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Evaluation of Solar-Powered Street Lighting Performance at Kamijoro Bridge, Yogyakarta

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Abstract

Indonesia's fossil fuel dependence has led to significant environmental problems, including greenhouse gas emissions, climate change, and ecosystem degradation. Given its location along the equator, Indonesia has enormous potential for harnessing solar energy. This research evaluates the solar insolation potential of solar-powered street lighting (PJU-TS) installed at Kamijoro Bridge, Yogyakarta. Solar radiation data were obtained from NASA POWER, while light intensity was measured in the field using a Lux Meter. Results show that average solar radiation intensity at the site was 251.87 W/m^2, equivalent to a theoretical energy yield of 163.77 kWh/day under ideal conditions with a 17% PV efficiency. Field measurements demonstrated that PJU-TS 3 achieved the highest illumination (589 Lux at 18:00 WIB), although the intensity declined throughout the night. Luminance calculations confirmed compliance with the Indonesian quality standard SKh 1.9.7. These findings demonstrate the viability of solar street lighting for public infrastructure and provide recommendations for improving system stability, monitoring, and maintenance.

Keywords: Solar energy, solar-powered street lighting, NASA Power, Lux Meter

1. Introduction

Indonesia is one of the fastest-growing economies in Southeast Asia, with an increasing demand for energy across industrial, commercial, and residential sectors. This growth has been historically dependent on fossil fuels, particularly coal, oil, and natural gas, which account for more than 80% of the country's energy mix [1]. Such dependence has contributed to severe environmental impacts, including greenhouse gas emissions, air pollution, and climate change. In response, the Government of Indonesia has introduced the National Energy Policy (KEN) and the General National Energy Plan (RUEN), which target 23% renewable energy in the national mix by 2025 and net zero emissions by 2060.

As a tropical archipelagic nation located along the equator, Indonesia is endowed with abundant solar energy resources, averaging 4–6 kWh/m^2/day across most regions [1]. Harnessing this potential through photovoltaic (PV) technology offers a strategic pathway for sustainable electrification, particularly in off-grid rural communities. The deployment of solar-powered street lighting (PJU-TS) offers multiple benefits, including reduced dependence on grid electricity, enhanced public safety, support for environmental protection, and lower long-term operational costs.

Street lighting is a critical component of urban infrastructure, directly influencing road safety, public comfort, and social well-being. However, conventional grid-based street lighting systems are energy-intensive and costly, especially in areas with limited access to electricity. Solar-powered street lighting has therefore emerged as a promising alternative. The performance of such systems, however, depends on solar radiation intensity, PV module efficiency, battery capacity, and operational conditions [2]. Previous studies [3,4] have demonstrated the technical feasibility of PJU-TS, but efficiency challenges remain, particularly with respect to long-term reliability and maintenance.

In global contexts, solar lighting technologies have been increasingly adopted in Asia, Africa, and Latin America. China and India, for example, have implemented large-scale solar street lighting programs as part of their national renewable energy strategies. The use of NASA POWER (Prediction Of Worldwide Energy Resources) datasets has further facilitated research and planning for solar energy projects worldwide. Sayago et al. [5] assessed the accuracy of NASA POWER daily solar radiation data, while Marzouk [6] tested its reliability over 39 years against meteorological records in Oman. Stackhouse et al. [7] highlighted the role of NASA POWER datasets in sustainable energy planning and infrastructure development.

In Indonesia, solar lighting projects have been carried out in various provinces. Sutopo et al. [8] proposed a model to improve standards for solar lighting. Ibrahim et al. [9] and Muhaisen et al. [10] conducted techno-economic analyses of smart solar street lighting in Egypt and Kuwait, respectively. Hartono et al. [11] highlighted the importance of proper maintenance for PV systems in West Kalimantan, while Tharo et al. [12] emphasized urban sustainability benefits in Binjai. Case studies in Balikpapan [15] and rural areas [16] also demonstrate that PJU-TS is not only feasible but socially beneficial.

This paper evaluates the solar energy potential and efficiency of PJU-TS installed at Kamijoro Bridge in Yogyakarta, Indonesia. By combining NASA POWER solar radiation data with field-based illumination measurements, this study aims to contribute to the broader discourse on renewable energy adoption, infrastructure sustainability, and the integration of solar technologies in Indonesia's public sector.

2. Research Method

2.1 Study Location

The study was conducted at Kamijoro Bridge, located in Bantul Regency, Yogyakarta, Indonesia (coordinates: 7°54′S, 110°17′E). The region is characterized by a tropical monsoon climate with average annual rainfall of 2,200 mm and an average temperature of 26–28 °C. The bridge serves as both a transportation and a recreational area.

The map of the study location is shown in Figure 1.

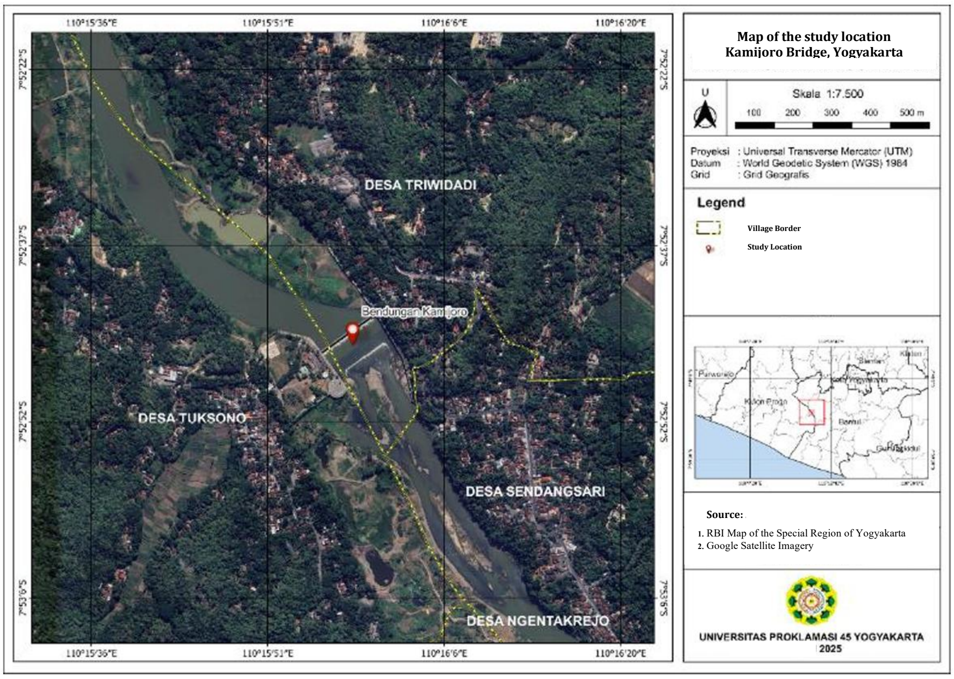

Figure 1. Map of the study location

In the Kamijoro Bridge, six solar-powered street lighting units (PJU-TS) were installed, of which three were selected as the study sample because they were fully operational during the study period. Each of them has the same system configuration, which can be seen in Figure 2.

Figure 2. The solar-powered street lighting units in Kamijoro Bridge

The solar-powered street lighting (PJU-TS), which is used as a sample study, has the specification as seen in Table 1.

Table 1. Technical parameters of PJU-TS at Kamijoro Bridge

Component	Specification
Solar Panel	Type: SOLANA (MONO -24V-250) Max. Power (Pmax): 250 Wp Optimum Operating Voltage (Vmp): 38.2 V Optimum Operating Current (Imp): 6.55 A Open-circuit Voltage (Voc): 45.8 V Short-circuit Current (Isc): 6.98 A Power Tolerance (Pmax): 0~±3% Module Dimension: 1,5 × 0,85 × 0,035 m^2 Weight: 14.0 Kg Max. Series Fuse Rating: 20 A
LED Lighting	Type: Ledenvo LED Street Light Model: Ledenvo Led ST 120W 757 Wattage: 120 W Rated Voltage: 220 – 240 V Rated Current: 0.67 A Frequency: 50 – 60 Hz Pout: 5 × (24 × 0,9 W/Led)
PJU Pillar	Total Height: 4 m Ornament Height: 3 m

2.2 Data Sources

Three sources of data were used:

1. NASA POWER – providing satellite-based solar insolation data (hourly, daily, monthly averages). The data was taken on the 15 days, from 1-15 January 2025. Only the highest value was used for analysis because the testing focused solely on the Solar Insolation Potential and Maximum Temperature.
2. Field measurements – illumination levels measured using a digital Lux Meter (model TES-1339R, accuracy ±3%). Field illumination measurements were taken at four intervals: 18:00, 21:00, 00:00, and 06:00 WIB.
3. Standards – Indonesian national interim specifications for solar-powered street lighting (SKh 1.9.7) [17].

2.3 Analytical Framework

The potential solar energy generation was estimated using Equation (1):

$$E = I \times A \times t \times \eta \times (1-C) \qquad \text{(Eq.1)}$$

where:

E = solar energy potential (Wh)
I = solar radiation intensity (W/m^2)
A = PV panel area (m^2)
t = daily sunlight duration (h)
η = PV panel efficiency (%)
C = cloud cover factor

3. Results and Discussion

3.1 Solar Energy Potential

NASA Power is used to help find data on solar radiation reaching the Earth's surface, known as solar insolation, measured in watts per square meter (W/m^2). This value varies depending on location, time of day, season, and atmospheric conditions such as cloud cover.

The data that has been analyzed were accessed from the NASA Power system at https://power.larc.nasa.gov/data-access-viewer/, as seen in Figure 3.

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POWER_Point_Daily_20250101_20250115_007d88S_110d27E_LST(1).txt - Notepad
File  Edit  Format  View  Help
-BEGIN HEADER-
NASA/POWER Source Native Resolution Daily Data
Dates (month/day/year): 01/01/2025 through 01/15/2025 in LST
Location: latitude  -7.8785   longitude 110.2669
elevation from MERRA-2: Average for 0.5 x 0.625 degree lat/lon region = 49.37 meters
The value for missing source data that cannot be computed or is outside of the sources availability range: -999
parameter(s):
ALLSKY_SFC_SW_DWN     CERES SYN1deg All Sky Surface Shortwave Downward Irradiance (W m-2)
-END HEADER-
YEAR  MO  DY  ALLSKY_SFC_SW_DWN
2025   1   1            166.31
2025   1   2            152.56
2025   1   3            251.87
2025   1   4            221.48
2025   1   5            140.33
2025   1   6            183.62
2025   1   7            200.00
2025   1   8            165.38
2025   1   9            192.74
2025   1  10            229.06
2025   1  11            201.98
2025   1  12            110.18
2025   1  13            204.76
2025   1  14            176.18
2025   1  15            179.43
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Figure 3. NASA Power Data Results on January 1-15, 2025

Figure 3 shows that the highest value on the Solar Insolation Potential and Maximum Temperature at Kamijoro Bridge was 251.87 W/m² on January 3, 2025. From equation (1), with a PV module area of 1.275 m^2, daily sunlight duration of 6 hours, panel efficiency of 17%, and cloud cover factor of 0.5, the potential energy generation was estimated at 163.77 kWh under ideal conditions.

This aligns with findings from Balikpapan [15], where similar systems achieved daily yields of 150–180 kWh. In West Kalimantan, Hartono *et al.* [11] observed slightly lower averages due to higher rainfall and cloudiness. Such comparisons highlight regional variability and the importance of site-specific assessments. If the system were applied to 1,000 street lighting units across Yogyakarta, the PJU-TS could collectively generate over 163 MWh/day, potentially reducing grid electricity demand by 58 GWh/year. Assuming an emission factor of 0.85 kg CO_2/kWh, this corresponds to a reduction of approximately 49,300 tonnes of CO_2 annually.

3.2 Field Illumination Performance

Field Illumination measurements using the Lux Meter were conducted to obtain luminance data in order to compare the light intensity performance of the Solar Street Lights at Kamijoro Bridge. The results of the measurements were shown in Figure 4.

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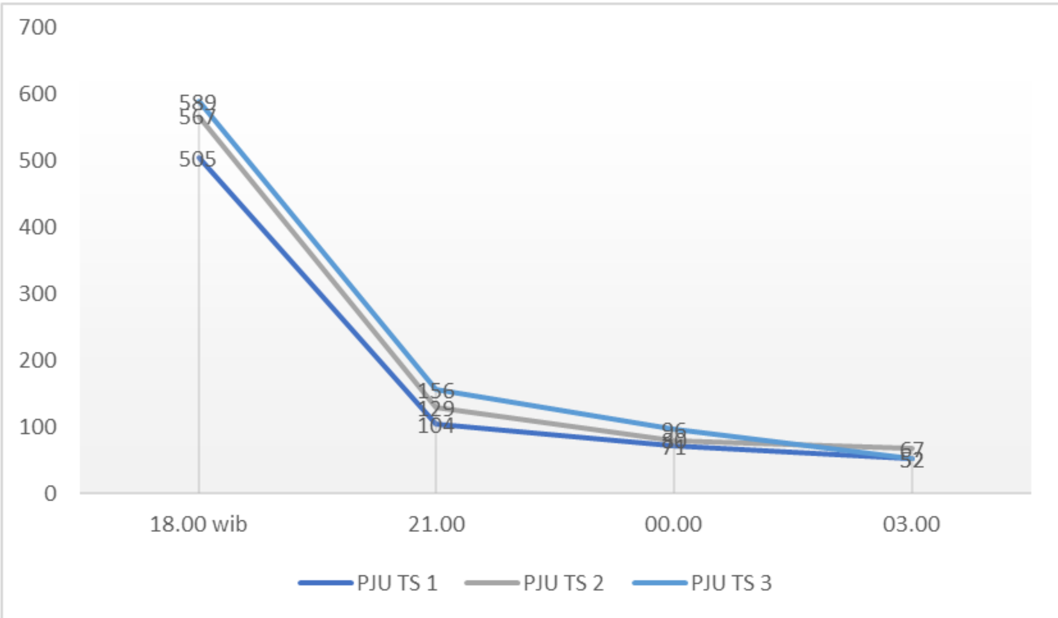

Figure 4. Diagram of Light Intensity Measurements on Each PJU-TS

Figure 4 showed that at 18:00 WIB, PJU-TS 3 recorded the highest illumination at 589 Lux, followed by PJU-TS 2 at 567 Lux, and PJU-TS 1 at 505 Lux. Illumination decreased gradually through the night due to battery discharge. At midnight, Lux values dropped by approximately 35% compared to initial readings. By early morning, illumination was significantly reduced, with some units unable to provide consistent output.

Despite fluctuations, calculated luminance values were 0.55 cd/m^2 (PJU-TS 1), 0.61 cd/m^2 (PJU-TS 2), and 0.64 cd/m^2 (PJU-TS 3). All exceeded the minimum requirement of 0.4 cd/m^2 set by SKh 1.9.7 [17]. This confirms compliance with Indonesian standards.

4. Conclusion

This study evaluated the performance of solar-powered street lighting at Kamijoro Bridge. Key findings include that the estimated solar energy potential was 163.77 kWh/day, confirming the adequacy of local solar resources. Field measurements showed that illumination levels were initially sufficient (up to 589 Lux) but decreased over time due to battery discharge. Luminance values ranged between 0.55 and 0.64 cd/m^2, exceeding the national standard SKh 1.9.7 for neighborhood roads. Scaling up PJU-TS deployment could generate substantial energy savings and reduce CO_2 emissions.

To improve the study's results, the study recommends regular preventive maintenance to ensure operational stability, the Integration of smart monitoring systems for real-time performance tracking, and policy support for the wider adoption of PJU-TS as part of Indonesia's renewable energy roadmap.

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