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Techno-Economic Feasibility Analysis of Rooftop Solar Power Plant Implementation Based on Electricity Consumption Patterns and kWh Export Schemes

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ABSTRACT

This study aims to analyze the techno-economic feasibility of implementing rooftop solar power plants based on electricity consumption patterns and kWh export schemes. The data used comes from the Kaggle dataset "Surabaya Electric Consumption by Sector" and is processed using Google Colab. The research method uses a descriptive-comparative quantitative approach through electricity consumption pattern analysis, technical simulation of rooftop solar power plants, and a comparison of 65% and 100% kWh export schemes. The results show that the industrial sector has the highest electricity consumption, followed by households and businesses and hotels. Simulations show that increasing solar power plant capacity increases energy production and kWh exports, but nighttime electricity imports still occur because the system does not use batteries. The 100% export scheme provides better economic feasibility than the 65% export scheme, with more optimal savings, ROI, and payback period. The best scenario is a rooftop solar power plant with a capacity of 12.0 kWp with a 100% export scheme, because it produces the highest technical and economic benefits.

1. Introduction

The increasing demand for electricity in various sectors is driving the need to utilize more efficient, sustainable, and environmentally friendly energy sources. Dependence on fossil fuels needs to be reduced through the development of renewable energy sources, one of which is solar energy. Indonesia has significant solar energy potential due to its equatorial location, making the implementation of rooftop solar power plants (PV systems) a strategic alternative to support the national clean energy transition. Rooftop PV systems can be installed in residential, commercial, office, and industrial buildings by utilizing available rooftop areas, thereby reducing dependence on conventional electricity generation while lowering greenhouse gas emissions.

The performance of rooftop PV systems is determined not only by their electricity generation capability but also by the characteristics of electricity consumption. Different sectors exhibit different electricity demand profiles in terms of both consumption magnitude and usage periods. These differences directly influence self-consumption, electricity exported to the utility grid, and electricity imported from the grid. Consequently, electricity consumption patterns become an important factor in determining both the technical performance and economic feasibility of rooftop PV systems, particularly under grid-connected configurations that implement export-credit mechanisms.

Previous studies have extensively investigated the techno-economic feasibility of rooftop PV systems from various perspectives. Khan et al. (2025) reviewed optimal sizing and techno-economic feasibility of renewable energy systems integrated with energy storage, while Hakim et al. (2024) evaluated the technical and economic feasibility of rooftop PV implementation in the manufacturing sector. Vai and Ohgaki (2023) analyzed the techno-economic feasibility of rooftop PV systems for rural electrification, whereas Sudiartha et al. (2025) investigated the influence of export–import kWh policies on the economic viability of rooftop PV systems in Indonesia. These studies have successfully demonstrated the importance of system sizing, investment cost, electricity tariffs, and export-credit mechanisms in determining project feasibility.

However, several important research gaps remain. Most previous studies evaluate rooftop PV systems using a single or fixed electricity demand profile without considering variations in electricity consumption patterns among different user sectors. Moreover, although previous studies have examined export-credit policies, they generally focus on evaluating a single policy scenario or assessing policy impacts without systematically comparing different export-credit schemes under identical electricity consumption characteristics. Consequently, the combined influence of sectoral electricity consumption patterns and different export-credit schemes on the techno-economic feasibility of rooftop PV systems has not been comprehensively investigated.

This limitation becomes increasingly important because changes in export-credit policies may significantly affect the economic attractiveness of rooftop PV investments. A rooftop PV system with identical technical performance may produce substantially different economic outcomes depending on the applicable export-credit mechanism and the user's electricity consumption pattern. Therefore, a comprehensive assessment integrating sectoral electricity demand characteristics with multiple export-credit scenarios is required to provide a more realistic evaluation of rooftop PV feasibility.

To address this gap, this study conducts a techno-economic feasibility analysis of rooftop PV implementation using the "Surabaya Electric Consumption by Sector" dataset processed in Google Colab. Electricity consumption patterns from different sectors are first analyzed to characterize electricity demand, followed by technical simulations of rooftop PV systems with various installed capacities. The simulations calculate electricity production, self-consumption, electricity exports, and electricity imports. Subsequently, the economic feasibility of rooftop PV implementation is evaluated by comparing two export-credit policies, namely 65% and 100% export schemes, using techno-economic indicators including

electricity cost savings, Return on Investment (ROI), Net Present Cost (NPC), Levelized Cost of Energy (LCOE), and payback period.

This study provides several important contributions to both academic research and practical implementation. Academically, it proposes an integrated techno-economic assessment framework that combines sectoral electricity consumption patterns, rooftop PV technical simulations, and comparative analysis of multiple export-credit policies within a single evaluation framework. Unlike previous studies that primarily focus on either technical performance or economic evaluation separately, this study demonstrates how electricity consumption characteristics influence the effectiveness of different export-credit mechanisms in determining rooftop PV feasibility. Practically, the findings provide useful insights for policymakers in evaluating the economic implications of export-credit regulations and assist prospective rooftop PV users in selecting appropriate system capacities according to their electricity consumption characteristics.

Accordingly, the novelty of this study does not merely lie in comparing the 65% and 100% export-credit schemes. Rather, it lies in the integration of sectoral electricity consumption pattern analysis, rooftop PV technical simulation, comparative export-policy evaluation, and comprehensive techno-economic assessment to identify the optimal rooftop PV scenario under different policy conditions. This integrated approach provides a more comprehensive decision-support framework for evaluating rooftop PV investments than conventional assessments that consider only annual electricity consumption or a single export-credit scenario.

2. Method

This research uses a quantitative approach with techno-economic methods. This approach is used because the data analyzed are numerical, including electricity consumption, solar power plant energy production, self-consumption, kWh exports, kWh imports, energy ratio, investment costs, electricity savings, ROI, LCOE, NPC, and payback period. The techno-economic approach is used to assess the feasibility of implementing rooftop solar power plants from two main aspects: technical and economic. Furthermore, this study also uses a descriptive-comparative approach because it compares two kWh export scenarios, namely 65% and 100% export schemes, to determine the most optimal scenario.

The rooftop PV capacities simulated in this study were 2, 4, 6, 8, 10, and 12 kWp. These capacity levels were selected to represent a gradual range of rooftop PV system sizes commonly applied in residential and small commercial installations in Indonesia. The 2 kWp interval allows a systematic evaluation of the influence of increasing installed capacity on electricity generation, self-consumption, exported and imported electricity, as well as techno-economic performance. Furthermore, this capacity variation facilitates the identification of the optimum rooftop PV capacity under different sectoral electricity consumption patterns and 65% and 100% kWh export-credit schemes.

The primary data used in this study is secondary data obtained from the Kaggle dataset titled "Surabaya Electric Consumption by Sector." This dataset is used to analyze the

characteristics and patterns of electricity consumption by sector. The electricity consumption data is then processed using Google Colab to generate information on monthly electricity consumption, annual electricity consumption, and electricity needs, which serve as the basis for simulating the implementation of rooftop solar power plants. In addition to the primary dataset, this study also utilized literature and regulatory documentation related to rooftop solar power plants (PV), on-grid systems, kWh exports and imports, and techno-economic feasibility indicators.

The object of this study was electricity consumption patterns by sector and the techno-economic feasibility of implementing rooftop solar power plants based on a kWh export scheme. The objects analyzed were not physical PV installations themselves, but rather electricity consumption data and simulation results of rooftop solar power plant implementation. Technical indicators analyzed included rooftop solar power plant capacity, PV energy production, self-consumption, kWh exports, kWh imports, self-consumption ratio, export ratio, and import ratio. Meanwhile, economic indicators include:

1. Payback Period: $Payback\ Period = \frac{initial\ investment}{annual\ savings}$ (1)
2. ROI: $Return\ on\ Investment = \frac{total\ savings - initial\ investment}{initial\ investment} \times 100$ (2)
3. NPC: $Net\ Present\ Cost = \frac{Total\ annual\ costs}{Capital\ Recovery\ Factor}$ (3)
4. LCOE: $Levelized\ Cost\ of\ Electricity = \frac{Construction\ Cost + Total\ Annual\ O\&M\ Cost}{Total\ Annual\ Energy\ Generation}$ (4)

The research stages began with problem identification, collecting electricity consumption data from Kaggle, processing the data using Google Colab, analyzing electricity consumption patterns, technical simulations of rooftop solar power plants, calculating economic indicators, comparing 65% and 100% export schemes, discussing the results, and drawing conclusions. These stages are used to answer the research objectives, namely to determine the electricity consumption pattern per sector, analyze the results of kWh export-import simulations, determine the influence of export schemes on techno-economic feasibility, and determine the most optimal kWh export scenario. The following is a picture of the steps in this research.

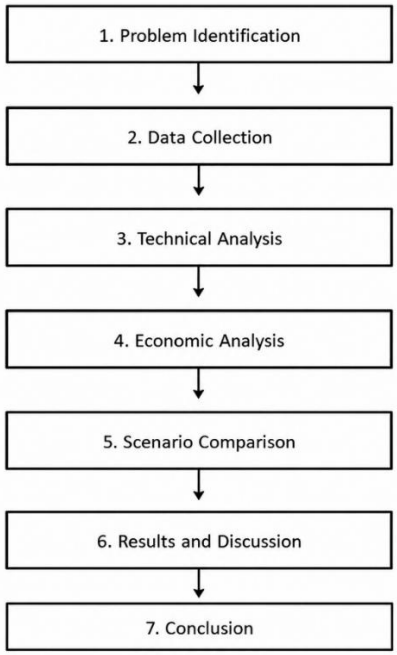

Figure 1. Research Flow
[Source: Research Methods]

Data analysis was conducted using Google Colab in several stages. The first stage involved loading the dataset, checking for data size, column names, data types, missing values, and duplicate data. Next, the data was cleaned by standardizing column names, removing duplicate data, detecting year columns, and converting the electricity consumption data to a numeric format. The initial electricity consumption data, measured in MWh, was then converted to kWh to meet the needs of the rooftop solar power plant analysis.

The next stage involved a technical simulation of the rooftop solar power plant. The simulation calculated the solar power plant's energy production, self-consumption, kWh exports, and kWh imports. Monthly simulation results were then aggregated into annual results based on the solar power plant's capacity in kWp. From these results, the self-consumption ratio, export ratio, and import ratio were calculated to assess the effectiveness of solar power plant energy utilization and the level of dependence on the PLN grid.

An economic analysis was conducted by comparing the simulation results for 65% and 100% kWh export schemes. This comparison was used to determine the effect of the export credit value on electricity cost savings, ROI, NPC, LCOE, and payback period. The results of the technical and economic analysis were then used to determine the rooftop solar PV scenario that offers the most optimal feasibility. In this study, the kWh export scheme was the primary comparison variable because it influences the economic value of the electricity exported to the grid.

Table 1. Research Variables and Indicators
[Source: Research Methods].

Variabel	Indicator	Purpose of Analysis

Electricity consumption patterns	Electricity user sector, monthly consumption, annual consumption	Know the characteristics of electricity needs per sector
Technical aspects of rooftop solar power plants	Solar PV capacity, energy production, self-consumption, kWh export, kWh import, energy ratio	Assessing the technical performance of rooftop solar PV
Economic aspects of rooftop solar PV	Initial investment, O&M costs, electricity tariffs, savings, NPC, LCOE, ROI, payback period	Assessing the financial feasibility of rooftop solar PV
kWh export scheme	65% and 100% export scheme	Compare the most optimal scenarios

Using this method, this study can provide a comprehensive overview of the relationship between electricity consumption patterns, kWh export-import simulation results, and the techno-economic feasibility of rooftop solar power plants. The data analysis technique in this study was conducted quantitatively using Google Colab. The analysis consisted of several stages, as follows:

1. Electricity Consumption Pattern Analysis
   Electricity consumption pattern analysis was conducted by processing the "Surabaya Electric Consumption by Sector" dataset. The data was examined, cleaned, and converted from MWh to kWh. The analysis results were used to identify the sectors with the highest electricity consumption and the electricity demand patterns, which served as the basis for the rooftop solar power plant simulation.
2. Rooftop Solar Power Plant Technical Simulation
   Technical simulations were conducted to calculate the solar power plant's energy production, self-consumption, kWh export, and kWh import. These simulation results were used to determine the rooftop solar power plant's ability to meet electricity needs and reduce dependence on the PLN grid.
3. Energy Ratio Analysis
   Energy ratio analysis was conducted by calculating the self-consumption ratio, export ratio, and import ratio. These ratios were used to assess the effectiveness of rooftop solar power plant energy utilization based on electricity consumption patterns.
4. Analysis kWh Export Scheme
   The export scheme analysis was conducted by comparing the 65% and 100% export schemes. This comparison aims to determine the effect of the export credit value on electricity savings and the economic feasibility of rooftop solar power plants.
5. Economic Feasibility Analysis
   The economic analysis was conducted by calculating investment costs, operational and maintenance costs, electricity savings, NPC, LCOE, ROI, and payback period.

These indicators are used to assess the financial feasibility of implementing rooftop solar power plants.

6. Determining the Optimal Scenario
   The optimal scenario was determined by comparing the technical and economic results of each scenario. The best scenario is the one that produces the highest savings, greater ROI, faster payback period, and the best technical and economic feasibility.

3. Result and Discussions

The results of the study show that the electricity consumption pattern of each sector has different characteristics. Based on electricity consumption data per sector, the industrial sector is the sector with the highest electricity consumption, followed by the household sector and businesses and hotels. Meanwhile, the building and offices, roads, and social events sectors have lower electricity consumption. These findings show that electricity demand is greatly influenced by the type of activity in each sector. The industrial sector has high consumption because operational and production activities require greater and relatively sustainable electrical energy. On the other hand, the social sector and public facilities have more limited consumption according to the intensity of their use. The following is also shown a picture of the results of the numerical data distribution, namely:

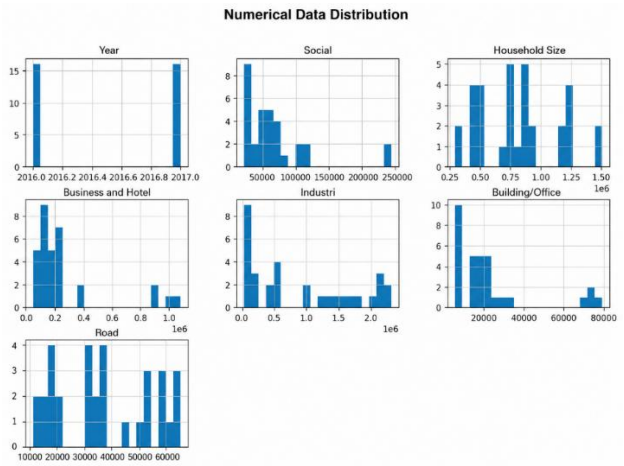

Figure 2. Numerical Data Distribution Results
[Source: Data Analysis Results]

The results of the technical simulation of rooftop solar PV show that the larger the capacity of the solar PV, the greater the production of electrical energy produced. The annual electricity consumption used in the simulation is 4,416.50 kWh/year, consisting of day consumption of 1,987.42 kWh/year and night consumption of 2,429.08 kWh/year. At a capacity of 12.0 kWp, solar PV production reached 15,768.00 kWh/year, energy

exports amounted to 13,780.58 kWh/year, while electricity imports remained at 2,429.08 kWh/year. This condition shows that increasing the capacity of solar power plants is able to increase energy production and exports, but has not been able to eliminate the need for electricity imports at night because the system analyzed does not use energy storage batteries. The following is shown a simulation of the export and import of kWh rooftop solar PV, which is as follows.

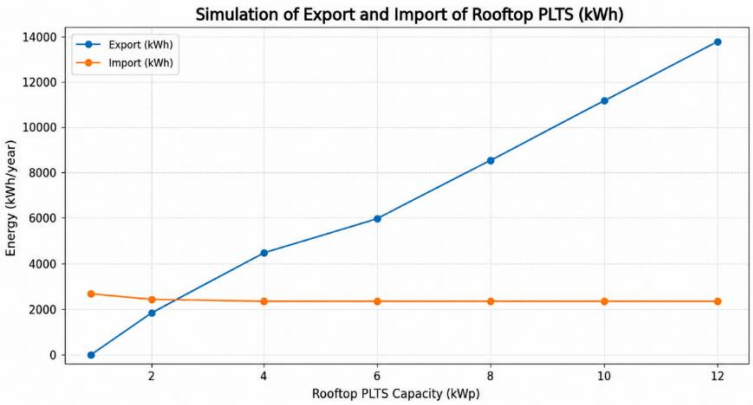

Figure 3. Simulation of Export and Import kWh of Rooftop Solar Power Plants
[Source: Data Analysis Results]

Technically, these results show that larger solar capacity does not necessarily increase the direct energy utilization of solar PV proportionately. When the daytime electricity needs have been met, the additional energy production from solar power plants will be excess energy exported to the grid. Therefore, electricity consumption patterns are an important factor in determining the effectiveness of rooftop solar PV. Without an energy storage system, daytime electricity production cannot be used to meet nighttime electricity needs, so electricity imports from PLN still occur.

In the economic aspect, the results of the study show that the 100% kWh export scheme provides better feasibility than the 65% export scheme. The average savings in the 100% export scheme reached IDR 12,556,135.36/year, while the 65% export scheme was only IDR 9,146,249.68/year. In addition, the average payback period in the 100% export scheme is 7.64 years, faster than the 65% export scheme of 10.01 years. The ROI of the 100% export scheme is also higher, which is 161.84%, compared to the 65% export scheme of 102.78%. Meanwhile, the LCOE value in both schemes is the same, namely Rp995.83/kWh, because LCOE is influenced by investment costs and energy production, not by the percentage of export credits.

The difference in economic results occurs because in the 100% export scheme, all electrical energy exported to the grid is fully counted as electricity cost reduction credits. In contrast, in the 65% export scheme, only part of the export energy is taken into account as credit. Thus, a 100% export scheme provides greater economic benefits through increased savings, accelerated return on investment, increased ROI, and decreased NPC.

These findings are in line with previous research that stated that an increase in the percentage of kWh export-import can accelerate the break-even period and increase the feasibility of rooftop solar investment. Based on the results of data processing, a 100% export scheme provides better economic benefits than a 65% export scheme.

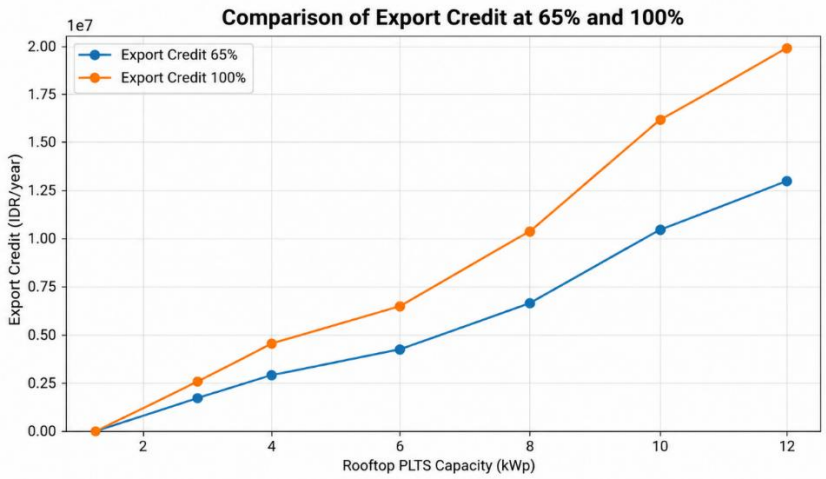

Figure 4. Comparison of Export Credit 65% and 100%
[Source: Data Analysis Results]

The determination of the most optimal scenario is carried out by comparing technical and economic indicators, including solar PV production, kWh exports, kWh imports, savings, NPC, payback period, ROI, and LCOE. Based on the ranking results, the best scenario is a 12.0 kWp rooftop solar power plant with a 100% export scheme. This scenario results in solar PV production of 15,768.00 kWh/year, exports of 13,780.58 kWh/year, imports of 2,429.08 kWh/year, savings of IDR 22,780,029.60/year, NPC of -IDR 88,205,274.49, payback period of 7.64 years, ROI of 161.84%, and LCOE of IDR 995.83/kWh.

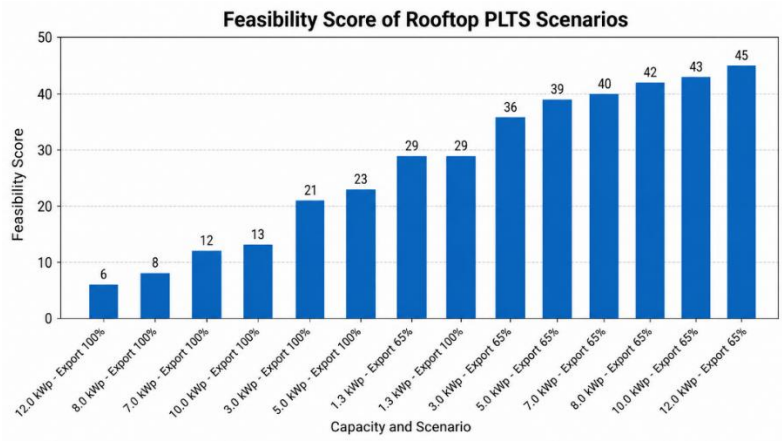

Figure 5. Feasibility Score of Rooftop Solar PV Scenario
[Source: Data Analysis Results]

These results show that the 12.0 kWp scenario with a 100% export scheme provides the greatest economic benefits compared to other scenarios. A capacity of 12.0 kWp results in the highest energy production, while a 100% export scheme provides full export credit value. The combination of the two results in the biggest annual savings, the highest ROI, and the lowest NPC. However, from a technical perspective, the size of the solar power plant capacity still needs to be adjusted to electricity consumption patterns, especially during the day. If solar PV production far exceeds the daytime needs, then most of the energy will be exported and the economic benefits are highly dependent on the kWh export policy.

Overall, the results of this study confirm that the implementation of rooftop solar is not only determined by the size of the system capacity, but also by the electricity consumption patterns and export schemes used. The 100% export scheme has proven to provide better economic viability than the 65% scheme, while from a technical perspective, a system without batteries still has limitations in meeting nighttime electricity needs. Thus, the novelty of this study lies in the integration of electricity consumption pattern analysis per sector, kWh export-import simulation, and comparison of 65% and 100% export schemes to determine the most optimal rooftop solar PV scenario.

4. Conclusion

Based on the results, the techno-economic feasibility of rooftop photovoltaic (PV) systems is influenced by electricity consumption patterns and the applied kWh export-credit scheme. The industrial sector exhibits the highest electricity consumption, and increasing PV capacity enhances electricity generation and export potential, although nighttime electricity imports remain necessary in battery-free systems. Among the evaluated scenarios, the 12.0 kWp rooftop PV system with the 100% export-credit scheme provides the best techno-economic performance, yielding the highest electricity cost savings, ROI, and the shortest payback period. This study contributes by integrating sectoral electricity consumption patterns, rooftop PV technical simulation, and comparative evaluation of 65% and 100% export-credit schemes into a single techno-economic assessment framework, providing a more comprehensive basis for evaluating rooftop PV feasibility under different policy scenarios. The findings offer practical insights for policymakers and prospective PV users in determining appropriate system capacities and assessing the economic impact of export-credit policies. Future research should incorporate battery energy storage, detailed load profiles, and additional technical parameters to improve the accuracy and applicability of the proposed framework.

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