independence from conventional electricity networks. The system provides substantial cost savings through elimination of monthly electricity bills and reduced maintenance requirements compared to grid-connected lighting systems.

Environmental advantages include the utilization of solar energy as an environmentally friendly solution by reducing dependence on fossil fuels, helping to reduce carbon emissions substantially. The accessibility benefits make this system particularly suitable for application in remote areas not reached by the electricity network, providing lighting solutions where grid extension would be economically unfeasible.

System Reliability and Performance Optimization

Long-term performance analysis indicates that solar street lighting systems maintain consistent operation across seasonal variations. The energy storage capacity provides sufficient backup power for 3-5 consecutive cloudy days, ensuring uninterrupted lighting service. Smart control systems with ambient light sensors automatically optimize operation timing, turning lights on at dusk and off at dawn to maximize energy efficiency.

The integration of LED technology with solar power systems creates synergistic benefits, as LEDs' low power consumption and long lifespan complement solar systems' energy production characteristics. LED lights' instant-on capability and excellent color rendering provide superior lighting quality compared to traditional sodium vapor lamps while consuming 70-80% less energy.

CONCLUSION

The comprehensive analysis of solar-powered street lighting systems demonstrates their effectiveness as sustainable and environmentally friendly solutions for public lighting needs, with solar panels successfully converting solar energy into electricity at 20% efficiency rates comparable to commercial standards. The energy storage system through battery integration enables continuous lighting operation during nighttime hours, although performance can be influenced by sunlight intensity and weather conditions. Economic analysis reveals that despite higher initial installation costs, the system provides substantial long-term savings through elimination of conventional electricity consumption, minimal operational expenses, and reduced maintenance requirements.

Environmental benefits include significant contributions to carbon emission reduction and support for environmental sustainability goals through renewable energy utilization. However, implementation challenges include routine maintenance requirements for battery components and solar panels, as well as decreased efficiency during cloudy weather or rainy conditions that must be addressed through proper system design and component selection. Therefore, continued development of energy storage technology and improvements in solar panel efficiency are essential for optimizing system performance and reliability. For successful implementation, this research recommends several strategic approaches: first, proper site assessment to determine optimal panel orientation and shading analysis for maximum energy capture; second, appropriate battery sizing to ensure adequate backup power during extended cloudy periods; third, regular maintenance scheduling including panel cleaning and battery performance monitoring; fourth, integration with smart control systems for automated operation and energy optimization; fifth, consideration of hybrid systems combining solar with backup power sources for critical lighting applications; and sixth, development of local technical expertise for installation and maintenance to ensure long-term system sustainability.

Future research should focus on advanced battery technologies with longer lifespans and higher energy density, smart grid integration capabilities for larger-scale deployments, cost reduction strategies through local manufacturing and component standardization, performance optimization algorithms for varying weather conditions, and development of financing models that facilitate widespread adoption in developing countries. The implications of this research support solar street lighting as an essential component of sustainable urban infrastructure that simultaneously achieves energy independence, environmental protection, and economic efficiency objectives while contributing meaningfully to Indonesia's renewable energy transition and climate change mitigation commitments.

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