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Rooftop PV System Optimization in an Educational Building Using SAM: A Case Study at UPN Veteran Jawa Timur

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ABSTRACT

The implementation of sustainable energy in educational institutions recognizes the potential of rooftop photovoltaic (PV) systems as a viable energy source. This research aims to evaluate and optimize the design of a rooftop photovoltaic (PV) system for Building 1 of the Fakultas Teknik dan Sains (FTS) at Universitas Pembangunan Nasional "Veteran" Jawa Timur (UPNVJT) using the System Advisor Model (SAM) software. Integrated data including meteorological data, building characteristics, and solar panel system specifications were utilized. The available rooftop area for PV system installation is approximately 200 m² with a north-facing orientation, which is estimated to accommodate a 30 kWp PV system capacity. Tilt angle and azimuth scenarios were varied to achieve maximum energy production. Based on SAM simulations, the optimal installation angle of 15° tilt and azimuth generated an annual energy output of 44,052 kWh with a performance ratio of 71% and a capacity factor of 17%. This study confirms that rooftop PV installation at FTS UPNVJT is technically feasible, and it is expected to serve as a foundation for the gradual implementation of PV systems as part of green campus initiatives and energy transition in educational institutions.

1. INTRODUCTION

Global warming is a major problem worldwide. Data shows that global surface temperatures have consistently risen, with an upward trend of approximately 0.18 °C per decade over the last 50 years(Samset et al., 2023). Furthermore, the World Meteorological Organization (WMO) has confirmed that 2024 was the warmest year on record, with temperatures approximately 1.55°C above pre-industrial levels (WMO, 2025). One of its main causes is the emissions from fossil fuel combustion like coal and oil, which produces too much carbon emissions. The energy sector is a major contributor to emissions, with a contribution of 44% in 2020 and increasing to 46% in 2021 (Climate Watch, 2022). To address this, many countries are starting to switch to renewable energy (RE). The Indonesian government is also promoting the same by targeting more use of renewable energy (RE) in the national energy mix. The Indonesian government targets a minimum 23% contribution of renewable energy to the national energy mix by 2025, which will then be increased to 31% by 2050 (Udin, 2020).

One of the increasingly important renewable energy sources in Indonesia is solar energy, given the abundant year-round sunlight. As a tropical country, Indonesia benefits greatly from high solar irradiance, which can be harnessed to meet energy needs in a sustainable and environmentally friendly manner (Erdiwansyah et al., 2024) .

Photovoltaic (PV) systems are technologies used to convert sunlight into electrical energy. These systems operate using solar cells that can be installed in various locations, such as building rooftops, open land, or in large-scale installations. In addition to being environmentally friendly, PV systems have also proven to be efficient in reducing dependency on fossil fuels(Al-Ali, Olabi, & Mahmoud, 2025; Bamisile, Acen, Cai, Huang, & Staffell, 2025)

UPN "Veteran" Jawa Timur is one of the educational institutions in East Java, Indonesia with significant potential for implementing renewable energy systems. Although the development of new and renewable energy (NRE) initiatives on campus is still limited, studies on the application of rooftop PV systems are highly relevant to promoting an efficient and sustainable energy transition (Md Khairi, Akimoto, & Okajima, 2022; Tarigan, 2020)

Conducting a feasibility study is essential before implementing a PV system in an educational setting. The study aims to determine the potential benefits from economic, environmental, and social perspectives. Through a feasibility study, the institution can properly assess the investment and identify appropriate and optimized projects for long-term implementation (Mehmood, Ren, & Zhang, 2023)

Simulating rooftop PV usage—such as in this study using the SAM (System Advisor Model) software—is a crucial step to determine how optimally solar energy can substitute electricity needs. This simulation provides a clear overview of potential electricity savings and the tangible contribution of PV systems in supporting renewable energy use within the educational environment, particularly at UPN "Veteran" Jawa Timur (Blair et al., 2018; Thaib, Amudy, & Rizal, 2019)

2. METHOD

2.1. Research Framework

Generally, a simulation-based quantitative approach was adopted to achieve optimal design targets for the rooftop solar panel system. Data collection of the building characteristics of Building 1 FTS UPNVJT included the northern roof area coverage and specific meteorological data (solar radiation, average temperature, wind speed) obtained from Badan Meteorologi, klimatologi, dan Geofisika (BMKG) data and calculated annually using SAM software.

Module data for solar panels and inverters were adjusted according to actual field data, where these types or models of equipment are accessible in Indonesia and widely utilized. Installation cost estimates and handling costs were not included in this study. For self-consumption analysis, daily electrical load data from Building 1 FTS UPNVJT were used. The collected data were subsequently input into SAM software. The simulation results comprised annual energy production (kWh), annual capacity factor, energy yield, and performance ratio.

2.2. Area and Data Characteristic

This research focuses on identifying the optimal potential for solar panel system installation. Figure 1 shows Building 1 FTS UPNVJT as the installation site, where the northern roof section was selected as the optimal potential due to the absence of potential obstructions or shading. The optimally identified area covers 200 m^2, with the roof orientation facing north at an inclination angle of approximately 15°.

Figure 1. PV installation location at FTS building UPNVJT.

In addition to physical location data, climate and technical component data constitute crucial steps. Historical climate data for the Surabaya region from verified sources were integrated with SAM software to represent actual weather conditions. Details of the collected data are presented in Table 1.

Table 1. Detail Data Collecting

Data Category	Spesific Types	Source
Location characteristic	Coordinate (-7.35°S, 112.78°E)	Survey, Google Maps
	Available area (200 m^2)	Building plan (FTS UPNVJT)
	Tilt angle orientation (15°)	Survey, Simple 3D modeling
	Shading Potential	
Meteorogical data	Global Horizontal Irradiance (5.60 $kWh/m^2/day$)	BMKG, TMY from NREL
	Direct Normal Irradiance (4.55 $kWh/m^2/day$)	
	Diffuse Horizontal Irradiance (2.42 $kWh/m^2/day$)	
	Average temperature (27.8°C)	
	Average wind speed (2.1 m/s)	
Module Spesification	Trinia Solar TSM-395DE09.08 (Mono-c-Si) Efficeincy (20.68%)	Manufacturer's datasheet, SAM database
	Max power (395 W)	
	Max power voltage (34 V)	
	Temperature coeffiecients (-0.357%/°C)	
	Dimensions area (1.9 m^2)	
Inverter spesification	Sungrow Power Supply Co – Ltd: SC250KU	
	Efficiency (96.120 %) Max AC/DC power (25/26 kW)	

2.3. System design SAM Setup

The System Advisor Model (SAM) software used was version 2025.4.16. The configuration was set to "Photovoltaic (PV) - Grid-connected" mode without battery storage, connected to the PLN grid. The location-specific climate data that had been obtained and validated were imported and integrated into TMY (Typical Meteorological Year) file format. SAM can display daily data in graphical form for a complete year, as shown in Figure 2.

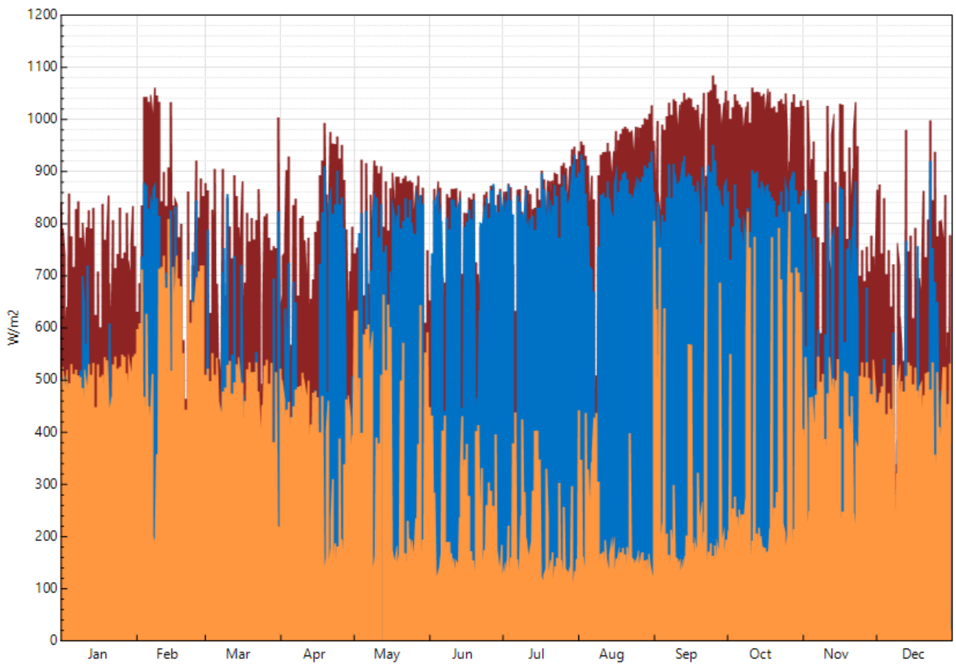

Figure 2. Daily GHI, DNI, and DHI Radiation Data over One Year in SAM.

Each PV system design parameter was configured in SAM to obtain optimal actual results. The number of efficient modules that could be installed was 75 modules (2 m²/module). The system capacity was established at 30 kWp, a value derived from the multiplication of the number of modules and the power generated per module. Various orientations (azimuth) and tilt angles of the solar panels were systematically simulated to identify the combination that produces the highest annual energy production. Tilt angle variations encompassed a range from 5° to 15° with 5° intervals. A 3D model was developed to assess shading potential, as shown in Figure 3.

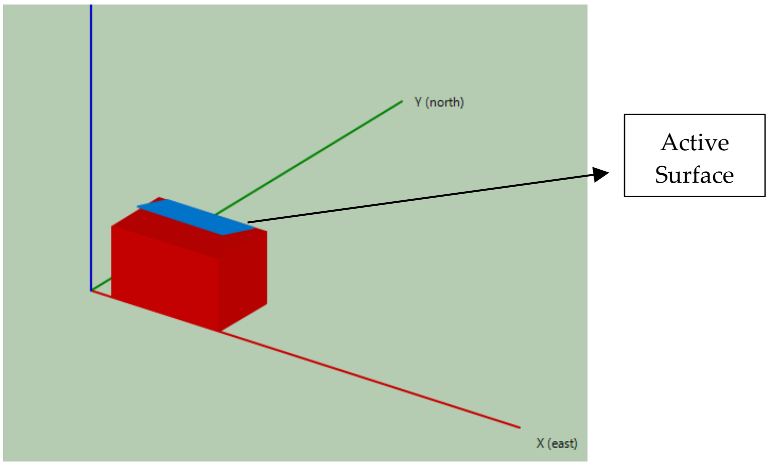

Figure 3. 3D Model Active Surface for Shading in SAM.

3. RESULTS AND DISCUSSION

3.1. Location Assessment and Solar Resource Analysis

The northern roof section of Building 1 Faculty of Engineering & Science has a total area of 200 m². The PV module area is 1.9 m². The identified number of modules that could be installed, considering the space requirements for ventilation, service pathways, and inter-row spacing, was 75 modules. Surabaya generally receives consistent global horizontal irradiance (GHI) with high potential each month. The annual average value reaches 2,045,700 Wh/m²/yr. The monthly consistency pattern can be observed in Figure 4.

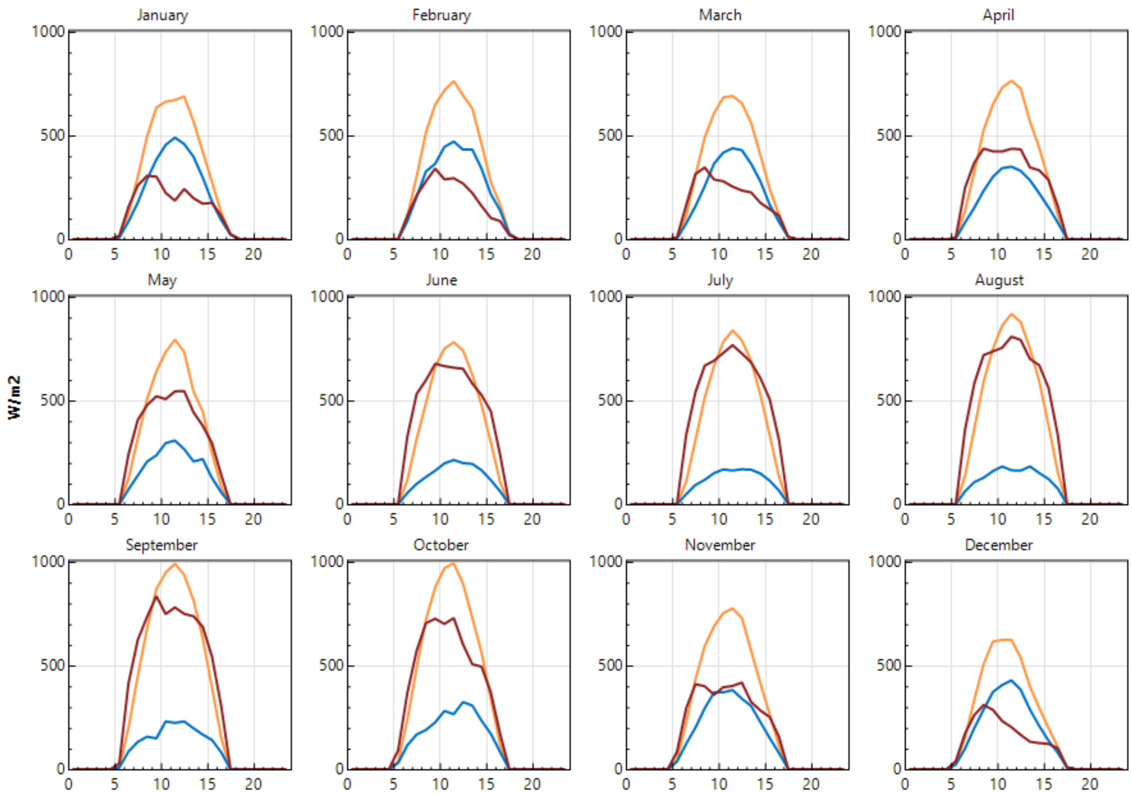

Figure 4. Monthly GHI, DHI, and DNI Irradiance Data.

The orange color indicates GHI values that appear consistent with high potential each month. August through October exhibit the highest GHI values, attributed to several scientific conditions. The sun's position approaches zenith relative to the equator, resulting in solar radiation incidence angles nearly perpendicular to the Earth's surface (maximum radiation). The dry season from August to October across most of East Java contributes to high DNI (dark red color) and GHI values due to minimal atmospheric interference. The blue line displays DHI values, showing that from November to March, DHI values nearly approach GHI and can exceed DNI. Contrary to the dry season, this indicates the transition to the rainy season.

During August–October, the sun's position is relatively close to the equatorial line, particularly around September (equinox). During equinox, the sun is positioned directly above the equator, enabling regions like Surabaya (located near the equator) to receive maximum and more perpendicular solar radiation throughout the day. Consequently, radiation energy received by the Earth's surface, especially during midday, reaches its peak (Arsyad, Alghifari, Susanto, Palloan, & Sulistiawaty, 2021)

August through October also coincides with the end of the dry season in eastern Java, where cloud cover tends to be low. Minimal cloud cover allows solar radiation reaching the ground surface to be nearly unobstructed, thereby increasing the total radiation energy received (Rimasilana & Islami, 2022; Vindel, Polo, & Zarzalejo, 2015). Clouds, dust, and atmospheric particles can limit the amount of solar radiation reaching the surface. Dry season months typically provide clearer skies, resulting in less obstructed solar radiation (Bamisile et al., 2025).

The atmosphere begins to be covered by thick clouds, causing solar radiation to scatter due to cloud particles, water vapor, dust, or what is termed the cloud scattering phenomenon. DHI dominance contributes to GHI values, consistent with standard equations in solar irradiance analysis, where θ represents the angle between the solar direction and the vertical line at the location point (Duffie & Beckman, 2013).

$$GHI = DNI \times \cos(\theta z) + DHI \quad (1)$$

(1)

3.2. System Performance Analysis

The optimal PV system configuration at the selected location comprises 1 subarray consisting of 5 strings. Each string contains 15 modules, resulting in a total of 75 modules. One inverter is utilized since only one subarray is present. Fixed tracking of the PV system with optimal tilt and azimuth angles, determined after conducting several testing options, yields a tilt angle of 15° and azimuth angle of 15°. The annual power generation reaches 44,052 kWh. Testing data for various angles are presented in Table 2.

Table 2. Annual Energy Production Test Result with Angle Variations (Tilt & Azimuth)

Tilt (deg)	Azimuth (deg)	Annual Energy Production (kWh)
5	5	43,556
5	10	43,569
5	15	43,577
10	5	43,918
10	10	43,943
10	15	43,957
15	5	43,999
15	10	44,034
15	15	44,052

SAM simulation results indicate that the PV system at Building 1 FTS UPNVJT is capable of generating annual energy up to 44.05 MWh/yr. The annual DC capacity factor achieved is 17%. This value is satisfactory given Surabaya's climatic conditions, indicating that the PV system can utilize a substantial portion of the energy potential from the installed capacity (kWp). The performance ratio achieved is also quite ideal at 71%, which serves as a key metric demonstrating that the installed PV system is sufficiently efficient in converting available solar radiation into electrical energy. Universitas Gadjah Mada has successfully implemented rooftop photovoltaic installations with a total capacity of 326.25 kWp across seven buildings, generating 169,689 kWh of renewable energy in 2022. Similarly, a feasibility study conducted at Hotel Rayz–UMM demonstrated the maximum rooftop PV potential of 37.4 kWp with an estimated annual energy production of 55,341 kWh (Effendy et al., 2024).

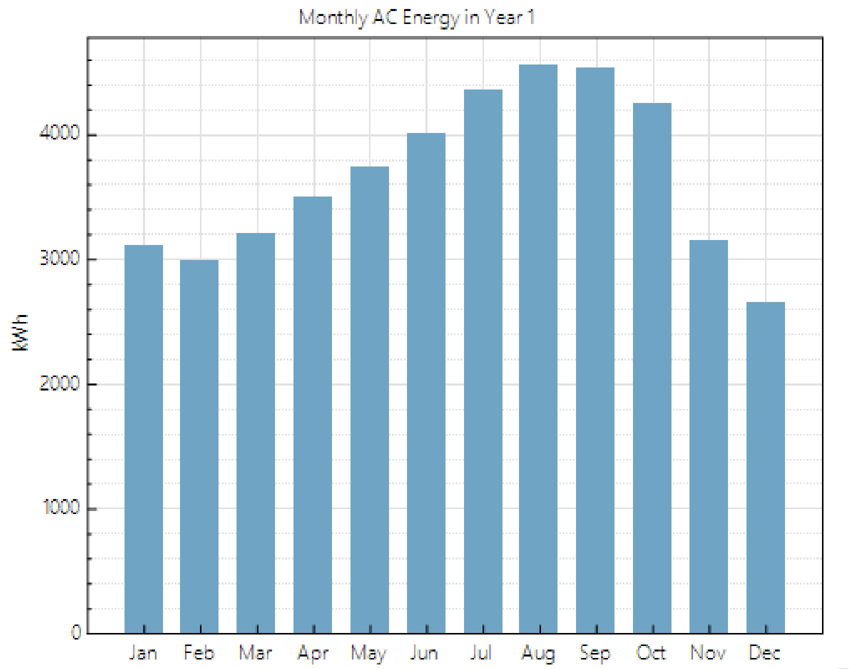

Figure 5. Monthly AC Energy in Year 1

Monthly energy production demonstrates variation consistent with patterns corresponding to solar resources/radiation, as shown in Figure 5. Peak production occurs during the dry season (July to October), with August achieving the highest energy production of up to 4.98 MWh. Conversely, increased rainfall during the different season indicates production decline, evident in December which generated the lowest energy output of 3.04 MWh. Details of monthly production can be observed in Table 3.

Table 3. Monthly Energy Production

Month	Energy Production (kWh/month)
January	3113.69
February	2993.61
March	3196.81
April	3496.77
May	3740.84
Juny	4009.29
July	4359.66
August	4553.49
September	4525.17
October	4251.24
November	3155.97
December	2655.61

4. CONCLUSION

The comprehensive case study using SAM reveals that the installation of a 30 kWp rooftop PV system proposed for Building 1 FTS, UPN "Veteran" Jawa timur, covering 200 m², is technically feasible. The installed capacity comprising 75 modules is capable of generating annual energy up to 44.052 MWh per year with a performance ratio reaching 71%. The optimal sensitivity analysis yielding the most favorable results occurs at tilt and azimuth angles of 15°. These results confirm that Surabaya represents an ideal location for PV installation with average solar radiation of 841 W/m². Moving forward, recommendations for practical implementation require integration with autonomous storage systems (batteries) to enhance PV system performance. Additionally, economic analysis could be conducted covering both installation costs and payback periods. This article strongly supports phased field implementation, positioning UPN "Veteran" Jawa Timur as a pioneer in sustainable campus development and contributing to renewable energy transition goals in Indonesia.

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