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Quantitative Analysis of the Impact of Solar Panel Utilization on PLN Electricity Purchases

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ABSTRACT: The use of on-grid photovoltaic (PV) systems has become increasingly common in the industrial sector. However, the extent to which PV electricity generation reduces dependence on grid electricity remains unclear. This study aims to provide empirical evidence by analyzing the relationship between on-grid PV electricity generation and grid electricity consumption using a quantitative approach. Daily operational data were processed by removing seasonal patterns and subsequently aggregated into weekly data to reduce short-term fluctuations. The relationship between the two variables was then analyzed using correlation analysis. The results indicate a negative relationship between PV electricity generation and grid electricity consumption, with a correlation coefficient of −0.19892. This finding suggests that while PV systems contribute to meeting energy demand, their impact on reducing electricity consumption from the grid is relatively weak. Therefore, further research using longer observation periods and additional influencing variables is required to better understand the role of PV systems in reducing grid dependency.

KEYWORDS: On-grid photovoltaic (PV), solar power generation, grid electricity consumption, Pearson correlation analysis, industrial energy systems

I. INTRODUCTION

The transition toward renewable energy in the industrial sector is a crucial agenda to improve energy efficiency, reduce operational costs, and meet sustainability targets [1,2]. The utilization of Solar Power Plants (PLTS) has become one of the main strategies for companies to reduce dependence on electricity supply from the main grid (in Indonesia, managed by PLN). Specifically, on-grid PLTS systems (grid-connected) are designed to operate in parallel with the grid, prioritizing self-consumption of the energy generated independently, thereby directly reducing the volume and cost of electricity purchases [2,3].

The primary engineering and economic challenges of adopting on-grid PLTS lie in its intermittent (fluctuating) production characteristics [1,2]. Daily energy production is highly dependent on weather conditions and solar irradiance levels, which cannot be controlled. These fluctuations directly create operational and financial uncertainties: the volume of electricity that must be purchased from the main grid to cover the company's operational needs will vary each day [3,4].

Understanding this relationship quantitatively is key to evaluating the real effectiveness and economic benefits of PLTS investment. Many studies focus on techno-economic feasibility analysis, both at the planning stage using simulations and by analyzing realization data in industrial contexts [1,3,5]. However, ROI (Return on Investment) calculations at the early stage are often only estimates. As noted in similar industrial case studies, real-world realization does not always align with the techno-economic analysis that has been conducted. This highlights the importance of validation using post-installation operational data—to demonstrate the system's actual effectiveness.

Therefore, this study addresses this challenge by conducting a quantitative analysis to model the relationship between PLTS production and grid electricity purchases, using actual data from an IoT company in Indonesia [2,6]. Unlike simulation-based planning studies, this research is important for validating actual system performance using the company's daily report data, addressing the gap between planning estimates and real performance. This study aims to identify the strength and direction of the relationship between the PLTS energy production variable (Variable Y) and the electricity purchase variable (Variable X). The implications of this research are practical for management. By having a quantitative model validated by real data, the company can predict cost savings more accurately, which ultimately contributes to better budgeting and optimization of long-term energy management strategies [4,7].

II. RESEARCH METHODOLOGY

This research methodology explains the stages of the study systematically so that it can be replicated by other researchers.

A. Research Design

This study uses a quantitative descriptive correlational approach with two main objectives. First, the descriptive objective is to provide an overview of the actual performance of the On-Grid PLTS system, including the average energy production, energy consumption, and the level of PLTS contribution to overall energy demand. Second, the correlational objective is to analyze the statistical relationship between PLTS energy production and electricity purchases from the PLN grid in order to identify the direction and strength of the relationship between these variables.

B. Data Sources

The data used in this study consist of secondary data obtained from the operational monitoring system of an On-Grid Solar Photovoltaic (PLTS) installation. The data were collected from the system data logger, which automatically records daily operational parameters of the PV system.

The dataset includes daily records of solar PV energy production, electricity purchased from the PLN grid, and total energy consumption. These data represent actual operational measurements of the PLTS system and were collected during the period July 1, 2025 to September 8, 2025.

Secondary data were selected because they are systematically recorded by the monitoring system, ensuring a relatively high level of reliability and accuracy. In addition, the use of operational data allows this study to analyze the real performance of the PV system under actual field conditions.

C. Population and Sample

The population in this study consists of all daily operational data of the On-Grid PLTS system. The initial sample includes approximately 70 daily data points collected during the study period. The sampling technique used is purposive sampling, where data are selected based on operational periods relevant to the research objectives.

However, daily data tend to exhibit high short-term variability due to weather conditions, fluctuations in operational loads, and changes in daily energy consumption. These variations may obscure the main relationship between PLTS energy production and electricity usage from the PLN grid.

To address this issue, data preprocessing was conducted through temporal aggregation. Daily data were grouped into 7 weekly periods, and the average values were calculated. This approach aims to reduce noise and short-term random fluctuations while preserving the overall trend of the data. Therefore, the unit of analysis used in this study consists of 7 aggregated weekly data points (N = 7).

D. Research Variables

This study uses two main variables and one supporting variable:

1. Variable X – Solar PV Energy Production

This variable represents the total electrical energy generated by the solar panels before inverter conversion. The unit of measurement is kilowatt-hours (kWh) per day, which is later aggregated into weekly values. The data source is obtained from the PLTS system data logger.

2. Variable Y – Grid Electricity Purchase

This variable represents the total electrical energy purchased from the PLN grid to meet energy demand when PV production is insufficient. The unit of measurement is kilowatt-hours (kWh) per day, which is later aggregated into weekly values. The data source is also obtained from the PLTS system data logger.

3. Supporting Variable – Total Energy Consumption

Total energy consumption is calculated as the sum of PLTS energy production and PLN electricity usage, expressed in kWh per day.

E. Data Collection Technique

The data collection method used in this study is documentation. Secondary data were obtained by collecting historical daily operational records stored in the monitoring system and data logger of the On-Grid PLTS.

F. Data Analysis Techniques

Data analysis was conducted using statistical software such as Microsoft Excel. Descriptive analysis was used to summarize the operational performance of the PLTS system, including key statistical measures and the contribution of PV energy through the Solar Fraction calculation.

Furthermore, Pearson correlation analysis was applied to examine the strength and direction of the relationship between PV energy production and electricity purchased from the PLN grid. Trend analysis was also performed to observe patterns and fluctuations over time through graphical visualization.

To support the findings, inferential statistical analysis was conducted using the Pearson Product-Moment Correlation with a significance level of $\alpha = 0.05$. The hypotheses tested were H_0 (no significant relationship) and H_a (significant relationship), with decisions based on the resulting P-value.

III. RESULTS AND DISCUSSION

This chapter presents the research findings obtained from the analysis of daily operational data of the PLTS system during the period of July 1, 2025 to September 8, 2025 (N = 70 days).

A. Descriptive Analysis of System Performance

Daily data from the three main variables (PLTS Production, PLN Purchases, and Total Consumption) were analyzed to obtain descriptive statistical values. A summary of the findings is presented in Table I.

Table I. Descriptive Statistics of Daily Operational Data

Statistic	Daily Production (kWh)	Daily Purchased (kWh)	Daily Consumption (kWh)
Data Points	70	70	70
Mean	17.331	17.544	34.439

Median	17.850	17.600	35.750
Standard Deviation	5.724	6.225	10.088
Minimum Value	0	0.2	0.6

Based on Table 1, during the 70-day study period, the average daily PLTS production was 17.33 kWh, while the average daily electricity purchase from PLN was 17.54 kWh. The building's total daily energy consumption was relatively stable, with an average of 34.43 kWh.

To examine monthly performance, the data were grouped by month (July, August, September). The results are presented in Figure I.

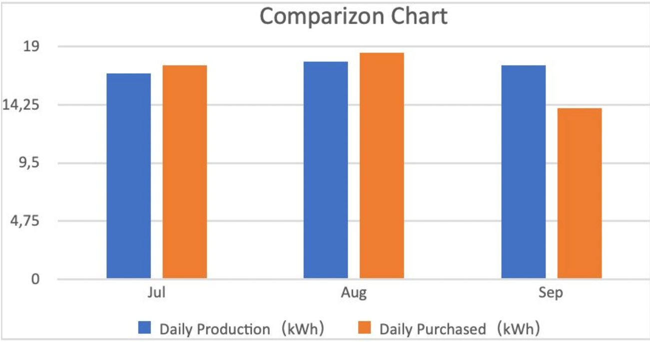

Figure I. Comparizon Chart for Daily Production and Daily Purchased

Comparison of Monthly Daily Averages. July (n = 31): Average Production = 18.81 kWh; Average Purchase = 609.8 kWh. August (n = 31): Average Production = 435.0 kWh; Average Purchase = 565.0 kWh. September (n = 8): Average Production = 420.1 kWh; Average Purchase = 579.9 kWh. These findings indicate that the highest PLTS performance (production) occurred in August, which consistently also recorded the lowest electricity purchase from PLN.

B. Efficiency Analysis (Solar Fraction)

The contribution of PLTS to total energy demand (Solar Fraction) was calculated using the formula established in the Methodology (Eq. 1).

PLTS Contribution (%) = (18.4452381 / 36.01071429) × 100% = 51.22%

C. Correlation Analysis

To test the hypothesis, the operational data were processed into 7 accumulated average data points (n = 7). Variable X represents the average electricity purchase, and Variable Y represents the average solar panel production. The data are presented in Table II.

Table II. Weekly Aggregated Average Data

Time Period (10 Days)	*Average of Daily Purchased (kWh)*	*Average of Daily Production (kWh)*
1	19.567	14.578
2	20.140	17.490
3	12.570	17.740
4	17.950	19.350
5	18.940	17.300
6	18.220	17.920
7	16.550	16.050

We assume that X represents the average electricity purchase and Y represents the average solar panel production. The data were then processed as shown in the table below:

Table III. Pearson Correlation Computation Table

No	*X*	*Y*	*X²*	*Y²*	*X × Y*
1	19.57	14.58	382.85	212.51	285.24
2	20.14	17.49	405.62	305.90	352.25
3	12.57	17.74	158.00	314.71	222.99
4	17.95	19.35	322.20	374.42	347.33
5	18.94	17.30	358.72	299.29	327.66
6	18.22	17.92	331.97	321.13	326.50
7	16.55	16.05	273.90	257.60	265.63

After that, substitute the values into the formula:

$$r = [\, n\cdot\Sigma(x_i\cdot y_i) - \Sigma x_i\cdot\Sigma y_i \,] \,/\, [\, \sqrt{(n\cdot\Sigma x_i^2 - (\Sigma x_i)^2)} \cdot \sqrt{(n\cdot\Sigma y_i^2 - (\Sigma y_i)^2)} \,] \quad \ldots(2)$$

with n = 7, the result obtained is:

r = −0.19892

D. Study Limitations

This study has several limitations that should be acknowledged. First, the number of aggregated observations (N = 7) is relatively small, which may reduce statistical power and sensitivity in detecting linear relationships between variables. The limited sample size increases the possibility of Type II error, where a true relationship may not be detected statistically. In addition, the aggregation process, while useful for reducing short-term fluctuations, may also obscure finer temporal dynamics present in daily data.

IV. CONCLUSION

Variable Relationship (Hypothesis Testing). The Pearson correlation analysis indicates a very weak negative relationship between Solar PV energy production and grid electricity purchases, with a correlation coefficient of r = −0.19892. The scatter plot visualization further supports this finding, as it shows a widely dispersed pattern without a clear linear trend. This suggests that increases in PV production were not consistently associated with proportional reductions in electricity imported from the grid during the study period.
Implications. These findings imply that the effectiveness of the on-grid PV system in reducing grid electricity purchases cannot be statistically confirmed based solely on the available dataset. While PV generation contributes to meeting part of the energy demand, other operational factors—such as load variability, consumption patterns, and system management

strategies—likely play a more dominant role in determining grid electricity usage.

Recommendations for Future Research. To obtain a more comprehensive understanding, future studies are recommended to:

1. Utilize higher-resolution temporal data (e.g., daily data instead of aggregated weekly data) to increase sample size and improve statistical sensitivity.

2. Incorporate additional independent variables, such as total building energy consumption, operational schedules, or environmental factors, to better explain variations in grid electricity dependence.

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