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Research Original Article

Potential Analysis of Rooftop Solar Power Plant Development Using PLN Mobile Application for Village Office Buildings in Lenek District, East Lombok, Indonesia

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Abstract
This study evaluates the potential for rooftop solar photovoltaic (PV) installations on village office buildings in the Lenek District, East Lombok, Indonesia, using the PLN Mobile application. The primary objectives are to assess the potential installed capacity of rooftop solar PV systems, estimate the economic and environmental impacts of their installation, and evaluate the performance of the PLN Mobile application in simulating solar PV systems. The findings reveal that the application provided generalized recommendations, with suggested capacities of 0.6 kWp and 1.32 kWp, despite variations in electricity consumption, roof orientation, and other structural characteristics. Estimated installation costs range from Rp10,452,380 to Rp26,130,952, with potential monthly savings between Rp103,464 and Rp227,620, and a uniform reduction in carbon emissions of 0.285 kg CO2 per month. While the PLN Mobile application offers valuable preliminary insights, it lacks the necessary specificity to deliver precise assessments, leading to a potential mismatch between recommendations and the actual energy needs and structural conditions of the village offices. As a result, the study concludes that more customized evaluation methods are required to optimize the installation and performance of rooftop solar PV systems in village offices.
Keywords: Rooftop Solar PV; PLN Mobile; Village Office; Economic Impact; Environmental Impact

Introduction
The global demand for energy continues to rise with the increasing population. The limited availability of fossil fuels has driven innovation to accelerate the energy transition, which is crucial as conventional energy resources are depleting. Currently, Indonesia heavily relies on fossil fuels such as coal, petroleum, and natural gas to support its economic activities (Rahman et al., 2021). However, fossil energy production has declined over the past decade, reaching only 740,000 barrels per day in 2019-2020 (Setiyono et al., 2023). Consequently, Indonesia aims to increase the use of new and renewable energy sources to at least 23% by 2025 and a minimum of 31% by 2050 (Yudiartono et al., 2023). This increase is expected to meet national energy needs and positively impact Indonesia's future economic performance (Santika et al., 2020).

In 2018, the Indonesian government issued a policy allowing customers of the State Electricity Company (PLN) to use rooftop solar power plants (Alifia et al., 2021). This policy is a crucial part of efforts to increase the utilization of renewable energy sources, targeting an ambitious 23% by 2025 (Veng et al., 2020). Concurrently, Indonesia is ranked among the top globally in planning coal-fired power plant capacity expansion (Ordonez et al., 2022). However, the increased use of coal energy has significant negative environmental impacts, necessitating a transition to more environmentally friendly energy sources (Dintchev et al., 1998).

PT PLN, the primary electricity provider in Indonesia, developed the PLN Mobile application to facilitate access to electricity services, provide a platform for complaints, and offer additional convenience options for customers (Yulistiar & Kriswibowo, 2024). This application is expected to enhance the efficiency of complaint management and customer service while reducing bureaucracy. Furthermore, the application features a marketplace offering electrical products such as electric vehicles and PV rooftops, as well as various non-electrical items such as food (Fikri, 2024).

While there are more sophisticated applications available for planning rooftop PV installations with detailed budget estimates (Melius et al., 2013), these applications are often complex and require professional handling to obtain accurate data. In contrast, the PLN Mobile application is user-friendly and aligns with PLN regulations to support the ongoing energy transition in Indonesia (Antikasari et al., 2023). Given the policy in West Nusa Tenggara (NTB) that mandates all public offices to use renewable energy in the coming years, there has been no prior research analyzing the potential of rooftop solar power plants using the PLN Mobile application.

This study aims to assess the potential of installing rooftop solar power plants (PLTS) on village office buildings in the Lenek district, as part of supporting NTB's 100% renewable energy transition outlined in the NTB energy roadmap. The primary objectives of this research are: (1) to evaluate the potential installed capacity of rooftop solar systems on village office buildings; (2) to estimate the economic and environmental impacts of installing rooftop solar systems in these offices, including cost savings, reduced carbon emissions, and fuel savings; and (3) to analyze the performance of the PLN Mobile application in simulating rooftop solar power plants, including the accuracy of its recommendations for installed capacity, energy production, and financial projections. Simulations are conducted to predict the potential electrical energy generated by on-grid rooftop solar power plants in the Lenek district, using village office buildings as representative structures for the study.

Literature Review

Various research methods have been employed to analyze the potential of rooftop Solar Power Plants (Byrne et al., 2015). These methods include location analysis, which determines the optimal orientation and inclination of roofs to maximize sunlight reception (N'Tsoukpoe, 2022). Additionally, Building Information Modeling (BIM) technology plays a crucial role in the design and simulation of energy-efficient buildings, as it efficiently integrates various aspects (Gao et al., 2019). Energy simulations using software such as PVsyst or NREL's SAM provide deep insights into the potential energy production of proposed PLTS systems (Riedel-Lyngskær, 2023).

Economic analysis through cost-benefit calculations and payback periods is also a key component in evaluating the feasibility of rooftop (Hekrle et al., 2023). Technical analysis ensures system compatibility and available power (Xiao et al., 2024), while environmental analysis assesses the installation's impact (Mehmood et al., 2023). Physical surveys for field inspection and measurement, along with energy requirement analysis based on building energy consumption profiles (Panicker et al., 2023), are also essential.

A mathematical model like a regression method can also be used to estimate the electrical energy consumption (Hasibuan et al., 2022). Furthermore, direct analysis through real-time performance evaluation using panels supported by web-based applications like Homer Pro, can help optimize the design and simulation of PLTS systems (Puglia, 2017). Moreover, utilizing sensors for solar PV can reduce the energy consumption for households (Akmal et al., 2024). Collectively, these references highlight the importance of a multidisciplinary approach in designing, implementing, and evaluating rooftop PLTS systems. This comprehensive methodology ensures that PLTS systems are not only energy-efficient but also economically viable, technically compatible, environmentally friendly, and aligned with the building's energy needs.

The PLN Mobile application is a digital platform developed by PLN to facilitate user access to various electricity-related services and information (Fikri, 2024). It includes features such as bill payments, service disruption reports, and analysis of rooftop PLTS installation potential (Putri & Samsudin, 2024). Its functions encompass location mapping, solar energy potential calculations, financial benefit simulations, and direct consultations with experts (Syafrizal et al., 2024). The advantages of this application include easy and quick access, accurate location mapping, comprehensive calculation capabilities, and expert support, which aid users in making more informed and efficient decisions regarding solar energy utilization (Chaerunisa & Farida, 2024).

This research leverages the PLN Mobile application as a tool for simulating rooftop solar power installations, an innovative approach that has not been extensively studied, particularly in the Lenek District. In line with the study objectives, this research integrates key methodologies from previous studies, including the analysis of installed capacity potential, economic impact, and environmental benefits of rooftop solar systems. This research builds on previous work by not only estimating the technical and economic potential of rooftop solar power systems but also by examining the accuracy and reliability of PLN Mobile in providing installation recommendations, financial estimates, and environmental impact projections. By adopting a multidisciplinary approach that includes location analysis, energy simulation, economic evaluation, and environmental assessment, this study offers new insights into the role of digital tools like PLN Mobile in accelerating the adoption of renewable energy solutions in village offices, contributing to broader renewable energy and sustainable development efforts in Indonesia.

Materials & Methods

This study involves several critical stages to comprehensively analyze the potential for rooftop Solar Power Plants (PLTS) in village office buildings in the Lenek District. The methodology integrates both field observations and the use of digital tools to ensure accurate data collection and analysis.

The first step involves identifying the exact geographical coordinates of the village office buildings using Google Earth. This tool allows for precise mapping of each building's location, which is crucial for subsequent analyses of solar potential. Using the Google Earth application, the coordinates of each village office building were recorded to ensure that the solar radiation data and other location-specific factors could be accurately assessed.

Next, the orientation (azimuth) and inclination (tilt angle) of each roof were observed and recorded. This step is essential because the angle and direction of the roof significantly impact the amount of solar energy that can be harnessed. These observations were conducted through on-site inspections, where the direction and slope of the roofs were measured using a digital inclinometer and a compass to ensure precise data collection.

Following this, the existing electrical infrastructure of the village offices was examined, specifically focusing on the installed meter power capacity. This involves checking the electrical meters to determine the maximum power they can handle. This step is critical to ensure that the proposed solar power system can be integrated without overloading the current electrical system.

A survey was then conducted to gather information on the monthly electricity bills paid by the village offices. This data provides insight into the current energy consumption patterns and the potential cost savings from installing a rooftop solar power system. The survey involved collecting electricity bill records from the office administrations, which were then analyzed to understand the energy usage and financial implications.

Energy simulations and environmental impact assessments were performed using the PLN Mobile application. This application provides a user-friendly interface for these tasks and helps streamline the data collection and analysis process.

The application's features, such as location mapping, energy potential calculation, financial simulation, and environmental impact assessment, were leveraged to enhance the accuracy and efficiency of the study.

Simulation Using PLN Mobile Application

Following the field observations for determining the placement of rooftop photovoltaic (PV) systems, the next step involves simulation using the PLN Mobile application. The primary objective of this simulation is to acquire necessary data, such as system size, capacity, and cost estimates required for the installation application of the solar panels.

The process begins by ensuring that the PLN Mobile application is installed on the mobile device and launching the app. After logging in, the user navigates to the "More" menu located at the bottom of the main menu. Within the "More" menu, the user selects the "PV Rooftop" shortcut to access the solar panel-related features.

In the simulation phase, users are prompted to input the precise geographic coordinates of the solar panel installation site, along with the applicant's name and details about the village office obtained during the previous observational phase. Once all required information is accurately entered, the user clicks the "Calculate Simulation" button to initiate the calculation process.

Upon completion of the simulation, the final step involves analyzing the generated data. The results from the simulation provide estimates of costs, energy efficiency, and other relevant information regarding the installation of solar panels at the specified location. This analysis is crucial for assessing the feasibility and benefits of investing in rooftop PV systems. Consequently, the PLN Mobile application proves to be a valuable tool in the planning and application process for solar panel installations. The procedure is summarized in the following picture:

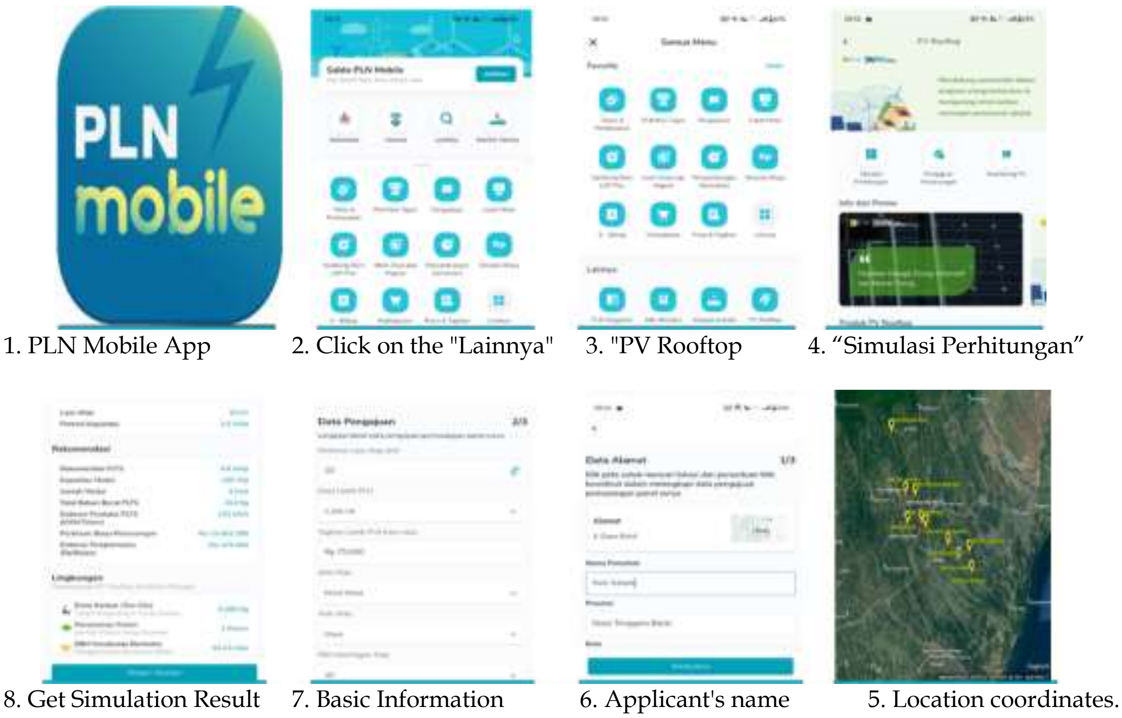

Figure 1. Flowchart of the simulation process using the PLN mobile application

Results and Discussion

This research was conducted over 11 days, from March 19, 2024, to March 29, 2024, in the Lenek District, East Lombok, West Nusa Tenggara, Indonesia. The aim was to analyze the potential for rooftop solar power installations in various village office buildings within the district. Detailed data collection, based on input from the PLN Mobile application, included geographical coordinates, roof types, roof orientations, and current electricity usage. The data collection locations, along with their respective coordinates, are illustrated in the following map.

Figure 2. Village Office Building Map in Lenek District, East Lombok, West Nusa Tenggara, Indonesia

The map in Figure 1 provides a visual representation of the village office buildings surveyed during the study. Each marker on the map corresponds to a specific village office, with precise coordinates obtained using the PLN Mobile application. This geographic information is crucial for planning the installation of rooftop solar panels, as it allows for accurate assessment of solar exposure, potential shading issues, and optimal panel placement. Basic information of Village Offices in Lenek District is given in Table 1.

Table 1. Basic Information of Village Offices in Lenek District

No	Village Office	Coordinates	Installed Capacity	Roof Material	Roof Orientation	Monthly Electric Bill (IDR)
1	Lenek Daya	8°34'00"S 116°29'45"E	900 watt	Metal	Timur	50,000
2	Ramban Biak	8°34'03"S 116°30'18"E	900 watt	Tile	Barat	70,000
3	Lenek Induk	8°34'55"S 116°30'42"E	900 watt	Tile	Timur	450,000
4	Lenek Duren	8°31'58"S 116°28'52"E	900 watt	Metal	Barat	110,000
5	Sukarema	8°35'31"S 116°31'50"E	2200 watt	Tile	Timur	200,000
6	Lenek Baru	8°36'34"S 116°33'47"E	900 watt	Tile	Barat	50,000
7	Kalijaga Baru	8°35'58"S 116°33'43"E	900 watt	Metal	Barat	50,000
8	Lenek Lauq	8°35'39"S 116°32'20"E	1200watt	Tile	Barat	200,000
9	Lenek Pesiraman	8°34'58"S 116°30'48"E	900 watt	Tile	Barat	100,000
10	Lenek Kali Bambang	8°34'57"S 116°29'52"E	900 watt	Tile	Barat	200,000

Table 1 provides comprehensive details regarding the physical conditions and geographical locations of ten village offices, including coordinates, installed PLN electrical capacity, roof type, roof orientation, and monthly electricity bills. The specific coordinates enable accurate location identification via the PLN Mobile application. Most offices have an installed electrical capacity of 900 watts, except for Sukarema Village Office (2200 watts) and Lenek Lauq Village Office (1200 watts), which indicates higher electricity demands at these locations.

The roof types vary between tile and metal. Lenek Daya, Lenek Duren, and Kalijaga Baru feature metal roofs, while the other offices, including Lenek Induk, have tile roofs. The type of roof influences the installation process for photovoltaic (PV) systems, as metal roofs may require additional considerations compared to tile roofs. Roof type also impacts thermal conditions inside the building, maintenance costs, and roof durability against environmental factors—all of which affect the performance of solar panels.

Roof orientation is a key factor for solar panel efficiency. Most village offices have roofs oriented westward with an average tilt of 30°, though some face east. Using a compass, the roof orientations were determined: Lenek Daya, Lenek Induk, and Sukarema have east-facing roofs, optimal for capturing morning sunlight, while Ramban Biak, Lenek Duren, Lenek Baru, Kalijaga Baru, Lenek Lauq, Lenek Pesiraman, and Lenek Kalibambang have west-facing roofs, which are more effective for capturing afternoon sunlight. This orientation is crucial for maximizing the efficiency of the solar panels. It is advisable to incorporate roof type and orientation data into the PLN Mobile application to improve the accuracy of solar power planning.

Additionally, Table 1 includes the monthly electricity bills for each village office, reflecting their electricity usage. The bills range from Rp 50,000 to Rp 450,000, indicating varying levels of electricity consumption across the offices. This data is vital for understanding the energy requirements of each office and assessing the financial implications of installing solar power systems. The correlation between electricity usage and solar power potential will be further explored in the subsequent technical analysis. The results of this assessment, including potential capacity, recommended PV system specifications, and estimated energy production, are summarized in Table 2.

Table 2. Technical Analysis Results of Rooftop Solar Potential Using PLN Mobile

No	Village Office	Potensi Kapasitas	Rekomend asi PLTS	Kapasitas Modul (wp)	Jumlah Modul	Total Berat PLTS	Estimasi Produksi Kwh/tahun
1	Lenek Daya	1.0kWp	0.6kWp	430Wp	3	214Kg	153 kWh
2	Ramban Biak	1.0kWp	0.6kWp	430Wp	3	214Kg	153 kWh
3	Lenek Induk	3.0kWp	1.32Wp	430Wp	7	535Kg	337kWh
4	Lenek Duren	1.0kWp	0.6kWp	430Wp	3	214Kg	153 kWh
5	Sukarema	3.0kWp	1.32Wp	430Wp	7	535Kg	337kWh
6	Lenek Baru	1.0kWp	0.6kWp	430Wp	3	214Kg	153 kWh
7	Kalijaga Baru	1.0kWp	0.6kWp	430Wp	3	214Kg	153 kWh
8	Lenek Lauq	3.0kWp	1.32Wp	430Wp	7	535Kg	337kWh
9	Lenek Pesiraman	1.0kWp	0.6kWp	430Wp	3	214Kg	153 kWh
10	Lenek Kali Bambang	3.0kWp	1.32Wp	430Wp	7	535Kg	337kWh

Table 2 provides information on the potential and recommended use of solar PV systems for ten village offices. Each row in the table includes the village office name, the potential maximum capacity of the PV system that can be installed, the recommended PV system capacity, the capacity of each solar module in watt-peak (Wp), the number of modules required, the total weight of the PV system, and the estimated annual electricity production in kilowatt-hours (kWh).

Village offices such as Lenek Daya, Ramban Biak, Lenek Duren, Lenek Baru, Kalijaga Baru, and Lenek Pesiraman each have a potential capacity of 1.0 kWp and a recommended PV system capacity of 0.6 kWp. With a module capacity of 430 Wp, each of these offices requires three modules (0.6 kWp / 0.43 kWp ≈ 3 modules), with a total PV system weight of 214 kg and an estimated annual electricity production of 153 kWh.

Village offices like Lenek Induk, Sukarema, Lenek Lauq, and Lenek Kalibambang have a potential capacity of 3.0 kWp and a recommended PV system capacity of 1.32 kWp. With the same module capacity of 430 Wp, each of these offices requires seven modules (1.32 kWp / 0.43 kWp ≈ 7 modules). The total PV system weight for each of these offices is 535 kg, with an estimated annual electricity production of 337 kWh.

It is important to note that the recommendations provided by the PLN Mobile application appear to be somewhat generalized. Despite the variations in electricity bills and roof orientations indicated in Table 1, similar recommendations are made for several offices. This suggests that the PLN Mobile application may not fully account for the specific energy generation and consumption analysis of each location. Instead, it tends to standardize recommendations based on a set of predefined options, which may not always align perfectly with the unique characteristics of each site.

To further analyze the feasibility and benefits of the proposed solar PV systems, an economic and environmental impact assessment was conducted directly using the PLN Mobile application. This assessment includes the estimated installation costs, potential monthly savings, reduction in carbon emissions, and fuel savings, summarized in Table 3.

Table 3. Estimated Economic and Environmental Impact Analysis

No	Office Name	Estimated Installation Cost	Estimated Monthly Savings (IDR)	Carbon Emission Reduction (kg CO2	Fuel Saved (liters)
1	Lenek Daya	Rp10.452.380	Rp. 103.464	0.285Kg	61,44Liter
2	Ramban Biak	Rp10.452.380	Rp. 103.464	0.285Kg	61,44Liter
3	Lenek Induk	Rp26.130.952	Rp. 227.620	0.285Kg	135,168Liter
4	Lenek Duren	Rp10.452.380	Rp. 103.464	0.285Kg	61,44Liter
5	Sukarema	Rp26.130.952	Rp. 227.620	0.285Kg	135,168Liter
6	Lenek Baru	Rp10.452.380	Rp. 103.464	0.285Kg	61,44Liter
7	Kalijaga Baru	Rp10.452.380	Rp. 103.464	0.285Kg	61,44Liter
8	Lenek Lauq	Rp26.130.952	Rp. 227.620	0.285Kg	135,168Liter
9	Lenek Pesiraman	Rp10.452.380	Rp. 103.464	0.285Kg	61,44Liter
10	Lenek Kali Bambang	Rp26.130.952	Rp. 227.620	0.285Kg	135,168Liter

Table 3 provides an economic and environmental impact assessment of the proposed solar PV systems for the ten village offices. This table includes the estimated installation costs, potential monthly savings, reduction in carbon emissions, and fuel savings. Despite the different basic information for each village office outlined in Table 1, such as electricity bills, roof types, and orientations, the results in Table 3 show a generalized outcome.

For instance, the installation cost for Lenek Daya Village Office, which has an electricity bill of Rp50,000 per month and a west-facing metal roof, is the same as that for Ramban Biak Village Office, which has a different bill of Rp70,000 and a west-facing tile roof. Both offices have an estimated installation cost of Rp10,452,380, estimated monthly savings of Rp103,464, and identical reductions in carbon emissions and fuel savings. Similarly, the Lenek Induk Village Office, with an electricity bill of Rp450,000 and an east-facing tile roof, has an installation cost of Rp26,130,952, the same as the Sukarema Village Office, which has an electricity bill of Rp200,000 and an east-facing tile roof. This pattern is observed across all village offices regardless of their unique characteristics and energy needs.

The consistent results in Table 3, despite the varying parameters in Table 1, indicate a limitation in the PLN Mobile application's assessment capabilities. The application tends to generalize recommendations for PV system installations without fully accounting for the specific energy consumption patterns, roof orientations, and other unique features of each village office.

This generalized approach can lead to suboptimal solar PV system installations, potentially affecting their efficiency and economic viability. A more detailed and customized assessment considering the unique characteristics of each site is essential for optimizing the installation and performance of solar PV systems. Therefore, relying solely on the PLN Mobile application may not be sufficient for a thorough and precise assessment of the potential for rooftop solar power installations.

Conclusions

The findings of this study highlight the potential for rooftop solar PV installations on village office buildings, with most offices demonstrating an installable capacity ranging from 1.0 kWp to 3.0 kWp. However, the PLN Mobile application provided generalized recommendations, suggesting capacities of 0.6 kWp and 1.32 kWp, with three to seven solar modules required per site. The economic analysis estimated installation costs between Rp10,452,380 and Rp26,130,952, with potential monthly savings ranging from Rp103,464 to Rp227,620, and consistent carbon emission reductions of 0.285 kg CO2 per month. Despite these insights, the PLN Mobile application's assessment of rooftop PV systems lacked specificity, offering uniform recommendations that did not fully account for the unique structural characteristics, electricity consumption, and roof orientations of each village office. This generalized approach limits the application's effectiveness in optimizing solar PV installations, as it may lead to suboptimal system performance and economic outcomes. Therefore, while PLN Mobile serves as a useful preliminary tool, it is insufficient for detailed and accurate assessments, underscoring the need for more customized evaluation methods to ensure optimal solar PV system design and performance tailored to each specific site.

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