



Research article

## Optimization of Solar Panel Power Estimation in Yogyakarta

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### ABSTRACT

*This research focuses on predicting the performance of photovoltaic (PV) systems using the PVWatts Calculator. The study examines three types of PV modules—Standard, Premium, and Thin Film—under the environmental conditions of Yogyakarta, Indonesia, with simulations set for the year 2024. Input parameters, including geographic coordinates, solar radiation intensity, average air temperature, and module specifications, were collected from reliable sources such as Suncalc. Simulations were conducted to evaluate annual and monthly energy outputs, considering factors such as system capacity, panel orientation, inverter efficiency, and system losses. The results show that Premium modules achieve the highest energy output, while Standard and Thin Film modules provide nearly comparable performance, making them cost-effective alternatives. Despite differences in efficiency, the performance gap between the module types remains relatively small under similar light intensity conditions. The findings highlight the importance of selecting PV modules based on specific needs, budget constraints, and environmental factors to optimize solar energy system performance. This study provides a comprehensive framework for PV performance calculations using PVWatts and offers valuable insights to support renewable energy development in the Yogyakarta region.*

## ABSTRAK

**Kata kunci:** Prediksi Kinerja Photovoltaic, Kalkulator PVWatts, Energi Surya, Energi Terbarukan

Penelitian ini berfokus pada prediksi kinerja sistem photovoltaic (PV) menggunakan PVWatts Calculator. Studi ini menganalisis tiga jenis modul PV Standar, Premium, dan Thin Film dalam kondisi lingkungan di Yogyakarta, Indonesia, dengan simulasi yang ditetapkan untuk tahun 2024. Parameter input, termasuk intensitas radiasi matahari, suhu udara rata-rata, dan spesifikasi modul, dikumpulkan dari sumber terpercaya dalam perhitungan kinerja photovoltaic. Simulasi dilakukan untuk mengevaluasi keluaran energi tahunan dan bulanan dengan mempertimbangkan faktor seperti kapasitas sistem, orientasi panel, efisiensi inverter, dan kerugian sistem. Hasil penelitian menunjukkan bahwa modul Premium menghasilkan output energi tertinggi, sedangkan modul Standar dan Thin Film memberikan kinerja yang hampir sebanding, sehingga menjadi alternatif yang lebih ekonomis. Meskipun terdapat variasi efisiensi, kinerja berbagai jenis modul tetap dapat dibandingkan dalam kondisi pencahayaan yang serupa. Temuan ini menekankan pentingnya pemilihan modul PV berdasarkan kebutuhan spesifik, keterbatasan anggaran, dan faktor lingkungan untuk mengoptimalkan kinerja sistem energi surya. Hasil perhitungan menunjukkan bahwa jenis panel surya Premium menghasilkan daya tahunan tertinggi dibandingkan dengan jenis Standar dan Thin Film, yaitu sebesar 129 kWh. Studi ini memberikan kerangka kerja komprehensif untuk perhitungan kinerja PV menggunakan PVWatts serta menawarkan wawasan berharga guna mendukung pengembangan energi terbarukan di wilayah Yogyakarta.

## 1. INTRODUCTION

Photovoltaics play a significant role in reducing fossil fuel consumption. The use of photovoltaics can contribute to increasing renewable energy adoption [1]. Experimental studies on photovoltaics have been extensively conducted to advance renewable energy development [2]. Historically, photovoltaic technology has faced various challenges in its development, such as material supply and manufacturing processes [3]. With recent advancements, the performance and total production of photovoltaic systems can now be predicted. Mathematical modeling for predicting photovoltaic performance can be based on specific PV specifications [4].

Model simulations are crucial for predicting energy conversion using detailed specifications. Solar energy configurations and solar radiation measurements are still conducted locally. Thus, model simulation studies are necessary to provide more detailed information regarding PV performance and solar radiation [5]. Research by Freeman et al. [6] analyzed the performance of nine photovoltaic systems, including three utility-scale systems and six commercial-scale systems, using several photovoltaic performance modeling tools compared with quality-controlled measurement data. The results showed that, after removing outliers, all modeling tools produced annual errors within a range of  $\pm 8\%$  and hourly root mean square errors of less than 7%, with proposed measures to reduce modeling errors. Psomopoulos et al. [7] compared photovoltaic electricity production estimates using three free software tools—PVGIS, PVWatts, and

RETScreen—with real measurement data from a PV installation in Greece over 24 months. The analysis revealed differences in estimation accuracy among the three tools, influenced by the size and characteristics of the tested PV systems, including systems with dual-axis tracking mechanisms.

Krishnan et al. [8] discussed the development of a mobile application-based energy calculator to provide quick estimates of cost-saving potential from solar photovoltaic installations. This method utilized high-quality solar radiation data from NIWE via SRRA, offering practical solutions for efficiently assessing solar energy potential in India. Research by Young and Rappe [9] employed the "shift current" theory applied to the electronic structures of density functional theory to calculate bulk photovoltaic responses in ferroelectric BaTiO<sub>3</sub> and PbTiO<sub>3</sub>. The findings demonstrated that photovoltaic current depends on electronic properties with asymmetric covalent bonding, not solely on material polarity, making it potentially applicable for solar energy conversion, photocatalysis, and sensor devices.

An analysis of photovoltaic performance calculation potential was conducted by Anselmo and Farerra [10]. This research analyzed 75 papers to understand the primary tools and inputs for GIS-based photovoltaic energy potential calculations, dominated by the use of 2.5D tools such as ArcGIS and QGIS that integrate weather data. The results indicated that although photovoltaic potential calculation formulas are widely accepted, comprehensive approaches often simplify some components, pushing research toward more accurate 3D models that consider time cycles and seasonal variations. Riley et al. [11] discussed the development of a spreadsheet-based tool by Sandia Laboratories to support the RAMP program in evaluating payback periods for photovoltaic systems installed on NNSA facility rooftops. This tool was designed to provide quick estimates of the financial value of photovoltaic systems, supporting installation decisions in line with federal renewable energy goals. Table 1 presents studies that discuss photovoltaic performance calculation and prediction in various regions and countries.

Photovoltaic performance calculation research was also conducted by Msiska [12], who designed a hybrid solar (photovoltaic) and biogas energy calculator to facilitate household and agricultural energy system design, using Visual Basic software with three main forms: solar system, biogas system, and their combination. The design results showed a system with a total capacity of 3.11 kW, including solar panels, inverters, batteries, biogas digesters, and biogas generators, designed based on electrical load parameters and daily usage assumptions.

**Table 1.** Research predicting photovoltaic performance in several countries

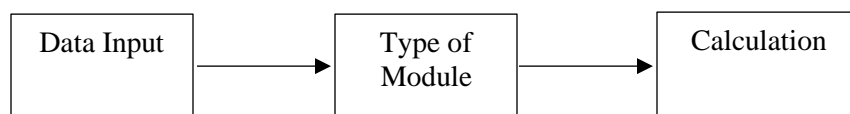
Country	Method	Result	References
Sverdlovsk region of Russia	Pvsyst model	simulation higher annual energy with slightly better PR (82.6%) than fixed system (82.3%),	[13]
143 countries from 2001 to 2020	correlation and principal components analysis	evaluate solar energy policies effectively	[14]
Germany	Long-Term Recurrent Convolutional	better performance compared to persistence models	[15]

Oman	<p>Network berbasis and state-of-the-art Numerical Weather methods. Predictions (NWP) Self-Organizing SOFM has the [16] Feature Map highest accuracy (SOFM) dan with MSE 0.0005, R<sup>2</sup> membandingkannya 0.9555, and MAE dengan model Multi- 0.36156, which is Layer Perceptron better than MLP and (MLP) serta Support Vector Machine SVM. (SVM)</p>
<p>Jakarta, Bandung, Semarang, Yogyakarta, Surabaya (Indonesia)</p>	<p>combination of PV power profiles [17] change point influence electrical detection methods, parameters, such as cyclic k-means improving voltage clustering (KMC), profiles and reducing Monte Carlo power losses in IEEE simulation (MCS), 33 Bus systems and KMC with soft- dynamic time warping (DTW)</p>

From previous research, only a few studies have used the PVWatts Calculator for photovoltaic performance prediction. This study aims to evaluate solar panel performance using calculation methods with the PVWatts Calculator. The performance prediction study of solar panels focuses on the Yogyakarta area. This research also provides performance predictions of solar panels using various materials. The expectation of this research is to provide an overview of solar panel performance predictions in the Yogyakarta area. This photovoltaic performance prediction can facilitate decision-making when considering the use of solar energy.

## 2. METHOD

This photovoltaic performance prediction research applies a simulation study method using calculations based on the PVWatts Calculator. The selected area for this simulation is Yogyakarta, with the simulation year set to 2024. Yogyakarta is located at S 7°48'5" E 110°21'52.99". Figure 1 illustrates the research scheme for predicting solar panel performance using the PVWatts Calculator. The PV module types were varied in this study. The module types used are standard, premium, and thin film. The photovoltaic module utilizes a capacity of 0.1 kW DC. This research aims to optimize the estimation of solar panel power output in the Yogyakarta region by utilizing the PVWatts Calculator software.

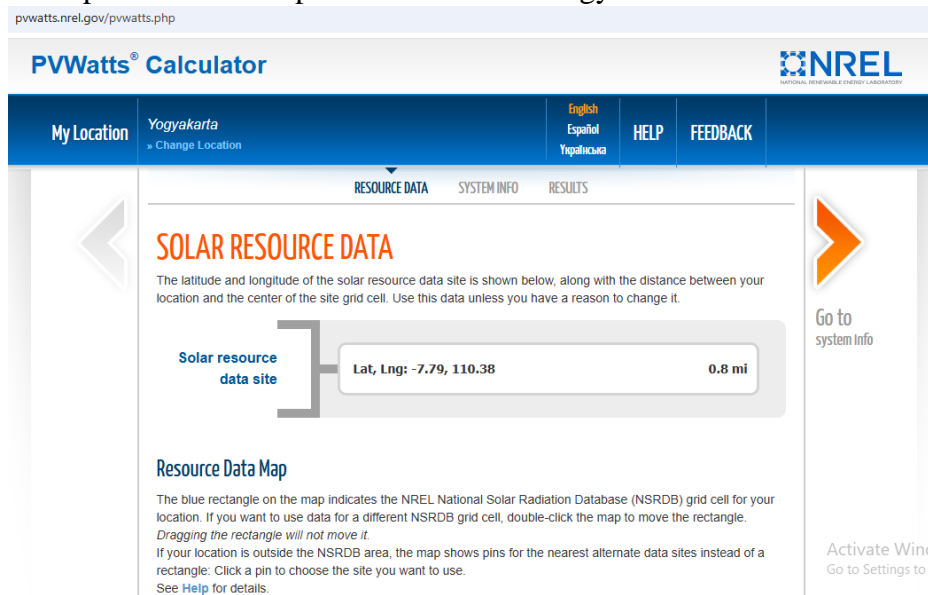


**Figure 1.** Schematic of research

The research begins with the collection of input data, which includes environmental and technical parameters such as geographic coordinates (latitude and longitude), solar radiation intensity data, average air temperature, and technical specifications of the solar panels.

The data was obtained from reliable sources such as SunCalc. Subsequently, simulations were conducted using the PVWatts Calculator, a web-based tool developed by the National Renewable Energy Laboratory (NREL) to calculate the performance of photovoltaic (PV) systems. Figure 2 shows the interface of the PVWatts Calculator. The simulation input settings include PV system capacity, panel orientation (tilt angle and azimuth), inverter efficiency, and system loss factors. The azimuth setting uses an angle of  $179.16^\circ$ , sourced from SunCalc. The tilt angle is set to  $20^\circ$ , while the array type configuration uses a fixed (open rack) type. The simulation results include projections of annual and monthly power output.

The simulation results were processed and analyzed using descriptive statistical methods to present the patterns of power output estimation, factors influencing efficiency, and technical recommendations for implementing PV systems in the study area. With this approach, the research is expected to provide comprehensive insights into PV system performance in Yogyakarta and support the development of more optimal renewable energy solutions.



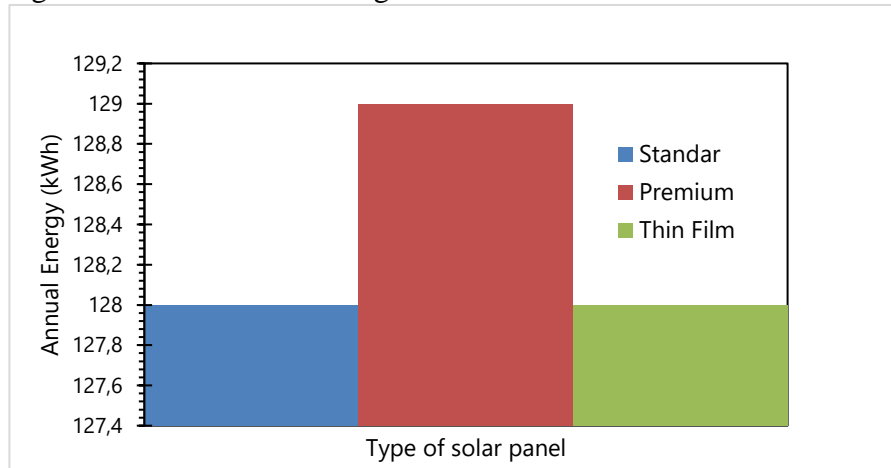
**Figure 2.** Display of PVWatts Calculator

### 3. RESULT AND DISCUSSION

Figure 3 illustrates the comparison of annual energy produced by different types of photovoltaic modules: Standard, Premium, and Thin Film. The annual energy values are presented in kilowatt-hours (kWh). Based on the graph, it is evident that the Premium module generates the highest annual energy compared to the other module types. The Standard module has lower annual energy performance compared to the Premium module but still performs better than the Thin Film module. Meanwhile, the Thin Film module produces the lowest annual energy among the three module types tested.

From these results, it can be concluded that the choice of photovoltaic module type significantly affects the energy performance. The Premium module demonstrates better efficiency, making it

the optimal choice for locations prioritizing maximum energy production. The Standard module, although less efficient than the Premium module, remains a viable alternative when budget constraints exist. Conversely, the Thin Film module tends to generate lower energy, making it more suitable for specific conditions, such as lower initial costs or other specific requirements. This analysis also highlights the importance of considering the type of module used in photovoltaic system planning to achieve results that align with the needs and available resources.



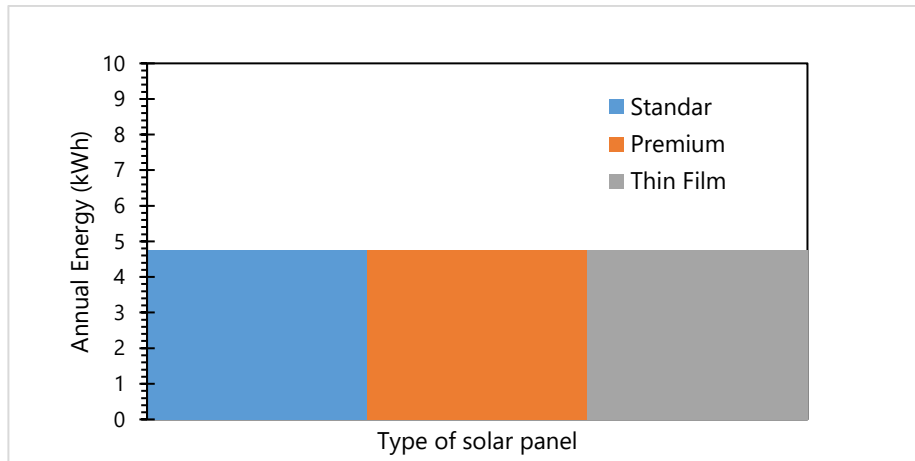
**Figure 3.** Result of Annual Energy Calculation

Figure 4 shows the comparison of annual energy generated by the three types of photovoltaic modules—Standard, Premium, and Thin Film—based on light intensity calculations using PVWatts. The data presented in the graph indicates that the three module types perform similarly, with relatively small differences in annual energy output.

Specifically, the Standard module produces energy nearly equivalent to the Premium and Thin Film modules, indicating that the available light intensity does not significantly affect the performance of these module types. The Thin Film module, although often considered less efficient than other modules, in this context shows performance nearly on par with the others, which may be due to its ability to utilize low light intensity effectively.

These findings suggest that under similar light intensity conditions, all three module types can be used without significant differences in annual energy production. However, the decision to choose a module type should also consider other factors such as cost efficiency, module lifespan, and specific application needs. This analysis indicates that more affordable modules, such as Standard or Thin Film, can be practical choices if budget constraints exist, without sacrificing too much annual energy production.

Table 2 compares this study with previous research that examined the performance of various PV module types. Previous studies often focused on temperature variations affecting photovoltaic performance. This study highlights its role by predicting the performance of photovoltaic systems using Standard, Thin Film, and Premium module types. Thus, this research provides an overview for calculating photovoltaic performance using PVWatts.



**Figure 4.** Result of Annual Intensity Calculation

**Table 2.** Comparison of this research with previous research which discussed the comparison of PV types

Type of photovoltaic	Method	Result	References
photovoltaic (PV) panel and an integrated collector-storage solar water heater	Experiment	with fins capable of lowering cell temperature and increasing total efficiency by around 12%	[18]
Si wafer-based and thin film photovoltaic modules	Case study in Thailand	modules with low temperature coefficient (<math> < -0.31\%/^{\circ}\text{C}</math>) have energy advantages	[19]
a-Si Thin film, polycrystalline panels, monocrystalline	Experiment in Turkey	a $1^{\circ}\text{C}$ increase in temperature increases the efficiency of a-Si and polycrystalline panels, but decreases the efficiency of mono-crystalline panels	[20]
Standard, thin film, premium	Prediction using PVWatts	The premium PV module type has the highest annual energy	In this work

#### 4. CONCLUSION

Based on the analysis results calculated using PVWatts, it can be concluded that the three types of photovoltaic modules—Standard, Premium, and Thin Film—show relatively small performance differences under specific light intensity conditions. The Premium module demonstrates slightly higher efficiency compared to the other modules; however, the Standard and Thin Film modules remain viable alternatives with nearly equivalent performance, especially when considering cost efficiency. Therefore, the selection of photovoltaic module types should be tailored to specific needs, budget, and environmental conditions to optimize the performance of the solar energy system.

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