Integration of renewable energy for sustainable electric vehicle charging in Sidoarjo, Indonesia: a techno-economic perspective

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ABSTRACT

This study explores the techno-economic feasibility of integrating solar photovoltaic (PV) systems for electric vehicle (EV) charging infrastructure in Sidoarjo, Indonesia. Through simulation using HOMER Pro software, both standalone PV and PV-grid hybrid configurations were evaluated under real-world EV load profiles. The analysis reveals that the PV-grid hybrid system demonstrates superior economic performance, achieving an annual energy production of 39,214 kWh, a levelized cost of energy (LCOE) of $0.3975/kWh, and a return on investment (ROI) of 62.01% over 20 years, despite a payback period exceeding 30 years. Sensitivity analysis confirms that the system remains moderately resilient under a 10% reduction in solar irradiance or a 20% increase in EV demand. The study also compares the standalone PV configuration, which, while suitable for off-grid applications, results in significant energy underutilization. Moreover, the PV-grid model supports surplus electricity sales, enhancing financial viability. These findings provide actionable insights for stakeholders, energy planners, and policymakers aiming to scale EV charging infrastructure sustainably in Indonesia's urban environments.

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1. INTRODUCTION

The rapid adoption of electric vehicles (EVs) in Indonesia is part of a broader initiative to reduce dependence on fossil fuels and minimize greenhouse gas emissions. Through Presidential Regulation No. 55 of 2019, the Indonesian government aims to accelerate the transition to cleaner energy by promoting battery-powered EVs for road transportation [1]-[3]. As a result, the use of EVs has steadily increased, according to Setiawan *et al.* [4]. The percentage of EV usage in Indonesia grew from 0.08% in 2018 to 0.36% in 2021, demonstrating a positive trend in adoption—furthermore, Veza *et al.* [5] by 2030, approximately 7.46 million EVs will operate nationwide, significantly increasing the demand for reliable and sufficient energy sources to support EV infrastructure.

Despite this positive growth, one of the significant challenges hindering large-scale EV adoption is the limited availability and uneven distribution of charging infrastructure [6], [7]. The State Electricity Company (PLN) has made substantial efforts to expand charging facilities across the country. As of the first semester of

2024, 1,582 public EV charging stations (SPKLU) are across 1,131 locations. However, most of these stations are concentrated in urban areas, leaving rural and remote regions underserved [8], [9]. Without accessible charging infrastructure, widespread EV adoption may be delayed, affecting the overall success of Indonesia's clean energy transition [10], [11].

One potential solution to address this challenge is the integration of renewable energy sources, particularly solar photovoltaic systems [12], [13]. As a tropical country, Indonesia receives an average solar radiation intensity of 4.8 kWh/m² per day, making it an ideal renewable energy source for EV charging stations [14], [15]. The use of solar-powered charging stations offers multiple advantages, including reduced dependence on conventional power grids, lower carbon emissions, enhanced energy security, and improved resilience against fluctuations in grid demand [16], [17]. However, deploying solar-based EV charging infrastructure on a large scale presents several technical and financial challenges that require a comprehensive feasibility analysis [18], [19].

This study proposes a techno-economic assessment of solar-powered EV charging stations, focusing on identifying the most cost-effective and efficient system configuration [20], [21]. Using HOMER Pro simulation software, this research explores various hybrid energy system scenarios, integrating PLTS, energy storage (batteries), and grid connections to optimize system performance [22], [23]. The novelty of this study lies in its systematic evaluation of solar-based EV charging infrastructure, considering both economic viability and technical reliability, to support the expansion of EV adoption in Indonesia [24], [25]. Table 1 summarizes recent studies on renewable energy integration for EV charging, including methods, results, and future research.

This research contributes to developing a more resilient EV ecosystem by addressing the current gap in charging infrastructure through a sustainable and scalable solution. The findings are expected to provide valuable insights for policymakers, energy providers, and infrastructure developers, enabling Indonesia's more efficient, cost-effective, and environmentally friendly transition toward clean energy mobility. The novelty of this study strengthens that contribution by presenting a techno-economic evaluation that directly compares standalone photovoltaic (PV) and PV-grid hybrid systems within the same Indonesian context, using real-world EV load profiles. Unlike previous studies that assess levelized cost of energy (LCOE) or net present cost (NPC) in isolation, this research integrates performance comparisons under variable irradiance and load conditions, offering a more comprehensive perspective on investment feasibility. As such, the outcomes are relevant to advancing infrastructure design and serve as practical guidance for local policymakers and developers in optimizing system sizing with greater financial and operational realism, particularly for deployment in semi-urban areas.

Table 1. State of the art

No	Method	Novelty	Result	Future research	Reference
1	Simulation with HOMER Pro	Economic and environmental impact analysis of an 11 kW PV system	NPC: $40,452, LCOE: $0.148/kWh	Battery integration and policy evaluation for increased PV adoption	[26]
2	Simulation with HOMER Pro for PV-Biomass	Economic and environmental evaluation of a hybrid system in Bangladesh	NPC: $4,712,218, LCOE: $0.0347/kWh	Model development for educational institutions and renewable energy policy integration	[27]
3	Simulation with PVsyst and HOMER Pro	Optimization and feasibility analysis of a rooftop PV system in Magelang	NPC: Rp2,010,979,043.89, LCOE: Rp673.09/kWh	Further study on various inverter configurations and energy storage integration	[28]
4	Simulation with HOMER Pro	Technical and economic analysis of a PV system in an elementary school in Laguna, Philippines	NPC: Php5,898,483, LCOE: Php6.94/kWh	Net metering benefits evaluation and impact assessment of larger-scale battery integration	[29]
5	Optimization of a microgrid system with EVCS using HOMER grid	Identification of the optimal scenario among seven resource-based scenarios	NPC: $1.62 million, LCOE: $0.0549/kWh	Implementation of an integrated system to achieve net-zero emissions and support the Green Deal policy	[30]
6	Simulation with HOMER Pro	Design and economic analysis of an on-grid PV system for an EV charging station in Karanganyar	NPC: Rp 187,599,296.61, LCOE: Rp 17,085/kWh	Large-scale development and system optimization to enhance energy efficiency and profitability	[31]

2. METHOD
2.1. Research methodology

Before designing a solar-powered EV charging station, it is essential to structure the research steps in a flowchart, as shown in Figure 1. The research begins with problem identification, followed by data collection on solar irradiation at the study location and the design of the system. Next, a preliminary analysis using HOMER Pro is conducted to estimate the required electrical load [32]. A simulation is then performed to obtain calculations on total electricity production and consumption, NPC, and LCOE [33]. HOMER Pro is a software developed by the National Renewable Energy Laboratory (NREL) to assist in modeling and evaluating renewable energy systems, both grid-connected (on-grid) and standalone (off-grid) [34]. The optimization algorithm tools compare different system configuration parameters from both technical and economic aspects [35], [36]. In this research study, HOMER Pro is used to analyze the economic feasibility of solar energy as a source of power for EV stations [37]. The analyses consist of NPC and LCOE values regarding the potential solar irradiation available to meet the required power demand [38]. The final system configuration will be selected based on simulation results, but is primarily dependent on NPC value criteria [39].

2.2. Site selection for PLTS charging station

The selected site for this PLTS charging station for EVs is at Rangkah Kidul, Sidoarjo District, Sidoarjo Regency, East Java. This location was chosen due to its relatively high population density, which is expected to support the growing demand for electric vehicle infrastructure through a solar-powered charging solution. Furthermore, Sidoarjo Regency is experiencing continuous development, particularly in the transportation and energy sectors, making it a strong candidate as a model for similar implementations elsewhere. Its strategic position also enables the local community and government to explore renewable energy opportunities further. To strengthen the feasibility of this site, solar resource availability was assessed using meteorological data from BMKG and the NASA-SSE database, which indicates that the region receives an average daily solar radiation of 4.8 to 5.2 kWh/m²/day throughout the year. These favorable irradiance conditions justify the suitability of the location for PV deployment and serve as the basis for simulation inputs in HOMER Pro, as illustrated in Figure 2.

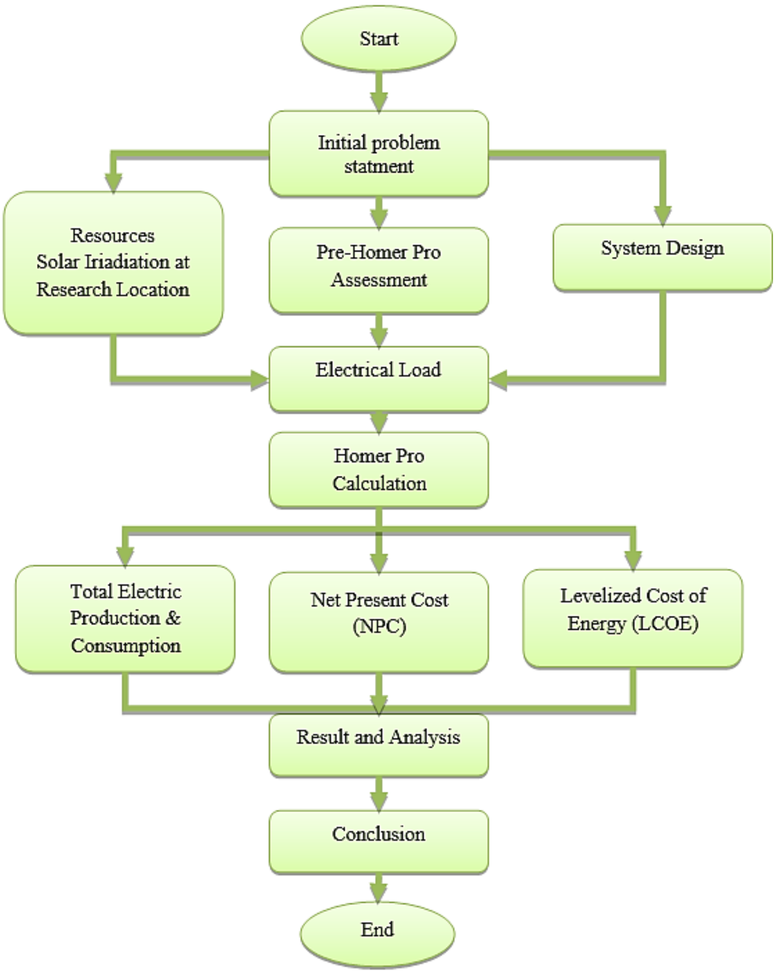

Figure 1. Flowchart of research process

Figure 2. Location of the PLTS charging station

3. RESULTS AND DISCUSSION

3.1. PV system (PLTS) design for EV charging station

To propose an appropriate PLTS system at home, an understanding of the daily energy use of an electric vehicle is essential. Hence, Table 2 gives the daily electricity consumption of the car. At the same time, Figure 3 shows the variation of power consumption of an EV over the 24 hours, marking the peak and off-peak demand periods.

Table 2. Daily EV charging and consumption

Vehicle	Hyundai Ioniq 5	Tesla Model 3
Battery (Wh)	58,000	75,000
Distance (km)	384	450
Cas power consumption (Wh)	7200	8500
Charging time (hours)	8	6
Distance traveled in 1 day (m)	50	60
Cas power consumption (Wh)	7500	8700

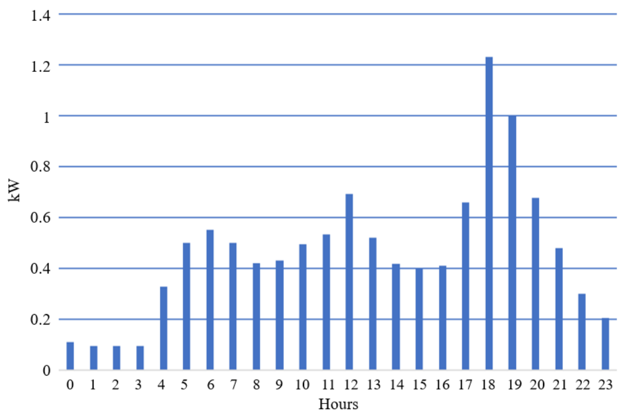

Figure 3. Load profile of EV charging station

Referring to the data in Figure 3, the overall energy consumption within 24 hours is 11.26 kWh. Throughout the daytime (07:00–17:00), the recorded energy usage is 4.812 kWh, whereas during the nighttime (17:00–07:00), it rises to 6.323 kWh. With a 30% increase in load, the revised energy requirement is determined accordingly.

$$Daytime\ energy = 4.812\ kWh \times 130\% = 6.26\ kWh$$
$$Night\ energy = 6.323\ kWh \times 130\% = 8.22\ kWh$$
$$Daily\ energy = 6.26 + 8.22 = 14.48\ kWh \quad (1)$$

System losses must also be considered when determining the total energy required for the electricity requirements of the charging station, since they will affect the overall energy supply. Losses commonly occur in a PV charging station, including environmental conditions, individual components' efficiency, and the entire system's design. Good cables can minimize losses; even shading on solar panels should be minimized, along with regular system maintenance. Besides, energy generation could be further enhanced by incorporating a solar tracking system, which would further strengthen energy generation by optimizing the orientation of the PV panel throughout the day. The various losses within the system are given in Table 3.

Table 3. System losses

Type of losses	Percentage (%)
PV module	11.5
Network inverter	3
Battery inverter	6
Wiring	2
Battery	15
Total loss at night	37.5
Total loss during the day	22.5

Most energy dissipation occurring during the day and at night is due to battery loss. Nighttime energy dissipation also involves battery inefficiencies, as the charging station works only by the stored power without PV support [40]. After losses have been determined. The system computes the total energy required from the modules; the calculation for total module energy is shown (2).

$$Total\ module\ energy = \frac{Night\ energy}{100\% - (night\ loss)} + \frac{Day\ energy}{100\% - (day\ loss)}$$
$$Total\ module\ energy = \frac{8.22}{62.5\%} + \frac{6.26}{77.5\%}$$
$$Total\ module\ energy = 21.23\ kWh \quad (2)$$

Based on the calculations, the total energy the solar modules need to generate to fulfill the required electricity demand is 21.23 kWh. Once this energy requirement is determined, the next step is calculating the necessary number of PV panels. PV panels consist of interconnected solar modules that transform sunlight into electrical power. The amount of electricity produced by the solar panel module can be estimated using the following formula without considering the impact of temperature on PV performance [41].

$$P_{PV} = F_{pv} \times Y_{pv}\ \frac{G_T}{G_{T,STC}} \quad (3)$$

Where,

P_{PV}: Power produced by the PV model (kW)
F_{pv}: PV performance reduction factor
Y_{pv}: Power output of PV at standard conditions (kW)
G_T: Instantaneous solar irradiance on the PV module surface (kW/m²)
$G_{T,STC}$: Instantaneous solar irradiance at standard conditions (1 kW/m²)

The next step is determining the necessary PV capacity to fulfill the module's energy requirements. In this solar power system, the installed PV has a capacity of 24,000 W.

$$PV\ amount = \frac{21.23}{24} = 0.88 = 1\ PV \quad (4)$$

Based on the previous calculations, supplying an electricity demand of 21,260 W with a PV system rated at 24,000 W requires a single PV unit. In the HOMER simulation, the selected PV model is the solar panel Fronius Symo 24.0-3-M with a generic PV, priced at $8,000 per unit, with annual operation and maintenance costs of $60, based on the product specification sheet from Fronius (Fronius Symo 24.0-3-M datasheet, 2024) and verified through official distributor pricing available on the Fronius International website (accessed March 2025). The specifications of the PV panel are presented in Table 4, while its visual representation is provided in Figure 4 [42], [43].

Table 4. Technical specifications of system components

Item	Specification	Value
Fronius Symo 24.0-3-M with generic PV	Rate capacity	24,000 W
	Temperature coefficient	-0.4100
	Operating temperature	45 °C
	Efficiency	17.30%
	Dc input	30 kW
Fronius Symo 24.0-3 480	Ac output	24,000 W
	Maximum efficiency	97.5%
	Capacity	24 kW
EnerSys PowerSafe SBS 1800	Voltage	12 V
	Nominal capacity	24.8 kWh
	Maximum capacity	2060 Ah
	Capacity ratio	0.298
	Roundtrip efficiency	97%
	Maximum charge current	1800 A
	Maximum discharge current	2300 A
	Maximum charge rate	1 A/Ah

Figure 4. Fronius Symo 24.0-3-M with generic PV module [42]

After deciding on the quantity of PV modules, the next step is determining the proper power rating and number of inverters. The inverter converts the direct current (DC) from the PV array into alternating current (AC) at either 50 Hz or 60 Hz. The formula for calculating the number of inverters required would thus be (5).

$$Inverter\ amount = \frac{14480 \times 125\%}{24000} = 0.75 = 1\ inverter \quad (5)$$

Thus, the demand for inverters is rated at 24,000 W and stands at one unit. The inverter modeled in the HOMER simulations is a Fronius Symo 24.0-3 480 inverter, which costs $3,000 and has an annual operation and maintenance cost of $60 per year, sourced from Fronius Symo 24.0-3 480 inverter documentation (Fronius, 2024) and verified through online retailer quotations and official distributor websites (accessed March 2025). Specifications for the selected inverter are provided in Table 4, and a picture of it is given in Figure 5 [44].

After selecting the inverter, the next step is determining the appropriate battery. Batteries function as energy storage, allowing the system to operate continuously, including during nighttime hours when solar power is unavailable. The method for calculating the required number of batteries, assuming each unit has a capacity of 24.8 kWh, is as (6).

$$Battery\ amount = \frac{14480}{24800 \times 80\%} = 0.73 = 1\ battery \quad (6)$$

According to the calculations, just one battery with a capacity of 24.8 kWh is required to meet the household's electricity demand. The battery model used in the HOMER simulation is EnerSys PowerSafe SBS 1800. The battery model used in the HOMER simulation is EnerSys PowerSafe SBS 1800, available at the market price of $1,223, based on technical datasheets published by EnerSys (PowerSafe SBS Series, 2024) and confirmed through EnerSys-authorized distributor pricing (accessed March 2025). The detailed specifications of the selected battery are presented in Table 4, while its graphical representation is shown in Figure 6 [45]. The system simulation is performed using HOMER software, incorporating the components that have been analyzed and chosen earlier. The layout of the on-grid PLTS setup within the HOMER software is presented in Figure 7.

Figure 5. Fronius Symo 24.0-3 480 [44]

Figure 6. EnerSys PowerSafe SBS 1800 [45]

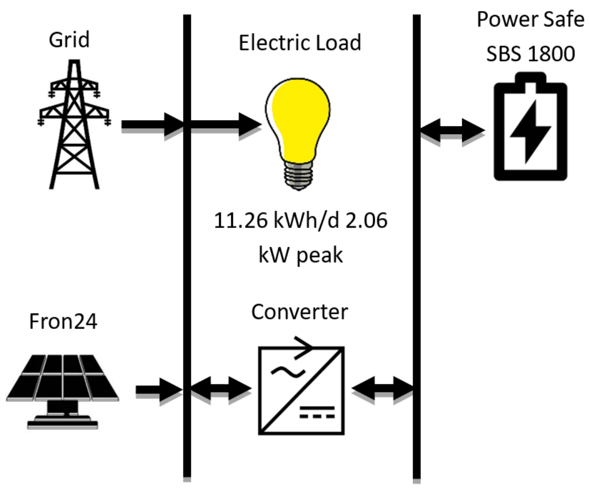

Figure 7. Schematic of the on-grid PLTS system

3.2. Analysis result

3.2.1. Electrical production and electrical consumption

This section discusses the balance between electricity production and consumption in the PV system used to support the operation of the EV charging station. This analysis is crucial to understanding the extent to which the generated energy can meet the load demand and the potential surplus that can be utilized. Table 5 presents the PV system's total electricity production, while Table 6 illustrates the yearly electricity consumption from various connected loads. Meanwhile, Figure 8 shows the monthly electricity output, with PV production consistently exceeding the system's consumption. It is also evident that in the PV-grid configuration, excess electricity accounting for 90% of the total was successfully sold to the grid, significantly enhancing economic viability. Furthermore, the PV-grid system benefits from the ability to import electricity during low solar periods, minimizing power interruptions. On the other hand, although producing the same amount of electricity annually (39,214 kWh), the standalone PV system lacks such flexibility and thus has no grid interaction for surplus or deficit balancing.

A comparison between the PV-grid and standalone PV systems reveals notable differences in energy utilization and system performance. While both systems generate equal annual energy (39,214 kWh), only the PV-grid setup can export surplus electricity (37,113 kWh), converting unused energy into financial returns. In contrast, the standalone PV system consumes only what it produces for the AC primary load (4,109 kWh), leaving the remaining energy underutilized due to the absence of storage or grid interaction. Additionally, the PV-grid system maintains operational resilience by purchasing 1,991 kWh from the grid when solar production is insufficient, whereas the standalone system risks unmet loads without over-dimensioned batteries. Figure 9 supports these findings by illustrating smoother energy availability throughout the year in the PV-grid case, compared to a less adaptive standalone setup. Thus, the PV-grid system offers superior performance not only in energy flexibility and reliability but also in enhancing long-term economic benefits through active grid participation.

Table 5. Electrical production

System type	Production	kWh/years	%
PV-grid	Fronius Symo 24.0-3-M with generic PV	39,214	95.2
	Grid Purchases	1,991	4.83
	Total	41,205	100
Standalone PV	Fronius Symo 24.0-3-M with generic PV	39,214	100
	Total	39,214	100

Table 6. Electrical consumption

System type	Consumption	kWh/years	%
PV-grid	AC primary load	4,109	10
	DC primary load	0	0
	Deferrable load	0	0
	Grid sales	37,113	90
	Total	41,222	100
Standalone PV	AC primary load	4,109	10
	DC primary load	0	0
	Deferrable load	0	0
	Total	4,109	100

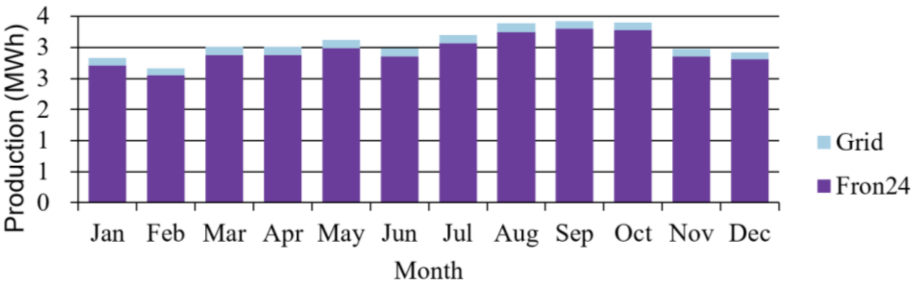

Figure 8. Monthly electrical production of the PV-grid system

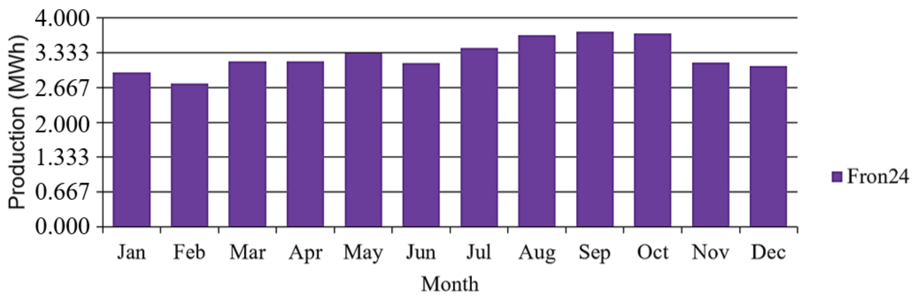

Figure 9. Monthly electrical production of the standalone PV system

3.2.2. Economic feasibility and energy balance analysis

The economic and energy performance of the solar-powered EV charging station is crucial for assessing its feasibility. Table 7 summarizes key financial aspects, including total net present cost, levelized cost of energy, and operating cost, which reflect the system's overall expenses and cost-effectiveness. Figure 10 illustrates the breakdown of these costs, showing that capital expenditures are the most significant component, primarily attributed to the PV system and battery storage. Operating and replacement costs also contribute to the overall expenditure, while salvage value and resource costs have minimal impact. Table 8 presents the monthly energy balance, showing that energy generation consistently exceeds consumption, leading to surplus electricity being exported to the grid. This reduces costs and enhances financial benefits. Peak demand values indicate the highest power usage, helping evaluate grid dependency. These findings highlight the system's economic sustainability and energy efficiency.

Table 7. Summary of economic

Total NPC	$348,977.70
Levelized COE	$0.3975
Operating cost	$3,932.95

To complement the financial evaluation, calculations of the payback period were conducted. The return on investment was also evaluated to assess the long-term investment feasibility of the system.

$$Payback\ Period = \frac{Initial\ Investment}{Annual\ Net\ Savings} \quad (7)$$

$$ROI = \frac{Net\ Benefit}{Total\ Investment} \times 100\% \quad (8)$$

The PV-grid hybrid system achieves a payback period of approximately 32.25 years, indicating that while the system provides consistent operational savings, the high upfront investment extends the return horizon. Over a 20-year operational lifespan, the projected return on investment (ROI) is 62.01%, which still reflects a positive economic outcome for long-term implementation. These results suggest that while financially feasible in the long run, further optimization, such as cost reduction in PV or battery technologies, is needed to shorten the payback period. This insight is crucial for policymakers and investors considering scalable deployment in urban EV charging infrastructure.

A sensitivity analysis was conducted to evaluate how fluctuations in solar irradiance and EV load levels affect the techno-economic performance of the PV-grid hybrid system. The results indicate that a 10% decrease in solar radiation leads to a 6.2% increase in LCOE, reflecting reduced energy production efficiency. Meanwhile, a 20% increase in daily EV load raises the net present cost (NPC) by approximately 11.5%, due to the need for additional generation capacity and operational resources. These outcomes underscore the system’s moderate resilience to variability and highlight the importance of accurate forecasting, flexible system design, and adaptive load management strategies. Incorporating real-time monitoring and predictive analytics can help optimize energy dispatch and reduce the financial impact of environmental and behavioral uncertainties.

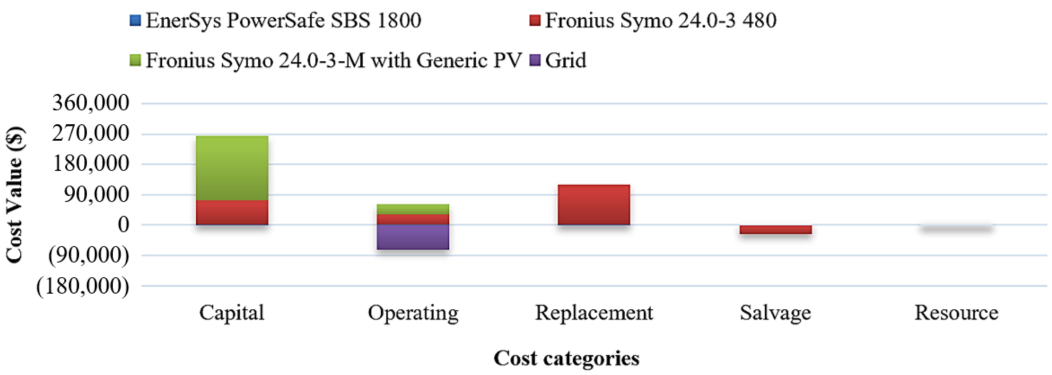

Figure 10. Cost breakdown of the solar-powered EV charging system

Table 8. Monthly energy balance of the solar-powered EV charging station

Month	Energy purchased (kWh)	Energy sold (kWh)	Net energy purchased (kWh)	Peak demand (kW)	Energy cost	Total charge
January	156	2,776	-2,620	1.93	-$254.19	-$254.19
February	143	2,577	-2,434	1.69	-$236.19	-$236.19
March	169	2,981	-2,812	1.90	-$272.75	-$272.75
April	175	2,999	-2,824	1.94	-$273.69	-$273.69
May	176	3,154	-2,978	1.75	-$289.02	-$289.02
June	174	2,971	-2,797	1.63	-$270.95	-$270.95
July	178	3,254	-3,075	2.00	-$298.61	-$298.61
August	184	3,486	-3,302	1.86	-$321.00	-$321.00
September	164	3,553	-3,390	1.87	-$330.78	-$330.78
October	159	3,522	-3,363	1.79	-$328.32	-$328.32
November	160	2,965	-2,805	2.09	-$272.48	-$272.48
December	153	2,875	-2,722	1.74	-$264.56	-$264.56
Annual	1,991	37,113	-35,121	2.09	-$3,413	-$3,413

3.2.3. Comparison of previous studies and this research

Several studies have evaluated renewable energy systems for EV charging stations. Zubair *et al.* [22] used HOMER Pro to analyze an 11 kW PV system, reporting an NPC of $40,452 and an LCOE of $0.148/kWh. This study, in comparison, has an NPC of $348,977.70 and an LCOE of $0.3975/kWh, which are higher due to the larger system scale and the potential for surplus energy sales to the grid.

Ali *et al.* [27] investigated a hybrid PV-Biomass system in Bangladesh, achieving an NPC of $4,712,218 and an LCOE of $0.0347/kWh. Their significantly lower LCOE results from integrating biomass, which reduces dependency on solar power alone. Conversely, this study focuses solely on an on-grid PV system without biomass, making it more relevant for Sidoarjo's conditions.

Amini *et al.* [28] optimized a rooftop PV system in Magelang, reporting an NPC of $126,572 and an LCOE of $0.0423/kWh. The substantial difference in NPC and LCOE compared to this study stems from differences in system scale. While their research concentrated on rooftop PV, this study includes complete infrastructure for an EV charging station. Nonetheless, their optimization approach provides valuable insights for improving this system's efficiency.

Adrian and Gabriela [29] evaluated a PV system in a primary school in the Philippines, with an NPC of $102,345 and an LCOE of $0.145/kWh. Their study highlights the benefits of net metering and large-scale battery integration. In contrast, this study emphasizes the potential of surplus energy sales to the grid to enhance economic feasibility. Güven and Yücel [30] optimized a microgrid system using HOMER grid, reporting an NPC of $1.62 million and an LCOE of $0.0549/kWh. Their higher NPC reflects the broader scope of their system, which is more complex than this study's PV-based EV charging station, which operates on a smaller scale.

Prasetyo *et al.* [31] designed an EV charging station in Karanganyar with an NPC of $11,796 and an LCOE of $1.069/kWh. Compared to this study (NPC $348,977.70, LCOE $0.3975/kWh), the significantly lower NPC in their research indicates a much smaller system scale. Meanwhile, this study proposes a system with higher energy production capacity and the potential for surplus energy sales, which could improve long-term economic efficiency.

This study provides a specific solution for a PV-based EV charging station in Sidoarjo. The system can enhance economic viability with the advantage of surplus energy sales. Future research could explore biomass integration or more efficient energy storage solutions to reduce LCOE further.

3.2.4. Research limitation

This research models a solar-powered EV charging station using HOMER Pro in Rangkah Kidul, Sidoarjo District, Sidoarjo Regency, East Java. However, the study is restricted to a small-scale system designed for private use. Considering Indonesia's abundant solar energy potential and the government's push for electric vehicle adoption, future work should focus on scaling up this concept for public charging facilities. Moreover, this study primarily assesses economic feasibility, but aspects such as energy losses and long-term efficiency degradation of system components are not fully considered due to software constraints. Further investigation is needed to evaluate these factors more comprehensively, ensuring a more accurate assessment of system performance and financial viability.

Nevertheless, system-level technical challenges must also be considered to ensure successful real-world implementation. Although the PV-grid system significantly reduces reliance on the utility grid, its inherent intermittency poses operational challenges, particularly during periods of low solar irradiance, such as cloudy or rainy days. These fluctuations can lead to load imbalances and voltage instability if not properly managed, especially in systems with high photovoltaic penetration. Without appropriate mitigation strategies, the reliability of the local grid and the EV charging infrastructure may be compromised. To address these challenges, utilities and operators should implement grid-support mechanisms such as demand-side response programs, dynamic electricity pricing, and intelligent battery scheduling. These solutions enhance system flexibility and ensure grid resilience while supporting the continued integration of renewable energy sources.

4. CONCLUSION

Indonesia has significant solar energy potential that can be utilized to support the development of EV charging stations. However, rising electricity demand challenges meeting energy needs through sustainable means. This study applies a simulation-based approach to design a solar photovoltaic (PLTS) system for an EV charging station, and the results indicate that the on-grid PLTS configuration is the most feasible, generating 39,214 kWh annually with a LCOE of $0.3975/kWh. The system meets local energy demands and produces surplus electricity that can be sold back to the grid, enhancing overall economic viability. Furthermore, the PV-grid hybrid system demonstrates stable performance under varying solar irradiance and EV load conditions, as shown by the sensitivity analysis, making it a reliable and scalable solution for urban and semi-urban contexts in Indonesia. Despite the current payback period exceeding 30 years, potential reductions in technology costs or improvements in energy pricing could significantly improve investment returns. These findings support the strategic deployment of grid-integrated renewable charging infrastructure and highlight the importance of supportive policies, grid optimization, and investment incentives for accelerating widespread adoption.

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AUTHOR CONTRIBUTIONS STATEMENT

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Yuki Trisnoaji	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓		✓
Zainal Arifin	✓		✓	✓			✓			✓	✓		✓	✓
Mochamad Subchan Mauludin		✓		✓	✓	✓	✓		✓					
Marsya Aulia Rizkita	✓				✓		✓			✓		✓	✓	
Singgih Dwi Prasetyo	✓			✓	✓		✓			✓	✓	✓		✓
Dony Perdana				✓	✓	✓				✓	✓	✓	✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY

The data used to support the research findings are available from the corresponding author, [MC], upon request.

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