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Optimization of On-Grid Rooftop PV Energy Utilization with Ev Charging Stations in Shopping Centers in West Kalimantan

Rizhal Ade Nugroho, Bambang Priyono
Universitas Indonesia
Email: rizhal.ade@ui.ac.id, bambang.priyono@ui.ac.id

ABSTRACT

The global shift toward renewable energy and electric mobility offers great potential for integrating photovoltaic (PV) systems with electric vehicle charging infrastructure. This study evaluates the feasibility and optimization of on-grid rooftop PV energy utilization with EV charging stations in shopping centers in West Kalimantan through an installation at Gaia Mall in Pontianak. Using HOMER Pro software, three scenarios were analyzed: Mall Only, SPKLU Only (electric vehicle charging stations), and combined Mall + SPKLU. The 1.16 MWp rooftop PV system produces around 1,524,240 kWh annually. The combined scenario emerged as the most optimal, with the lowest Net Present Cost (NPC) of IDR 29.8 billion, the highest Internal Rate of Return (IRR) at 10.3%, and a payback period of about 10 years. In this case, the mall's yearly electricity use of 1,198,868 kWh is fully met. Excess energy of 325,372 kWh can supply about 15 SPKLU, each consuming 20,615 kWh per year. A 10,900 kWh lithium-ion battery storage system enhances supply stability and reliability. Environmentally, this combined system reduces carbon dioxide emissions by more than 1.8 million kilograms annually. The study demonstrates that integrating rooftop PV with EV charging stations is a technically viable, economically attractive, and environmentally sustainable solution aligning with Indonesia's clean energy goals.

KEYWORDS *carbon emissions reduction; HOMER Pro; Internal Rate of Return; Net Present Cost; rooftop solar PV;*

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INTRODUCTION

Climate change and increasingly high greenhouse gas emissions are urgent global issues requiring immediate attention (Filonchyk et al., 2024; Shen et al., 2020). Global GHG emissions reached 53.5 Gt CO2eq in 2020, a figure expected to rise to 62 Gt CO2eq by 2030 if no action is taken . One major effort to address this is the energy transition from fossil fuels to renewable energy (Chapman et al., 2018; Saleh & Hassan, 2024; York & Bell, 2019). The transportation sector is a key focus, with the use of electric vehicles (EVs) considered a promising solution (Aggarwal & Singh, 2025; Kashem et al., 2024). To support EVs, adequate infrastructure such as public electric vehicle charging stations (SPKLU) is essential (Atryomadepa & Putra, 2024; Ramadhan & Wibowo, 2024; Willyanto & Iskandar, 2023). PT PLN (Persero) has deployed SPKLU in various regions, including West Kalimantan, but availability remains limited, hindering EV adoption (Prakoso & Anggarani, 2024). Globally, lack of SPKLU facilities is a main barrier to EV uptake. Meanwhile, renewable energy like solar is growing cheaper, opening opportunities to use solar energy in SPKLU development (Juwana et al., 2024).

The Indonesian government focuses on increasing EV numbers to facilitate energy transition and reduce transport sector carbon emissions (Fathoni et al., 2025; Resosudarmo et al., 2023). Presidential Regulation No. 55 of 2019 targets rapid deployment of Battery-Based Electric Motorized Vehicles (KBLBB), aiming for two million four-wheeled and thirteen million two-wheeled EVs by 2030 (Lesmana, 2025). Policies include fiscal incentives, infrastructure development (SPKLU), and private investment stimulation to reduce dominant fossil fuel consumption in transport, a significant source of national emissions (Rosdiana & Shakira, 2024).

The government also targets constructing about 31,000 SPKLU units by 2030, per the National Energy General Plan (RUEN) and EV roadmap. Adequate SPKLU infrastructure is vital to build public trust and alleviate range anxiety. Policies easing licensing, fiscal incentives, and special tariffs encourage private and state enterprises to develop and manage SPKLU. Collaboration with the private sector promotes even distribution of SPKLU, including high-potential urban areas. Strategically sited SPKLU at shopping centers, offices, and public spaces can significantly boost EV market penetration (Atryomadepa & Putra, 2024). Integrating rooftop solar power plants as renewable sources with SPKLU strengthens EV infrastructure and supports national carbon reduction and clean energy transition goals (Fitriana et al., 2024).

In line with rising EV and SPKLU targets, the government promotes rooftop Solar Power Plants (PLTS) as core renewable energy sources (Juwana et al., 2024). Regulation of the Minister of Energy and Mineral Resources (EMR) No. 26 of 2021 targets 3.6 GWp rooftop solar PV capacity by 2025 to accelerate renewable integration and meet Indonesia's Paris Agreement commitments. Commercial sector rooftops, especially shopping centers, can significantly contribute due to ample roof space and stable energy needs (Akbari et al., 1999). Rooftop solar provides economic benefits via electricity cost savings and environmental benefits through carbon emission reduction, fostering an energy-saving culture and renewable adoption across Indonesian industry and commerce.

West Kalimantan is well-suited for solar energy development, with high sun exposure averaging 2000 hours annually (Central Statistics Agency, 2023). Rooftop PV at SPKLU can lower operational costs and charging fees. The cost of rooftop solar panels has dropped sharply; in 2023, the global average price is 0.8 USD/Wp and expected to fall to 0.5 USD/Wp by 2030 (IRENA, 2023).

This study evaluates the technical and economic feasibility of rooftop solar power at Gaia Mall Pontianak and optimizes its use for mall and SPKLU operations. Simulations via HOMER Pro software aim to identify the optimal system configuration for energy efficiency, cost-effectiveness, and environmental impact. Academically, this research expands knowledge on renewable energy integration in commercial buildings and EV infrastructure in tropical equatorial regions with underutilized solar potential.

METHOD

In this study, the case study is located in the GAIA Mall Pontianak shopping center with Rooftop Solar Power Plants and Public Electric Vehicle Charging Stations (SPKLU) which are located in Pontianak, West Kalimantan.

Figure 1. SPKLU PLN UID West Kalimantan

Some data was obtained by interview methods and literature studies with the following data details:

Table 1. Data collection methods

No	DATA TYPES	
	PRIMARY	SECONDS
1	SPKLU usage data	PLN Electricity Tariff
2	GAIA Mall electricity usage data	SPKLU Tariff
3	SPKLU Specifications	Iridiation of West Kalimantan
4	Specification of ATAP PV	Electricity Profile of PLN West Kalimantan
Method	**Interview**	**Literature Study**

This study used two main data categories: primary and secondary data, both essential to ensure validity and comprehensiveness in the analysis. Primary data were collected directly from the field through interviews and observations. This included data on SPKLU usage, such as the frequency and volume of electric vehicle charging at Gaia Mall, electricity consumption patterns of the mall, and technical specifications of the SPKLU and rooftop solar systems. Collecting this primary data was crucial as it provided an empirical picture of operational and technical conditions on-site, allowing the research to accurately reflect real-world conditions.

Secondary data were obtained from official documents, government reports, and academic literature. These included electricity tariffs from PLN and special SPKLU tariffs for economic calculations, population data of West Kalimantan to provide regional context, and PLN's regional electricity profile detailing infrastructure and system capacity. This secondary data supported the conceptual and regulatory framework of the study and helped clarify market dynamics and policies affecting SPKLU and rooftop solar developments.

Combining primary and secondary data enabled a thorough analysis: primary data captured concrete field facts, while secondary data offered macro-level context and theoretical grounding. The data collection methods, blending interviews and literature review, ensured data integrity and strengthened the reliability of the research findings, contributing meaningfully to renewable energy technology and policy development, particularly concerning SPKLU and solar PV expansion in West Kalimantan.

RESULTS AND DISCUSSION

Location and System Description

1. **Case Study Location**

Gaia Mall Pontianak is located in the center of Pontianak City, West Kalimantan, at coordinates 0°02′24" N and 109°16′25" E. This mall has a total building area of 20,000 m² with a flat roof area of 8,500 m², which will be used for rooftop solar installations. This location is strategic because it is located in a major business district with high potential for the use of solar energy and high community activities that allow for the optimization of electricity consumption.

Figure 2. Gaia Mall Pontianak (Google Maps, 2024)

2. **Specification of Rooftop Solar Power System**

The solar PV system is designed with a total capacity of 1,160 kWp using two types of modules: Trinasolar TSM-DEG19C.20 (550 Wp) and Jinko Solar Tiger Neo N-Type 72HL4-BDV (570 Wp). The main inverters are Huawei SUN2000-100KTL-M1 (100 kVA) and SUN2000-60KTL-M0 (60 kVA). The selection of two types of solar modules aims to increase design flexibility as well as maximize energy production efficiency by considering technical specifications, performance, and availability in the local market.

3. **Module Area and Layout**

Table 2. Rooftop Solar Panel Area

LOCATION	AREA (M2)
BUILDING A	**4080**
CAP 1A	1500
CEILING 2A	1150
CEILING 3A	1300

LOCATION	AREA (M2)
CEILING 4A	130
BUILDING B	**3790**
PARKING 1	755
PARKING 2	855
PARKING 3	590
PARKING 4	1055
CEILING 1B	60
CEILING 2B	45
CEILING 3B	160
CEILING 4B	220
CEILING 5B	50
TOTAL	**7870**

Each Trinasolar module measures 1,742 m × 1,038 m (1,808 m²), and Jinko Solar is 2,384 m × 1,303 m (3,108 m²). Total module area 7,870 m². The module layout takes into account the southern orientation of the equator with a roof tilt of 12° for radiation optimization, which is important to minimize energy loss due to shading and ensure optimal module performance throughout the year.

Climate Data and Solar Potential

1. Solar Radiation Data

Figure 3. Solar radiation of Pontianak (Renewable Ninja, 2023)

The average daily irradiation in Pontianak is 4.5 kWh/m²/day (range 3.3–5.25 kWh/m²/day). This data shows that Pontianak has high solar energy potential, especially because it is located on the equator with a fairly even intensity of solar radiation throughout the year, strongly supporting the development of an efficient rooftop solar system.

2. Solar Energy Production

The production of electrical energy from a rooftop Solar Power Plant (PLTS) system is highly dependent on the installed capacity of the solar panels, the intensity of solar radiation on site, and the overall efficiency of the system. To calculate the estimated electrical energy that can be produced, the nominal capacity parameters of solar power plants (in kilowatt peak, kWp), average daily solar radiation (kWh/m²/day) are used.

Load Profile

1. Mall Operational Load

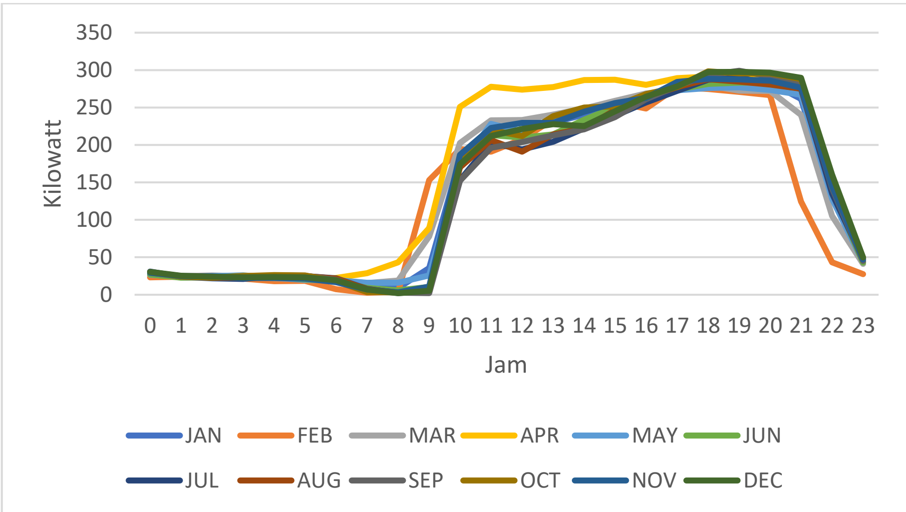
The average load of the mall is 2,400 kWh/day (876,000 kWh/year), the peak of 18:00–20:00 reaches 35–40 kW, and the base load is 6–8 kW. This profile reflects the mall's busy operational activities from afternoon to night, in line with the pattern of consumer visits, so energy supply planning from solar PV needs to take into account this peak time optimally.

Based on Gaia Mall's smart meter data at 1-hour intervals, daily consumption is divided into four phases: morning ramp-up (06:00–10:00), midday plateau (10:00–16:00), evening peak (16:00–22:00), and night base (22:00–06:00). The average daily load is 2,400 kWh, with a daily peak of 40 kW at 18–20:00 and a minimum load of 6 kW in the early morning.

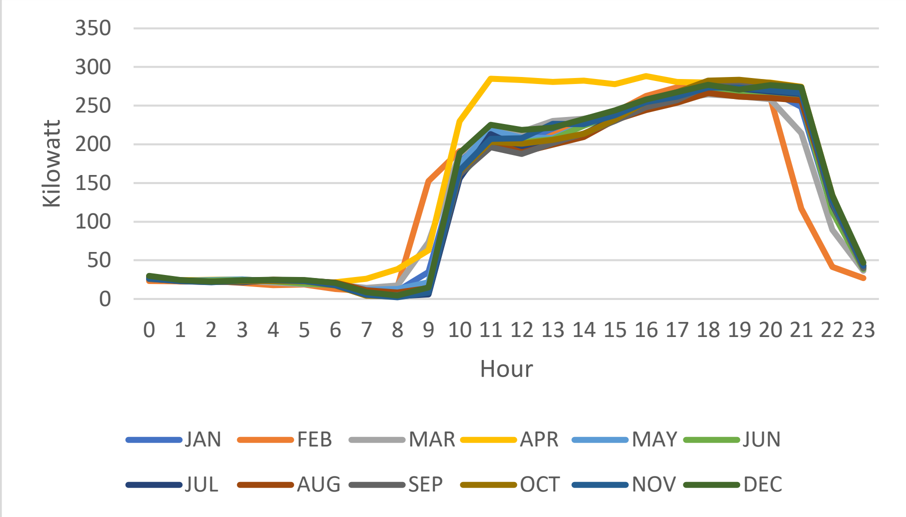
Table 3. Gaia Mall Daily Load Profile

Daily Phase	Hour	Average Load (kW)	Time Proportion (%)
Morning Ramp-Up	06–10	10–25	17
Midday Plateau	10–16	25–35	25
Evening Peak	16–22	35–40	25
Night Base	22–06	6–10	33

From the table above, it can be seen that 50% of the daily load occurs in the range of 10:00–22:00, according to the mall's operating hours. This profile is perfect for direct absorption of solar energy during the day.



Gambar 4. Profile beban weekend Gaia Mall



Gambar 5. Profile beban weekday Gaia Mall

The monthly load profile of Gaia Mall's electricity load in 2024 shows dynamic consumption patterns and is influenced by seasonal factors and socio-cultural activities. In general, the electrical load begins to increase significantly in the morning around 9 a.m. and peaks between 5 and 8 p.m., with a typical difference in consumption intensity between weekdays and weekends. When analyzed in more depth per month, it was found that April 2024 experienced a significant increase in energy consumption compared to other months.

The increase in electricity consumption in April is very likely influenced by the moment of Eid al-Fitr, which in the context of Indonesian culture is one of the periods with very high social and economic activity. During this period, the mall experienced a significant surge in visitors due to Eid preparations and celebrations, including a drastic increase in shopping activities. In addition, special events, promotions, and extended mall operations during this period contributed to the increase in electricity usage, especially in lighting, cooling, and electronic equipment that operated for longer.

This phenomenon is reflected in both the weekend and weekdays load profile graphs, where April shows consistently higher peak loads throughout operating hours than other months. Although national holidays usually have the potential to reduce operational activities, the commercial nature of malls and the high mobility of people during Eid al-Fitr actually increase the demand for electrical energy significantly.

In addition to April, the variation in monthly expenses tends to be stable with more moderate increases in other months related to the year-end holiday season, such as December. The difference in load between weekends and weekdays remained consistent throughout the year, with weekends showing higher consumption due to increased visitor activity.

2. SPKLU Load

The SPKLU load profile shows an average of 50 kWh/day (18,250 kWh/year), peaks of 09:00–12:00 and 16:00–19:00 of 10–15 kW. This load reflects the increasing need for electric vehicle charging in line with the hours of economic activity of the community around the mall, emphasizing the importance of integrating solar PV with energy storage systems to manage the surge in SPKLU loads.

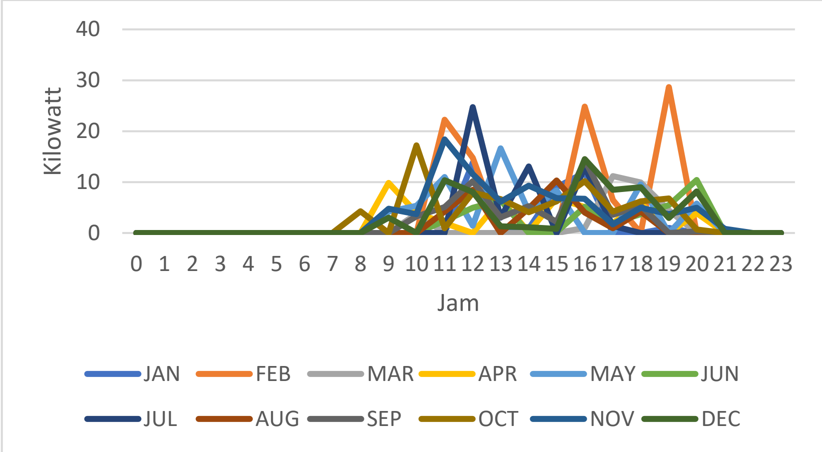


Figure 6. Profile of SPKLU weekend load (Kilowatts)

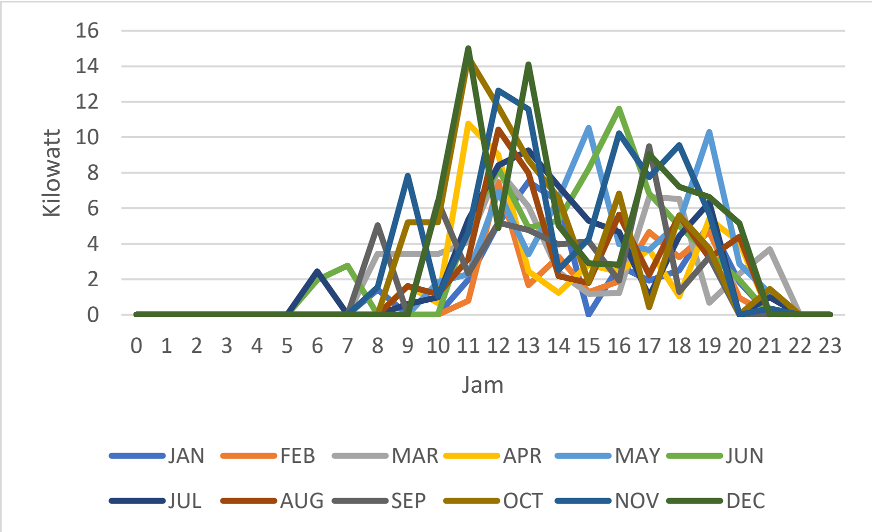


Figure 7. Profile of SPKLU weekday load (Kilowatts)

Electricity load at SPKLU showed a significant increase in the afternoon to evening hours, which is in line with the pattern of more intensive electric vehicle charging activities in that period. This can be interpreted as a reflection of the habits of EV users who take advantage of working hours or after hours to charge, so that peak loads occur in the time range around 10 am to 7 pm.

Load Factor

Load Factor (LF)

$$LF = \frac{\text{Average Energy (Annual)}}{\text{Peak load x 8760}} = \frac{\text{8760 Kwh}}{\text{40 kW x 8760 h}} = 0{,}25 \;= 25\%$$

The LF ≈ 25% indicates that only a quarter of peak capacity is used on average. Indicates the existence of energy storage opportunities during the daytime surplus for afternoon peak loads.

Simulation Models in HOMER Pro

In this simulation, three main scenarios were tested. The first scenario is "Mall Only", where all solar PV production is fully allocated to meet the mall's operational energy needs.

The second scenario, namely "SPKLU Only", prioritizes the production of solar PV to meet the needs of SPKLU. Meanwhile, the third scenario called "SPKLU+Mall" prioritizes meeting SPKLU needs first, with the excess energy generated then used for the mall's energy needs. The main parameters used in this simulation include a solar power plant capacity of 1,160 kWp, a Performance Ratio (PR) of 0.80, and the option to use a storage battery with a capacity of 60 kWh. The grid electricity tariff used as a reference is Rp 1,114.74 per kWh, with a discount rate of 8% and the system life is assumed to be 25 years. This arrangement was chosen to reflect realistic operational conditions and relevant to electricity tariff policies and long-term investment planning.

1) Scenario Mall Only

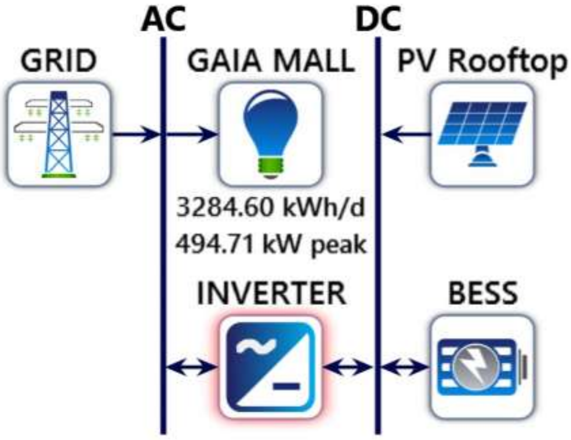


Figure 8. Mall Only Scheme

The HOMER simulation image shown in the "Mall Only" scenario depicts a hybrid energy system that integrates a rooftop solar power source with a specific capacity that generates energy in the form of direct current (DC), which is then converted by the inverter into alternating current (AC) to meet the electricity needs of Gaia Mall. In this scenario, the energy generated by rooftop PV is exclusively allocated to meet the mall's electricity consumption, with a daily consumption value of 3,284.60 kWh and a peak load of 494.71 kW. The system also involves the option of using a Battery Energy Storage System (BESS) which functions as an energy store to accommodate fluctuations in production and consumption, thereby improving the reliability and stability of the electricity supply. The entire energy distribution process is also connected to the main power grid (GRID) as a backup source when solar PV production and battery capacity are insufficient. This scenario approach aims to optimize the use of renewable energy from rooftop PV for internal mall consumption, reduce dependence on conventional power grids, and improve the efficiency and sustainability of overall mall energy operations.

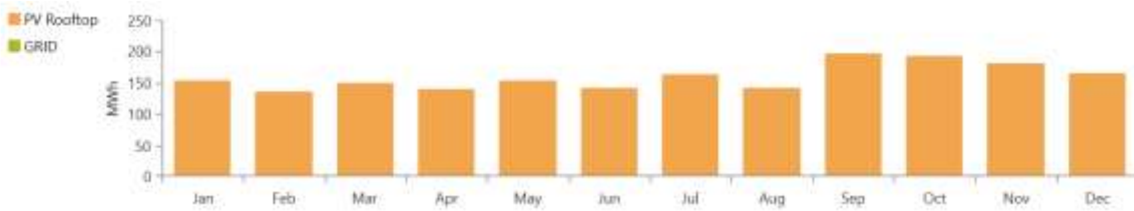


Figure 9. Monthly electricity production of the Mall Only scenario

Based on the results of HOMER modeling on the "Mall Only" scenario for Gaia Mall Pontianak, the system uses rooftop solar power and is supported by a generic Lithium-Ion battery storage system of 12,600 kWh (126 strings of 100 kWh batteries), this system is designed to meet the mall's electricity needs independently by utilizing solar energy from rooftop solar PV.

This system also succeeded in reducing CO2 emissions by 1,825,893 kg/year and eliminating fossil fuel consumption. In terms of meeting electricity needs, the system is able to consume 1,198,868 kWh for the main load of the mall. The inverter's operation for 8,760 hours per year with a capacity factor of 28.3% demonstrates the reliability of energy conversion. The battery autonomy reaches 73.7 hours with a nominal effective use capacity of 10,080 kWh.

Overall, this system shows optimal technical and economic performance to provide the mall's electricity needs independently with renewable energy sources. This model offers a sustainable solution with reduced carbon emissions and dependence on fossil energy, as well as providing cost efficiency through the integration of suitable storage and inverter technologies. These results form a solid foundation for the development of hybrid energy systems in other commercial centers that prioritize sustainability and energy efficiency.

2) SPKLU Only Scenario

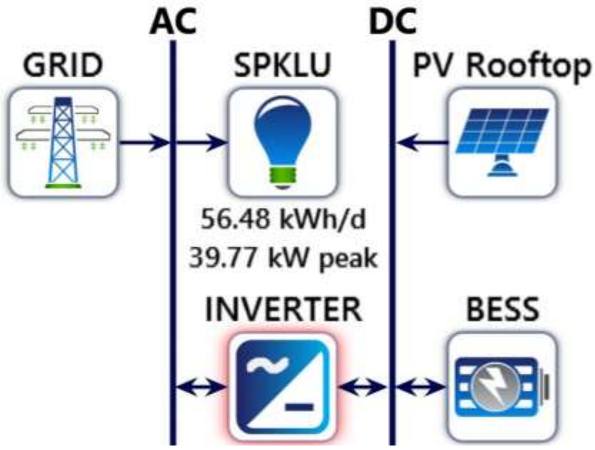


Figure 10. SPKLU Only Scheme

In the "SPKLU Only" scenario, the configuration of the energy system consists of a rooftop photovoltaic module, a battery energy storage system (BESS), an inverter, and a connection to the main power grid (GRID) to meet the electricity needs of the Public Electric Vehicle Charging Station (SPKLU). In this scenario, the energy generated by rooftop PV in the form of direct current (DC) is converted through the inverter into alternating current (AC) to supply the SPKLU's electrical load with a daily consumption of 56.48 kWh and a peak load of around 39.77 kW. Energy storage systems serve as a buffer to manage fluctuations in supply and demand, ensuring continuity of electricity supply especially when solar production decreases, such as at night or less favorable weather conditions. Integration with the main power grid allows for backup supply when renewable energy and battery capacity are insufficient. This model displays an optimal approach in the utilization of renewable energy sources and storage for SPKLU needs, while supporting clean energy transition strategies and carbon emission reduction in the electric transportation sector.

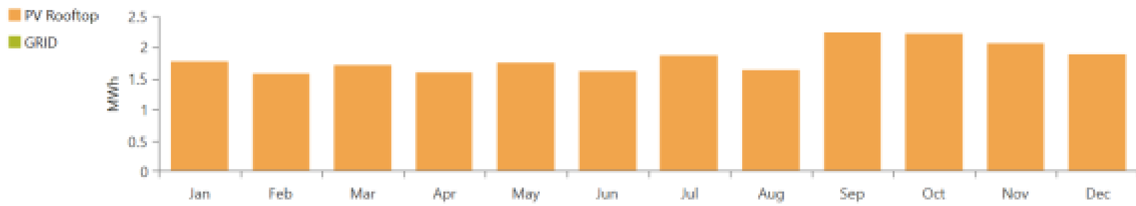


Figure 11. Monthly electricity production in the SPKLU Only scenario

Based on the results of HOMER modeling for the SPKLU Only scenario, the system uses rooftop solar power with a capacity of 80.3 kW and a generic Lithium-Ion battery with a nominal capacity of 2,400 kWh (consisting of 24 strings of 100 kWh batteries). The annual electricity consumption from the SPKLU load is 20,615 kWh.

The system is able to eliminate carbon emissions of 31,397 kg of CO2 per year, signifying the full use of renewable energy without direct emissions. The inverter is operated for 4,063 hours per year with an average output capacity of 2.43 kW and a maximum capacity of 39.8 kW indicating the efficient utilization of the energy produced. The battery autonomy reaches 816 hours, which is enough to stabilize the energy supply under varying conditions of production and consumption.

3) Mall + SPKLU Scenario

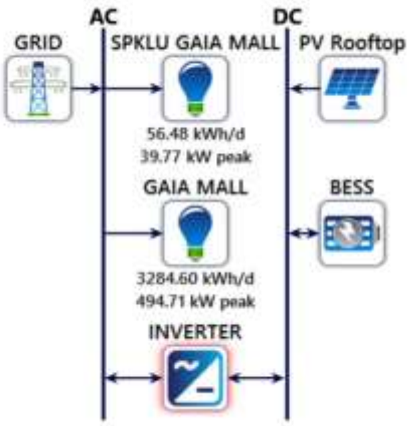


Figure 12. Mall+SPKLU Scheme

The energy system simulation in the Mall + SPKLU scenario illustrates the integration of renewable energy sources, energy storage, and conventional power grids in meeting the electricity needs of two main loads, namely Gaia Mall and Public Electric Vehicle Charging Stations (SPKLU). The system uses solar panels (rooftop PV) as the main energy source that generates electrical energy in the form of direct current (DC). This energy is then converted by the inverter into alternating current (AC) which is then distributed separately to the SPKLU and Gaia Mall loads.

In terms of consumption, SPKLU has a daily energy requirement of 56.48 kWh with a peak load of around 39.77 kW, while Gaia Mall has a much greater need, namely 3,284.60 kWh per day with a peak load of 494.71 kW. This difference in scale demonstrates the complexity of the energy management required for both loads to be optimally met.

Battery Energy Storage Systems (BESS) play an important role in storing excess energy production from rooftop PV and providing backup when load requirements exceed instant energy production, especially at night or adverse weather conditions that reduce the output of solar panels. BESS also helps maintain system stability and the quality of power supplied.

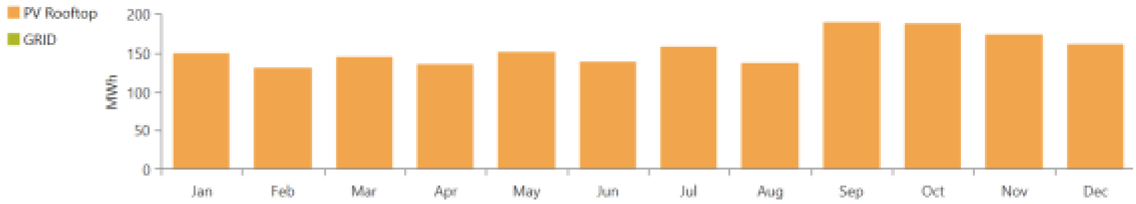


Figure 13. Monthly electricity production in the SPKLU Only scenario

The Mall + SPKLU scenario utilizes rooftop solar power plants and an energy storage system in the form of a generic Lithium-Ion battery with a nominal capacity of 10,900 kWh (109 strings of 100 kWh batteries) providing a large storage capacity with an autonomy of about 62.6 hours, allowing balancing energy supply and load demand during periods of production fluctuations.

The system also managed to reduce CO2 emissions by 1,857,290 kg/year and eliminate fossil fuel consumption. Of the total energy produced, 1,219,494 kWh is used directly to meet the load needs of the air conditioner. indicates that there is a surplus of optimal energy production that can be utilized.

4) Calculation of the number of SPKLU

$$\text{Total SPKLU} = \frac{\text{Energy Surplus}}{\text{Energy per SPKLU per year}} = \frac{325.372}{20.615} = 15{,}78 = 15$$

With a total rooftop solar PV production of 1,524,240 kWh and mall consumption of 1,198,868 kWh per year, the available energy surplus is around 325,372 kWh per year. This surplus can be used to operate around 15 SPKLU units with an average energy consumption of 20,615 kWh per year per SPKLU unit. This shows significant potential in the utilization of surplus energy from rooftop solar power plants to expand electric vehicle charging infrastructure efficiently and sustainably.

5) Payback Period

a. Skenario 1 – Mall Only

In this scenario, the entire Mall load (1,198,868 kWh/year) is converted into mall electricity cost savings multiplied by the electricity tariff of IDR 1,114.74 / Kwh to get IDR 1,336,426,114 per year. With a total investment in solar panels and inverters of IDR 22,000,000,000 plus a 12,600 Kwh battery of IDR 1,738,800,000, then

$$\text{PBP}_{\text{Mall}} = \frac{22.000.000.000 + 1.738.800.000}{1.336.426.114} = 17{,}76 \text{ tahun}$$

The payback period of around 17.76 years is relatively competitive in the retail industry considering the technical life of the module >25 years.

b. Scenario 2 – SPKLU Only

This scenario generates revenue of IDR 50,857,205 per year (20,615 kWh × IDR 2,467) With a total investment in solar panels and inverters of IDR 22,000,000,000 plus a 2,400 Kwh battery of IDR 331,200,000 and SPKLU investment costs of IDR 32,000,000,

$$\mathrm{PBP_{SPKLU}} = \frac{22{,}000{,}000{,}000 + 331.200.000 + 32.000.000}{50.857.205} = 439.72 \text{ tahun}$$

The payback period passes the lifetime of the asset so this scenario is considered unfeasible. This confirms that the SPKLU load (56.48 kWh/day) is too small to absorb the capacity of 1,160 kWp of solar PV.

c. Scenario 3 –SPKLU+Mall

This scenario generates revenue of IDR 50,857,205 per year (20,615 kWh × IDR 2,467) and savings of IDR 1,336,426,114 With a total investment in solar panels and inverters of IDR 22,000,000,000 plus a 10,600 Kwh battery of IDR 1,462,800,000 and SPKLU investment costs of IDR 32,000,000, then:

$$\mathrm{PBP_{Mix}} = \frac{22{,}000{,}000{,}000 + 1.462.800.000 + 32.000.000}{1.336.426.114 + 50.857.205} = 16 \text{ tahun}$$

Less (1 year) than the mall scenario alone, while adding new revenue streams from SPKLU. This result shows a small but crucial optimization with a 2% increase in revenue without sacrificing the needs of the mall.

6) NPC dan IRR

Table 4. Comparison of NPCs and IRRs

Scenarios	NPC (Rp)	IRR (%)
Mall Only	IDR 34,500,000,000	8,5%
SPKLU Only	IDR 32,000,000,000	0,07%
SPKLU + Mall	IDR 29,800,000,000	10,3%

The Net Present Cost (NPC) and Internal Rate of Return (IRR) values in the three scenarios of rooftop solar energy utilization at Gaia Mall and SPKLU show significant differences that reflect the efficiency and profitability of the investment. In the Mall Only scenario, the highest NPC indicates a relatively large investment and operational cost burden, while a lower IRR indicates a slower rate of return on investment than in other scenarios. In contrast, the SPKLU Only scenario shows lower NPCs and IRRs that are close to zero, suggesting that this scenario is uneconomical if it relies only on such small revenues. The SPKLU + Mall combination scenario provides the most optimal results with the lowest NPC and highest IRR, indicating that the integration of the two loads is able to maximize the use of solar energy, reduce total costs, and accelerate the return on capital period. This analysis confirms that the simultaneous load management strategy and utilization of surplus energy not only increases the economic value of the project, but also strengthens financial sustainability in the development of renewable energy systems in the commercial and electric transportation sectors.

CONCLUSION

Modeling and economic analysis of rooftop solar power at Gaia Mall Pontianak across three scenarios showed the combined Mall + SPKLU scenario as most optimal. This system, with 1.16 MWp capacity, generated 1,854,152 kWh annually—meeting mall demand and supporting public electric vehicle charging stations (SPKLU). It achieved the highest internal rate of return (10.3%), lowest net present cost (IDR 29.8 billion), and the shortest payback period (16 years), while eliminating approximately 1.86 million kg of CO_2 per year. The Mall Only scenario was feasible but less efficient, with higher cost and a longer payback. The SPKLU Only scenario proved economically unviable due to excessive payback time. The combined integration enhanced energy use efficiency and provided strong economic and environmental benefits. Future research could explore scalability of this integrated system in diverse urban settings, incorporating real-time demand response and advanced battery management to further optimize performance and cost-effectiveness.

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