Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

Maximizing Self-Consumption in Industrial Hybrid PV Systems: A Case Study on Indonesia's Energy Policies

Herri Gusmedi, Osea Zebua, Alif Ghia Khairan, Ahmad Saudi Samosir

Department of Electrical Engineering, Faculty of Engineering, University of Lampung, Bandar Lampung, Indonesia
Email: herri.gusmedi@eng.unila.ac.id

An environmentally friendly source of energy is an urgent demand. Recent advances in solar technology, especially when combined with energy storage batteries, have generated high hopes for the potential of the solar energy revolution. However, in Indonesia, the deployment of solar panels in industrial environments is limited by policies that limit the power generation allowed. Permitted rooftop solar systems in the industrial sector, under the National Electricity Company (PLN) framework, are limited to 10%-15% of the connected electricity capacity. The study focuses on assessing the level of self-consumption in industrial-scale hybrid photovoltaic (PV) systems by exploring three scenarios: maximizing self-consumption, peak shaving, and utilizing batteries exclusively at night. The findings show that when solar panel capacity accounts for only 15% of peak load demand, the ratio of own consumption to total energy demand, known as the Self-Sufficiency Rate (SSR), reaches about 5.113%. However, assuming that the load data represents only 15% of the total actual load, the SSR increases significantly to 30.157%. This variation results from energy production that is aligned with energy demand. As a result, promoting policies that facilitate optimal utilization of solar panels and batteries is recommended to achieve higher levels of self-consumption and reduce dependence on conventional energy sources.
Keywords: Solar Energy, Energy Storage, Self-Consumption, Self-Sufficiency Rate.

1. Introduction

The rapid advancement of technology has led to an increased demand for energy. Per capita electricity consumption in Indonesia has seen a significant rise, increasing by 178.6 GWh from 909.91 GWh in 2015, with an electrification ratio of 88.30%, to 1,088.51 GWh in 2020, with an electrification ratio of 99.20%. The connected power capacity for the industrial customer group in Indonesia also experienced a growth of 6,112.39 MVA in 2020 compared to 2015[1], highlighting the urgent need for sustainable energy solutions. As the country continues to industrialize, integrating renewable energy sources into the grid will be crucial for meeting future demands while minimizing environmental impact. [2]. This increase in electricity consumption is in line with the nation's progress and economic needs. By Presidential Regulation No. 79 of 2014 concerning the National Energy Policy, the target for new and renewable energy by 2025 is at least 23%, and by 2050, it should reach 31%. However, as of the end of 2021, the utilization of new and renewable energy in Indonesia has only reached 11.5% of the total national energy.[3]. Considering that Indonesia, as an equatorial country, has a renewable energy potential of 207.8 GWp, utilizing only about 0.08% of its potential, indicates a relatively low utilization rate. The increase in the use of renewable energy sources (RES) aimed to promote the energy transition is essential to reduce the effects of carbon emissions and mitigate the risks related to climate change. [4].

The low utilization of solar energy in Indonesia is attributed to the government and stakeholders. The obstacles in the development of solar energy can be categorized into four interrelated categories: social, managerial, economic, and policy-related barriers. [5]. A plant is a facility dedicated to providing a localized power source to an energy user. They are often used in industrial facilities or large offices. [6]. One benefit of incorporating photovoltaic systems into buildings is their potential to decrease space requirements and equipment costs when integrated into structural installations. [5-6]. Rooftop PV systems allowed in the industrial sector within the PLN (National Electricity Company) system are restricted to 10%-15% of the connected power capacity. Further detailed evaluations are conducted for customers with high power demands (High Voltage and Medium Voltage). Based on Regulation of the Minister of Energy and Mineral Resources (ESDM) No. 26 of 2021 regarding rooftop PV systems, the installed solar energy capacity is allowed to be 100% of the connected power capacity. The policy established by PLN contradicts the rules set by the Minister of ESDM, leading to controversies regarding installing rooftop PV systems in the industrial sector. These discrepancies highlight the need for more explicit regulations that align with national energy goals and encourage investment in renewable technologies, fostering a collaborative environment where stakeholders can work together to overcome barriers and promote sustainable practices. [9].

Recent advances in solar technology, especially in combination with energy storage batteries, have shown significant potential to revolutionize energy generation, but the practical application of this technology in industrial settings is still limited, especially in Indonesia. The restriction policy under the framework of the National Electricity Company (PLN), which limits rooftop solar systems in the industrial sector to only 10%-15% of the connected electricity capacity, poses a significant obstacle to fully realizing the benefits of solar energy [22].

This study focuses on evaluating the level of self-consumption in industrial-scale hybrid PV systems, with the expectation that the policies set by PLN can analyze the impact of the combination of battery and solar panel systems. The recent development and marketing of battery systems combined with solar energy have been seen by many as a catalyst for the renewable energy revolution [9]. The recent development and marketing of battery systems combined with solar energy have been seen by many as a catalyst for the renewable energy revolution. As industries increasingly adopt these technologies, understanding their efficiency and integration becomes crucial for maximizing energy savings and reducing carbon footprints. Moreover, this research aims to identify best practices and innovative strategies that can enhance the performance of these hybrid systems, ultimately contributing to a more sustainable energy landscape[11]. Significant energy absorption from the combination of solar panels and batteries is now seen as a possibility in the future that will lead to increased decentralized generation and higher levels of self-consumption [12]. Solar power is considered one of the most effective solutions suggested for mitigating both the economic and environmental impacts of energy production [13]. Additionally, the benefits of battery systems are closely related to higher levels of self-consumption, thereby maximizing tax relief and reducing utility network costs [14]. To provide an indicator of efficiently utilized power consumption, it is necessary to assess the volume of self-consumption possible by standalone PV systems or a combination of solar panel and battery systems. Off-grid PV systems located in regions with highly changing seasons, such as a monsoon season, and that are farther away from the equator face an even more significant challenge in terms of reliability [15]. Furthermore, with autonomous solar systems, any excess solar energy is wasted when there is no need for it or when it cannot be stored, resulting in a decrease in the system's efficiency and feasibility [16]. Most studies in the literature have mostly examined the performance of grid-connected photovoltaic (PV) systems rather than standalone PV-battery systems [17].

Studies on hybrid PV systems focus on the system's ability to trim peak load demand (peak-shaving). This increasing emphasis on peak shaving not only reduces the economy of grid operation but also lowers the utilization ratio of power equipment, resulting in a significant waste of social resources. [7-9]. Self-consumption is defined as the PV production consumed directly by the producer, who often is the owner of the PV system. [19].

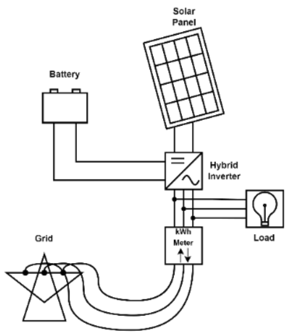
Although solar and battery technology has developed rapidly, the application of hybrid PV systems on an industrial scale in Indonesia is still limited by PLN's policy that only allows the installation of rooftop solar systems up to 15% of the connected electricity capacity. This suggests there is a great opportunity for further research assessing the impact of these restrictions and how more supportive policies can be proposed [20].

Consumption and production profiles directly affect the self-sufficiency level; the quality of load profile data is crucial when evaluating self-consumption and the potential for energy storage solutions [21]. By analyzing real-time data and historical usage patterns, stakeholders can make informed decisions that optimize energy distribution. Additionally, the role of policy frameworks and incentives cannot be overlooked, as they play a significant part in encouraging investment and innovation in this sector.[22]. The ultimate objective is to develop a simple computational tool in the form of a model for calculating self-consumption in industrial-scale hybrid PV systems. Furthermore, this modeling can also be employed to assess the influence of installing hybrid PV systems on self-consumption levels and determine the suitable battery capacity [23]. The research proposes an approach that will be used for self-consumption analysis:

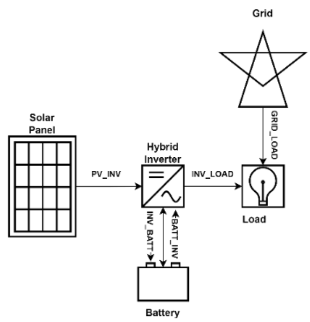
1. Database of 30-min electricity consumption. These scenarios are simulated in coordination with a PV generation model and a basic battery model.

2. The volume of self-consumption is derived as a function of the relative sizes of the demand, solar panel generation, and battery capacity. This analysis was carried out for the industrial profiles, and their quantity is considered substantial enough to obtain statistically significant Self-Consumption Rate (SCR) and Self-Sufficiency Rate (SSR) values.

The typical installation considered in this paper is illustrated in Figure 1 (a). It consists of a DC-coupled PV system integrated with a battery. Solar energy is the main source of power, and the power from the grid is the supplementary source [13]. This configuration allows for efficient energy management, ensuring that excess solar power can be stored for later use, thereby enhancing the overall reliability of the energy supply. Moreover, the integration of smart grid technologies further enhances this system by enabling real-time monitoring and control, which optimizes energy flow and reduces costs [6].



(a)



(b)

Figure 1. (a) Conceptual scheme of the considered DC-coupled hybrid system and (b) hybrid PV system self-consumption modeling

2. RESEARCH METHOD

This modeling is aimed at calculating the self-consumption of a hybrid PV system [12]. The hybrid PV system is considered a means to meet load requirements [24]. This model incorporates a logic system for energy distribution, guided by the conditions and rules illustrated in Figure 1 (b). Precise prediction of power consumption and PV generation is crucial for efficient energy system planning, operations, and performance evaluation, leading to enhanced energy utilization [25].

Monitoring data

We collected a database of historical industry electricity consumption profiles obtained from accessible sources, following these criteria:

- load profile data was collected every day from January 1st to February 28th, 2021. Assuming that the load coincides with the year of solar panel power production data collection,

- solar panel power production occurs from 06:00 a.m. to 05:30 p.m. From From January 2nd to February 28th, 2023;
- time steps of 30 min;
- disaggregated (i.e., non-averaged) data.

Single Line Diagram

The solar component consists of 2480 solar panel modules installed, with a total power generated of 1,339.2 kWp. Each string of solar panels consists of 20 modules. It is equipped with two types of on-grid inverters, namely those with a capacity of 110 kVA and 50 kVA. A total of 10 inverters have been installed. Each Inverter is capable of accommodating 7 to 13 strings of solar panels, with a maximum capacity of 140.4 kWp for a 110 kVA inverter and 75.6 kWp for a 50 kVA inverter. It can be seen in Figure 2 single line diagram

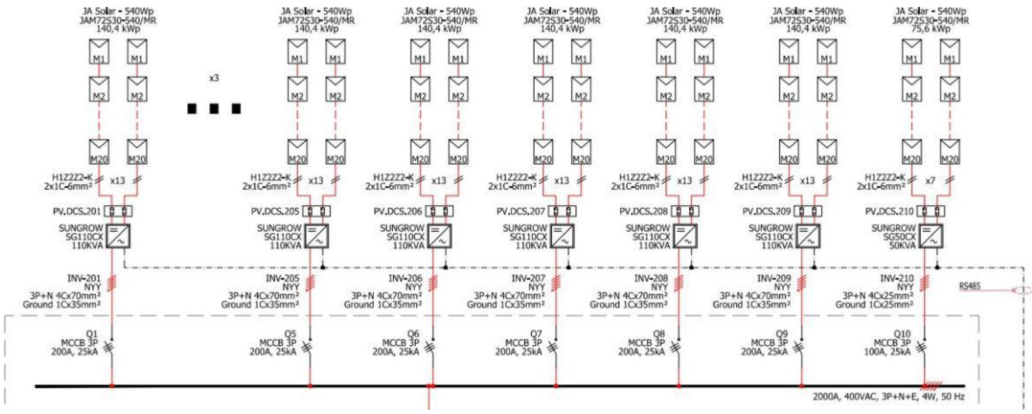


Figure 2. Single Line Diagram

Self-Consumption Model

This modeling is aimed at calculating the self-consumption of hybrid solar PV. Hybrid solar PV systems are considered a means to meet load requirements. This model contains the logic to deliver energy based on the conditions and rules given to the diagram in figure 3.

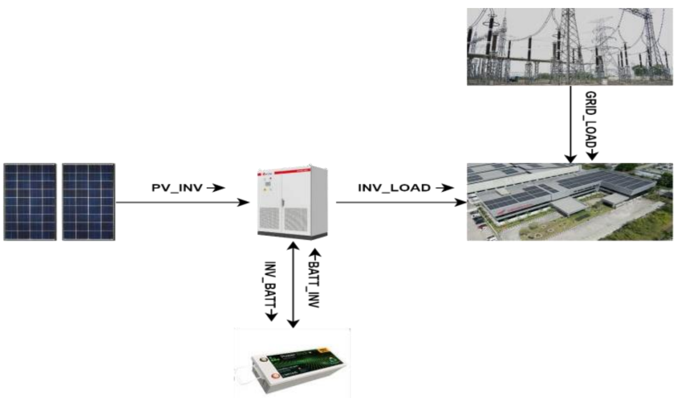


Figure 3. Self-Consumption simulation System

In this modeling, there are three dispatch functions implemented:

- dispatch_max_sc:

Its function calculates the battery charge, the power processed by the Inverter, and the power flow to and from the battery. In addition, this function models how the battery charges from the solar panel and how the battery supplies the load. This function provides an overview of how the solar panel and battery work together to meet the load demand, considering efficiency and power flow in a given time step.

- dispatch_max_sc_ps:

This function is used to implement peak-shaving scenarios to optimize power usage from solar panels and battery storage. The find_threshold function is used to determine the threshold power level at which excess power from the solar panel will be stored in the battery. The purpose of the threshold is to find the point of excess energy generation where the excess solar energy should be stored in the battery [26]. The threshold is calculated using the Brentq optimization technique to find the point where excess energy can be stored in the battery while considering the remaining battery capacity. The threshold value is then used in the main loop of code to determine whether or not excess solar energy should be stored in the battery. This value is compared to the excess energy actually generated by the solar panel for each step of time. If excess energy is above the threshold, some of that energy is stored in the battery. Otherwise, all excess energy is stored in the battery.

- dispatch_max_sc_time:

This function is designed to maximize power flow and energy storage by taking into account the time factor. Specifically, this function takes into account the time period when battery storage occurs between 06.00 WIB to 17.30 WIB, and the time period when battery discharge occurs between 19.00 WIB to 00.00 WIB.

The battery storage capacity is used to maximize its own consumption, if the production power of the solar panel is higher than the load, then the extra power is used to charge the battery fully. If the production power of the solar panel is lower than the load, then the energy transfer uses the battery. The disadvantages that are taken into account are the efficiency of the battery reciprocating and the efficiency of the Inverter [27].

Load profile

The constraint experienced by this daily load profile data is that there are instances where data was not collected at certain times, resulting in zero values. To complete zero values in the data, linear interpolation can be employed as a method to estimate the data based on two data points adjacent to the point that needs interpolation in a one-dimensional data sequence, using linear interpolation [28]. Figure 4 displays a graph of the daily load profile that was created using interpolation. The maximum power required is 6.15 MW, with an average daily power of 2.88 MW.

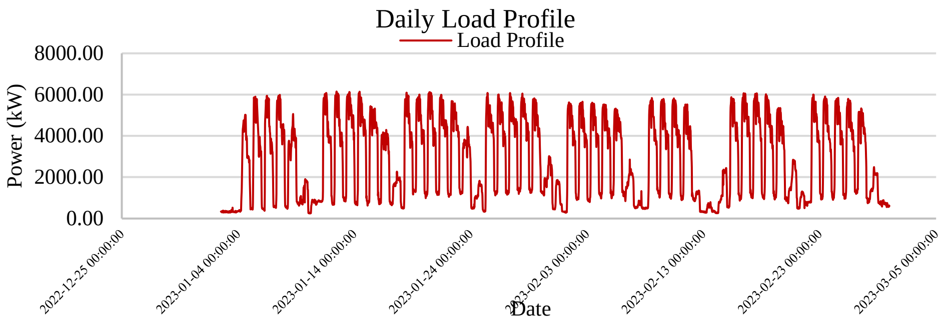


Figure 4. Daily Load Profile

In accordance with the daily load data, the total energy requirement is calculated by multiplying the daily load values for each time step from January to February by the respective time step duration. The cumulative energy demand amounts to 3.97 GWh, with an average daily energy requirement of 1.46 MWh. Therefore, the energy demand is summarized in Table 1.

Table 1. Total Energy Demand

Month	Power (kW)	Energy (kWh)
January	4144.61	2072.30
February	3799.32	1899.66
Average/Day	2.93	1.46
Total	172.87	3971.97

PV Power Production

The solar panel system used is an on-grid system with a capacity of 1,339.2 kWp, comprising a total of 2,480 solar panels. Data collection was conducted through a power production dashboard, commencing on January 2, 2023, and continuing until February 28, 2023, with readings taken every 30 minutes from 06:00 AM to 5:30 PM local time. Figure 18, which contains the solar power production graph. The average solar power output is 149.60 kW, with a total energy generation of 206.37 MWh. Figure 5 shows The energy production produced by PV. Figure 5 shows The energy production produced by PV.

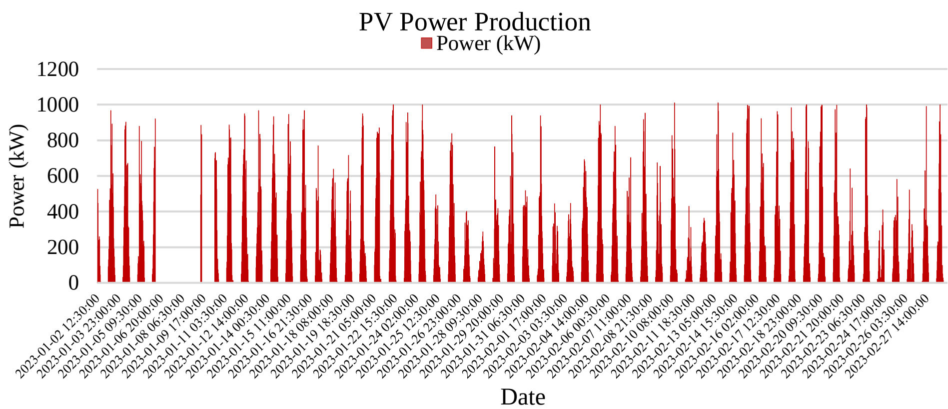


Figure 5. PV Power Production

3. RESULTS AND DISCUSSION

Each function considers the solar panel power and load values provided over time, as well as parameters such as battery capacity, battery discharge limit, inverter efficiency, battery efficiency, maximum battery cycles, and initial charge rate. Table 2 presents the parameters used in the self-consumption modeling.

PV and battery dispatch models

The battery storage capacity is utilized to maximize self-consumption. If the solar panel production exceeds the load, the excess power is used to charge the batteries to their full capacity [29]. In cases where solar panel production is lower than the load, energy is redirected using the battery system. Losses taken into account include the round-trip efficiency of the batteries and the inverter efficiency. At each time step, the following simple dispatch algorithm is executed [12]:

The power served by the solar panels is determined by the following:

The excess power produced by the solar panels:

$$\mathrm{res_{PV}} = \max\left(0, \mathrm{P_{PV,DC,i}} - \frac{\mathrm{P_{load,i}}}{\eta_{\mathrm{inv}}}\right) \quad (1)$$

The power transferred from the Inverter to the battery:

$$\mathrm{inv_{Batt}} = \mathrm{res_{PV}} \times \eta_{\mathrm{Batt}} \quad (2)$$

The battery capacity after charging:

$$\mathrm{CAP_{Batt,cha,i}} = \sum_{\mathrm{i=i-1}}^{\mathrm{N}} \mathrm{inv_{Batt}} \quad (3)$$

The discharging capacity of the battery:

$$\mathrm{Batt_{inv}} = \min\left(\mathrm{CAP_{Batt,cha,i}} - \mathrm{Batt_{SoC}}, \mathrm{P_{load,i}}\right) \quad (4)$$

The power delivered from the battery to the load:

$$\mathrm{P_{Battload}} = \mathrm{Batt_{inv}} \times \eta_{\mathrm{inv}} \quad (5)$$

Adjusts the battery capacity after discharging

$$\mathrm{CAP_{Batt,cha,i}} = \mathrm{CAP_{Batt,cha,i}} - \mathrm{Batt_{load}} \quad (6)$$

Explanation:

$\mathrm{P_{PV,DC}}$ = Solar panel power production (kW)

$\mathrm{P_{load,i}}$ = Load (kW)

η_{inv} = Inverter efficiency

η_{Batt} = Battery efficiency

$\mathrm{Batt_{SoC}}$ = Battery State of Charge limit

This simulation yields time vectors representing the battery state of charge and purchased power. An effective energy model should not only facilitate the growth of decentralized energy generation but also efficiently oversee the system to optimize the consumption of locally generated energy [30]. All these models and data processing procedures are implemented using the Python programming language [31] .

Energy profiling

In a comprehensive time-based simulation, the primary variable of focus is the overall level of self-consumption, often expressed as either SSR or SCR. For this simulation, the Self-Consumption Rate (SCR) is defined as the ratio between self-consumed energy and the total energy production from solar panels [32]:

$$SSR = \frac{E_{SC}}{E_{load}} = \frac{\sum_{i=1}^{N}(P_{Battload} + P_{SC,DC,0,i}) \times \eta_{inv}}{\sum_{i=1}^{N} P_{load,i}} \quad (7)$$

$$SCR = \frac{E_{SC}}{E_{PV,DC}} = \frac{\sum_{i=1}^{N}(P_{Battload} + P_{SC,DC,0,i}) \times \eta_{inv}}{\sum_{i=1}^{N} P_{PV,DC,i}} \quad (8)$$

Meanwhile, the Self-Sufficiency Rate (SSR) is defined as the ratio between the total self-consumed energy and the total energy demand. Where E refers to the energy flow, P represents the power output, N is the number of time steps, and $P_{SC,DC,0,i}$ is the solar panel generation consumed directly without passing through battery storage [12].

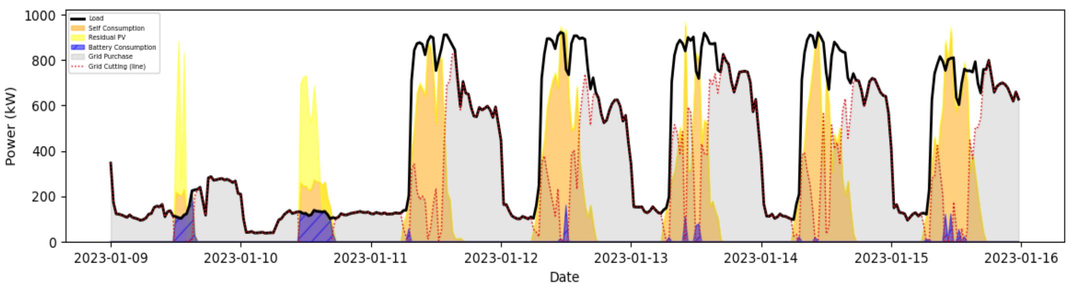


Figure 6. Power dispatch for a typical week of January

Results of self-consumption analysis

The self-consumption modeling includes three scenarios: dispatch_max_sc, dispatch_max_sc_ps, and dispatch_max_sc_time. This function implements a dispatch algorithm to maximize self-consumption in a solar panel system with a battery. Scenario 1, known as "dispatch_max_sc," is the foundational function that calculates the power flow between the solar panels, battery, and load. This calculation aims to maximize self-consumption while considering a variety of parameters. Building upon Scenario 1, we have Scenario 2, "dispatch_max_sc_ps." This function extends the capabilities of the previous scenario by factoring in cost availability. It optimizes battery dispatch by taking into account the solar panel power profile and load forecasts, resulting in more efficient energy utilization. Extending the functionality further, Scenario 3, "dispatch_max_sc_time," introduces time-based control scenarios. Here, battery charging and discharging are scheduled based on the time of day, which can lead to enhanced self-consumption and improved energy efficiency. Table 2 provides an overview of how energy from solar panels and batteries is utilized to meet load requirements, as well as the efficiency levels in utilizing self-consumed energy based on actual load and 15% of actual load data.

Table 2. Total energy from solar panels and batteries with SCR and SSR values

Scenario	Solar Panel to Load	Battery Charging Capacity	Battery to Load	Self-Consumption	SCR	SSR
	MWh				%	
Actual load						
Scenario 1		2.283	2.580	203.636	98.676%	5.127%
Scenario 2	201.056	2.332	2.553	203.609	98.663%	5.126%
Scenario 3		1.223	0.905	201.961	97.864%	5.085%
15% load						
Scenario 1		39.286	22.715	185.816	90.041%	31.188%
Scenario 2	163.101	27.178	18.126	181.227	87.817%	30.418%
Scenario 3		10.910	8.876	171.977	83.335%	28.865%

As shown in Figure 7 (a), it presents a comparison of the battery energy capacity with the Self-Sufficiency Rate (SSR). The relationship between the battery charging capacity and SSR is directly proportional. The more energy the battery can store, the higher the resulting SSR. This is because with increased energy production, there is more energy available for consumption. Hence, the ratio between energy consumption and energy production is directly proportional.

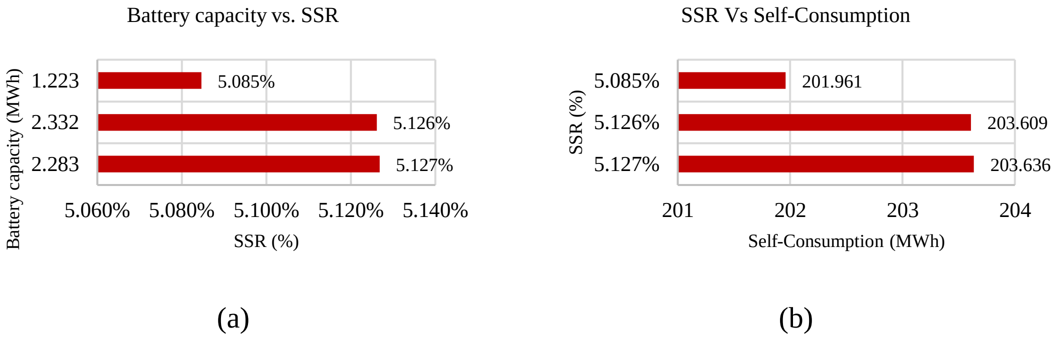
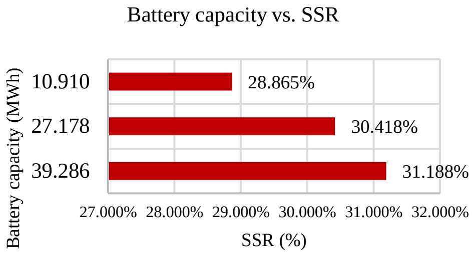


Figure 7. (a) Battery capacity vs. SSR actual load and (b) SSR vs. self-consumption actual load

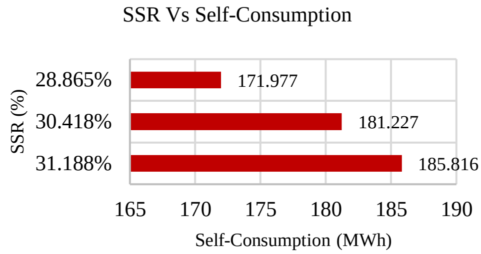
Figure 7 (b) it shows a comparison between the energy storage capacity of the battery and the Self-Sufficiency Rate (SSR). The relationship between the battery charging capacity and SSR is directly proportional. The more energy that can be stored in the battery, the higher the resulting SSR. This is due to the fact that as more energy is generated, there is also an increased amount of energy available for consumption. Therefore, the ratio between energy consumption and energy production is directly proportional.

From the results of the self-consumption modeling analysis, it can be observed that in each scenario applied using actual load data, the Self-Sufficiency Rate (SSR) is approximately 5.113%. This is primarily due to the higher load demand compared to the power production of the installed solar panels. The limitation applied is that the solar panel capacity covers only 15% of the total peak load. Hence, there exists a gap between the solar panel power production capacity and the load demand that needs to be met. To enhance battery usage and achieve a higher utilization rate in this simulation, it can be assumed that each load data only encompasses 15% of the actual total load.

When considering a 15% load, the self-consumption ratio, which reflects the portion of self-generated energy in relation to the total energy demand, is found to be 30.157% in all three scenarios. This occurs when energy production is proportionate to energy demand. As this alignment improves, the self-consumption rate naturally increases, highlighting the growing significance of the energy generated by solar panels and subsequently stored in batteries.



(a)



(b)

Figure 8. (a) Battery capacity vs. SSR 15% load and (b) SSR vs. self-consumption 15% load

In examining the three scenarios presented in Figure 6, it becomes evident that self-consumption, the utilization of energy produced by solar panels and stored in the battery to fulfill the load requirements, exhibits significant variation. Scenario 1 stands out as the most efficient in terms of self-consumption, boasting an impressive self-consumption rate of 90.041%. Meanwhile, Scenario 2 and Scenario 3 also perform admirably, achieving substantial self-consumption rates of 87.817% and 83.335%, respectively. Furthermore, the self-sufficiency rate (SSR), representing the proportion of the load met using the combined energy from solar panels and the battery, ranges from 28.865% to 31.188% across these scenarios. These findings underscore the critical role that different operational conditions and dispatch algorithms play in optimizing self-consumption and enhancing self-sufficiency. These results provide valuable insights into improving the efficiency and sustainability of solar panel systems with batteries under varying conditions.

The more energy a battery can store, the greater the SSR level produced. This is due to the fact that the more energy produced is produced, the more energy can be consumed. The more energy consumed, the more energy needs can be met. Because the ratio between the total energy that can be supplied and the energy produced is directly proportional, the more energy is produced, the more energy can be consumed to meet the load requirements. This is because in the first scenario, the solar panels and batteries are intended to produce as much energy as possible that can be directly consumed by the load. Thus, the surplus energy from the solar panels is stored in the battery and used when needed. This leads to a high level of self-consumption. Meanwhile, in peak-shaving scenarios, the main focus is to reduce energy use during peak loads by using battery storage to offset energy needs. This leads to lower energy usage from solar panels and batteries during off-peak periods. In this scenario, some of the energy generated by the solar panel system and the battery may not be directly used by the load, resulting in lower SCR and SSR values compared to the first scenario. In the third scenario with a time-based scenario, the resulting SCR and SSR values tend to be lower compared to the first and second scenarios. This is due to the pattern of energy use that occurs at night, where energy demand is generally lower compared to during operating hours.

In this study, the expected result is that the self-consumption rate or Self-Sufficiency Rate (SSR) is close to 100%. This makes it possible to evaluate that hybrid solar renewable energy systems can be recommended as an alternative to decentralized power generation on an industrial scale. To achieve an increase in the level of self-consumption, it is necessary to increase the installation capacity of solar panels, so that the energy produced can meet the load requirements and be stored in the battery to the maximum. In addition, the set battery capacity configuration also plays an important role in achieving high self-consumption targets.

Therefore, the policy of restricting the installation of solar panel capacity on an industrial scale can hinder the development of renewable energy systems in the solar energy renewal sector. It is recommended to encourage policies that support increasing the installation of solar panel capacity and more optimal use of batteries to encourage the use of renewable energy and achieve a higher level of self-consumption in an effort towards energy sustainability and reducing dependence on conventional energy sources.

4. CONCLUSION

In the first scenario, the solar panel and battery aim to generate as much energy as possible for direct consumption by the load. Therefore, the battery stores the excess energy from the solar panels for later use. In the peak-shaving scenario, the primary goal is to minimize energy consumption during peak load. Batteries to offset energy needs. This leads to lower energy usage from solar panels and batteries during off-peak periods. In this scenario, some energy generated by the solar panel system and battery may not be directly used by the load, resulting in lower SCR and SSR values compared to the first scenario. In the time-based scenario, the resulting SCR and SSR values are lower than in the first and second scenarios. This is due to the pattern of energy use that occurs at night, where energy demand is generally lower compared to during operating hours. The analysis shows significant potential to improve self-sufficiency in solar panel systems with batteries. With solar panels initially meeting only 15% of peak load demand, the self-sufficiency ratio (SSR) starts at 5.113%. However, using a 15% load significantly increases the SSR to 30.157%. Among the scenarios studied, "dispatch_max_sc" emerged as the most effective option. Its straightforward approach and robust SSR performance efficiently manage power flow, reduce dependence on external energy sources, and promote grid independence. In practical applications, Scenario 1 is an attractive option for projects that aim to achieve higher energy utilization and self-sufficiency.

References

1. Kementerian Energi dan Sumber Daya Mineral, “Statistik Ketenagalistrikan Tahun 2020, 34th ed. Jakarta,” Jakarta, 2021.
2. J. Hossain, A. F. A. Kadir, H. Shareef, R. Manojkumar, N. Saeed, and A. N. Hanafi, “A Grid-Connected Optimal Hybrid PV-BES System Sizing for Malaysian Commercial Buildings,” Sustain., vol. 15, no. 13, 2023, doi: 10.3390/su151310564.
3. Y. Yudiartono, J. Windarta, and A. Adiarso, “Sustainable Long-Term Energy Supply and Demand : The Gradual Transition to a New and Renewable Energy System in Indonesia by,” vol. 12, no. 2, pp. 419–429, 2023.
4. B. da Costa Paulo, N. Aginako, J. Ugartemendia, I. Landa del Barrio, M. Quartulli, and H. Camblong, “Surrogate model of a HVAC system for PV self-consumption maximisation,” 2023. doi: 10.1016/j.ecmx.2023.100396.
5. E. Karakaya and P. Sriwannawit, “Barriers to the adoption of photovoltaic systems: The state of the art,” May 2015, Elsevier Ltd. doi: 10.1016/j.rser.2015.04.058.
6. Z. A. Liza, H. Aktar, and M. R. Islam, “Solar Energy Development and Social Sustainability: A Case Study on the Teknaf Solar Power Plant in Bangladesh,” J. Asian Energy Stud., vol. 4, no. 1, pp. 1–8, 2020, doi: 10.24112/jaes.040001.
7. A. J. Aristizabal, D. Ospina, M. Castaneda, S. Zapata, and E. Banguero, “Optimal power flow model for building integrated photovoltaic systems operating in the andean range,” Indones. J. Electr. Eng. Comput. Sci., vol. 16, no. 1, pp. 52–58, 2019, doi: 10.11591/ijeecs.v16.i1.pp52-58.
8. T. Yang and A. K. Athienitis, “A study of design options for a building integrated photovoltaic/thermal (BIPV/T) system with glazed air collector and multiple inlets,” Sol. Energy, vol. 104, pp. 82–92, 2014, doi: 10.1016/j.solener.2014.01.049.
9. B. Zakeri, S. Cross, P. E. Dodds, and G. C. Gissey, “Policy options for enhancing economic profitability of residential solar photovoltaic with battery energy storage,” Appl. Energy, vol. 290, no. February, p. 116697, 2021, doi: 10.1016/j.apenergy.2021.116697.
10. M. Tauffauzan, C. Junihartomo, S. Thamrin, and M. S. Boedoyo, “Potential Analysis and Regulations of Solar Power Plant Development in Indonesia,” Int. J. Innov. Sci. Res. Technol., vol. 7, no. 4, pp. 518–522, 2022, doi: 10.5281/zenodo.6519378.
11. E. Schulte, F. Scheller, D. Sloot, and T. Bruckner, “A meta-analysis of residential PV adoption: the important role of perceived benefits, intentions and antecedents in solar energy acceptance,” Energy Res. Soc. Sci., vol. 84, 2022, doi: 10.1016/j.erss.2021.102339.
12. S. Quoilin, K. Kavvadias, A. Mercier, I. Pappone, and A. Zucker, “Quantifying self-consumption linked to solar home battery systems: Statistical analysis and economic assessment,” Appl. Energy, vol. 182, pp. 58–67, Nov. 2016, doi: 10.1016/j.apenergy.2016.08.077.
13. H. L. T. Thuy and D. N. Nguyen, “Feasibility Analysis of the Power Supply Model Using Solar PV for the Public Lighting System in Hanoi,” J. Asian Energy Stud., vol. 5, no. 1, pp. 14–21, 2021, doi: 10.24112/jaes.050002.
14. K. Obaideen et al., “On the contribution of solar energy to sustainable developments goals: Case study on Mohammed bin Rashid Al Maktoum Solar Park,” Int. J. Thermofluids, vol. 12, 2021, doi: 10.1016/j.ijft.2021.100123.
15. J. Lagorse, D. Paire, and A. Miraoui, “Sizing optimization of a stand-alone street lighting system powered by a hybrid system using fuel cell, PV and battery,” Renew. Energy, vol. 34, no. 3, pp. 683–691, 2009, doi: https://doi.org/10.1016/j.renene.2008.05.030.
16. S. Odeh and I. Ibrik, “Performance assessment of standalone PV systems for rural communities,” Aust. J. Mech. Eng., vol. 20, pp. 1–10, Nov. 2019, doi: 10.1080/14484846.2019.1679005.
17. D. D. Milosavljević, T. M. Pavlović, and D. S. Piršl, “Performance analysis of A grid-connected solar PV plant in Niš, republic of Serbia,” Renew. Sustain. Energy Rev., vol. 44, pp.

423–435, 2015, doi: https://doi.org/10.1016/j.rser.2014.12.031.

18. M. Wei, Y. Wen, Q. Meng, S. Zheng, Y. Luo, and K. Liao, "Combined hybrid energy storage system and transmission grid model for peak shaving based on time series operation simulation," Glob. Energy Interconnect., vol. 6, no. 2, pp. 154–165, 2023, doi: 10.1016/j.gloei.2023.04.003.
19. R. Luthander, J. Widén, D. Nilsson, and J. Palm, "Photovoltaic self-consumption in buildings: A review," Mar. 2015, Elsevier Ltd. doi: 10.1016/j.apenergy.2014.12.028.
20. H. Gusmedi and L. Hakim, "Policy Optimization of Residential Rooftop Solar PV System Adoption in Indonesia : Considering Stakeholders," vol. 44, no. 7, 2023, [Online]. Available: https://harbinengineeringjournal.com/index.php/journal/article/view/692/516
21. S. Forrousso et al., "Optimal sizing of off-grid microgrid building-integrated-photovoltaic system with battery for a net zero energy residential building in different climates of Morocco," Results Eng., vol. 22, no. March, p. 102288, 2024, doi: 10.1016/j.rineng.2024.102288.
22. J. López Prol and K. W. Steininger, "Photovoltaic self-consumption is now profitable in Spain: Effects of the new regulation on prosumers' internal rate of return," Energy Policy, vol. 146, Nov. 2020, doi: 10.1016/j.enpol.2020.111793.
23. A. S. Irshad et al., "Optimization of grid-photovoltaic and battery hybrid system with most technically efficient PV technology after the performance analysis," Renew. Energy, vol. 207, no. March, pp. 714–730, 2023, doi: 10.1016/j.renene.2023.03.062.
24. R. J. J. Molu, S. Raoul Dzonde Naoussi, P. Wira, W. F. Mbasso, S. T. Kenfack, and S. Kamel, "Optimization-based energy management system for grid-connected photovoltaic/battery microgrids under uncertainty," Case Stud. Chem. Environ. Eng., vol. 8, no. August, p. 100464, 2023, doi: 10.1016/j.cscee.2023.100464.
25. M. A. A. Abdalla, W. Min, W. Bing, A. M. Ishag, and B. Saleh, "Double-layer home energy management strategy for increasing PV self-consumption and cost reduction through appliances scheduling, EV, and storage," Energy Reports, vol. 10, pp. 3494–3518, 2023, doi: 10.1016/j.egyr.2023.10.019.
26. I. Jamil, H. Lucheng, S. Habib, M. Aurangzeb, E. M. Ahmed, and R. Jamil, "Performance evaluation of solar power plants for excess energy based on energy production," Energy Reports, vol. 9, pp. 1501–1534, 2023, doi: 10.1016/j.egyr.2022.12.081.
27. A. M. Eanes and A. E. Smith, "Optimizing solar capacity for commercial-scale PV systems: An empirical cost-benefit framework for all stakeholders," Sol. Energy, vol. 269, no. January, p. 112323, 2024, doi: 10.1016/j.solener.2024.112323.
28. G. Huang, "Missing data filling method based on linear interpolation and lightgbm," in Journal of Physics: Conference Series, IOP Publishing Ltd, Feb. 2021. doi: 10.1088/1742-6596/1754/1/012187.
29. S. Sarfarazi, S. Sasanpour, and K. K. Cao, "Improving energy system design with optimization models by quantifying the economic granularity gap: The case of prosumer self-consumption in Germany," Energy Reports, vol. 9, pp. 1859–1874, 2023, doi: 10.1016/j.egyr.2022.12.145.
30. L. M. Pastore, G. Lo Basso, G. Ricciardi, and L. de Santoli, "Smart energy systems for renewable energy communities: A comparative analysis of power-to-X strategies for improving energy self-consumption," Energy, vol. 280, 2023, doi: 10.1016/j.energy.2023.128205.
31. P. Herring et al., "BEEP: A Python library for Battery Evaluation and Early Prediction," SoftwareX, vol. 11, p. 100506, 2020, doi: 10.1016/j.softx.2020.100506.
32. Q. Hassan et al., "Collective self-consumption of solar photovoltaic and batteries for a micro-grid energy system," Results Eng., vol. 17, no. January, p. 100925, 2023, doi: 10.1016/j.rineng.2023.100925.