Mechatronics and Intelligent Transportation Systems
https://www.acadlore.com/journals/MITS

Economic Feasibility of Solar-Powered Electric Vehicle Charging Stations: A Case Study in Ngawi, Indonesia

Singgih Dwi Prasetyo[1*], Farrel Julio Regannanta[1], Mochamad Subchan Mauludin[2], Zainal Arifin[1*]

[1] Department of Mechanical Engineering, Universitas Sebelas Maret, 57126 Surakarta, Indonesia
[2] Department of Informatics Engineering, Universitas Wahid Hasyim, 50236 Semarang, Indonesia

[*] Correspondence: Singgih Dwi Prasetyo (singgihdwipras@student.uns.ac.id);
Zainal Arifin (Zainal_arifin@staff.uns.ac.id)

Received: 10-03-2023 **Revised:** 11-15-2023 **Accepted:** 11-22-2023

Citation: S. D. Prasetyo, F. J. Regannanta1, M. S. Mauludin, and Z. Arifin, "Economic feasibility of solar-powered electric vehicle charging stations: A case study in Ngawi, Indonesia," *Mechatron. Intell Transp. Syst.*, vol. 2, no. 4, pp. 201–210, 2023. https://doi.org/10.56578/mits020402.

Abstract: In the context of increasing electric vehicle (EV) prevalence, the integration of renewable energy sources, particularly solar energy, into EV charging infrastructure has gained significant attention. This study investigates the economic viability of grid-connected photovoltaic (PV) systems for EV charging stations in Ngawi City, Indonesia, selected due to its substantial solar energy potential and ongoing renewable energy initiatives. Key factors influencing the economic feasibility of these systems include load requirements, renewable energy potential, system capacity, levelized cost of electricity, payback period, net present cost (NPC), and cost of energy (COE). A comprehensive techno-economic assessment was conducted to estimate the capital recovery time, incorporating both utilization costs and payback periods. The analysis utilized the Hybrid Optimization Model for Electric Renewables (HOMER) software, focusing on the application of PV energy in EV charging stations within Ngawi Regency. Findings indicate that a PV system-based generation approach can adequately meet the power needs of EV charging stations. Notably, this system is capable of generating surplus energy, which presents an opportunity for additional revenue, thus enhancing its economic attractiveness. The analysis determined that to produce an annual output of 562,227 kWh, a total of 1245 PV modules, each with a 370-watt capacity, are necessary. This off-grid PLTS system, relying exclusively on PV modules for electrical energy generation, can sufficiently supply a daily load of 342.99 kWh for an EV charging station. The study underscores the potential of solar-powered EV charging stations in contributing to sustainable urban development, reinforcing the integration of renewable energy into urban infrastructure.

Keywords: PLTS; EV; Charging station; HOMER; PV

1 Introduction

Situated in a prime tropical location adjacent to the equator, Indonesia extends between 6° North and 11° South latitude and 95° East and 141° East longitude, ensuring consistent sunlight exposure throughout the year [1, 2]. The potential of this abundant solar resource, particularly for electricity generation, must be judiciously harnessed. Electrical energy, a key indicator of societal welfare, is predominantly generated from diminishing fossil fuel sources, necessitating the exploration of alternative energy solutions [3–7].

Solar energy emerges as a viable alternative for electricity generation, including powering EV charging stations [8]. Characterized by its environmental benignity, solar energy, devoid of chemicals and radioactivity, does not contribute to greenhouse gas emissions or carbon monoxide production, factors critical in climate change. In the context of escalating environmental concerns, electric vehicles offer a sustainable solution, reducing air pollution, greenhouse gas emissions, and dependence on fossil fuels [9, 10]. With increasing governmental support and technological advancements, electric vehicles are witnessing a global surge in popularity [11]. Kumar et al. [12] reported a 40% increase in EV sales in 2019, accounting for 2.6% of global vehicle sales, while Setiawan et al. [13] highlighted a substantial growth in the Indonesian EV market from 0.08% in 2018 to 0.36% in 2021. Affordable and environmentally safe electrical energy is imperative for sustainable economic development [14]. EVs, compared to conventional combustion engine vehicles, offer environmental advantages, enhanced performance, and reduced operational costs [15].

This study employs the HOMER software to simulate the use of PV energy in powering EV charging stations in Ngawi Regency. The effectiveness of on-grid photovoltaic systems is assessed through HOMER's advanced numerical methods and optimization algorithms, facilitating evaluations of project cost-effectiveness, including NPC and levelized cost of electricity (LCOE) [16–18]. This research addresses the feasibility of grid-connected PV systems for household power consumption, incorporating key factors such as load requirements, renewable energy potential, and system composition. Techno-economic studies are conducted to calculate capital repayment times, amalgamating utilization costs with payback periods. A comprehensive techno-economic analysis is conducted to ascertain the most cost-effective design by comparing factors like total power production, consumption, NPC, COE, and Break-Even Point (BEP) values.

2 Methodology

2.1 Model Description

In the proposed study, the off-grid PLTS configuration is employed for the EV charging station. To optimize the PLTS system's functionality, a comprehensive design incorporating various auxiliary components is essential. The HOMER software models the under-development generating system, integrating batteries, converters, and PV solar panels as pivotal elements. Figure 1 illustrates the PLTS system as modeled within the HOMER program.

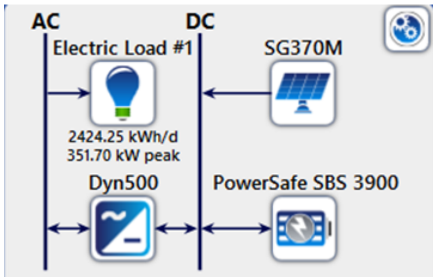

Figure 1. Modeling scheme for PLTS

The electrical load consumption is estimated by HOMER, based on the daily battery consumption load of 10 EVs, each with a capacity of 26.7 kWh. It is postulated that the duration required for fully charging an EV is one hour. Therefore, with the charging station operational for 10 hours per day, it is capable of charging a maximum of 10 EVs, culminating in a daily load of approximately 267 kW. Figure 2 details the charging station's electrical load profile.

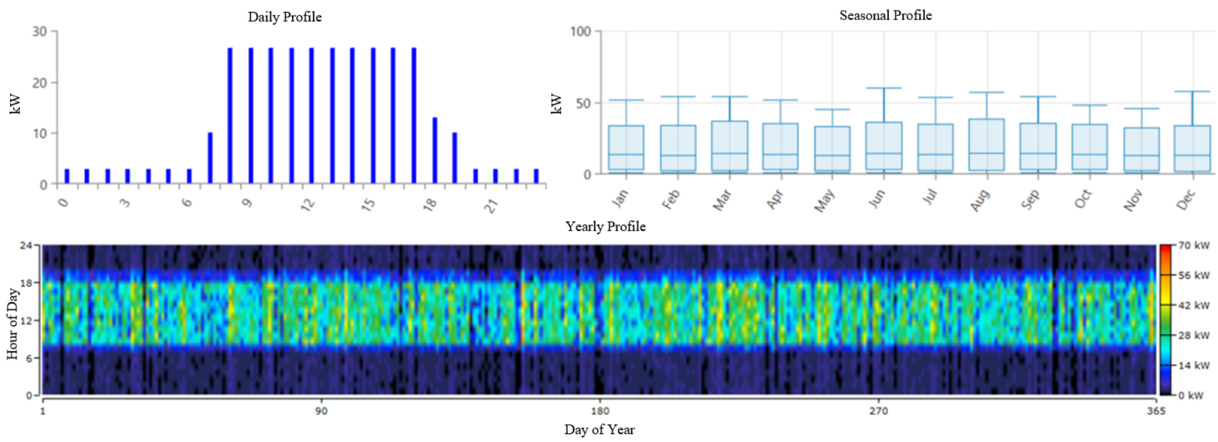

Figure 2. Electrical load profile of a charging station

Table 1. Specifications for the wulling Air-EV long range

Parameter	Specification
Engine power	30 kW
Engine torque	9.34
Battery capacity	Lithium Ferro-Phosphate; IP67 Rating 26.7 kWh

For simulation purposes, a Wulling Air-EV Long Range model, equipped with a 26.7 kWh battery capacity, was utilized. Table 1 enumerates the specific attributes of this vehicle model.

An integral aspect of the methodology involves the calculation of initial investment costs for each component, which is crucial for the economic analysis of the PLTS. Table 2 presents the initial investment costs required for the establishment of the PLTS Charging Station.

Table 2. Initial PLTS EV Charging Station investment costs

Parameter	Peimar SG370M	Enersys PowerSafe SBS 3900	Dynapower IPS-500
Capital Costs	IDR 4,980,000,000.00	IDR 412,200,000.00	IDR 7,187,501.00
Replacement Cost	-	IDR 412,200,000.00	IDR 7,187,501.00
O&M Costs	IDR 5,000,000.00	IDR 500,000.00	IDR 500,000.00
Lifetime	30	15	15

2.2 Description of PLTS Design Location

The PLTS under consideration is located within a residential setting in Ngawi Regency, East Java. The location for the PLTS was identified using the National Aeronautics and Space Administration (NASA) Prediction of Worldwide Energy Resources (POWER) integrated with the HOMER software. This function within HOMER enables the identification and selection of optimal project sites based on various environmental and geographical factors. Figure 3 depicts the selected location for the PLTS installation.

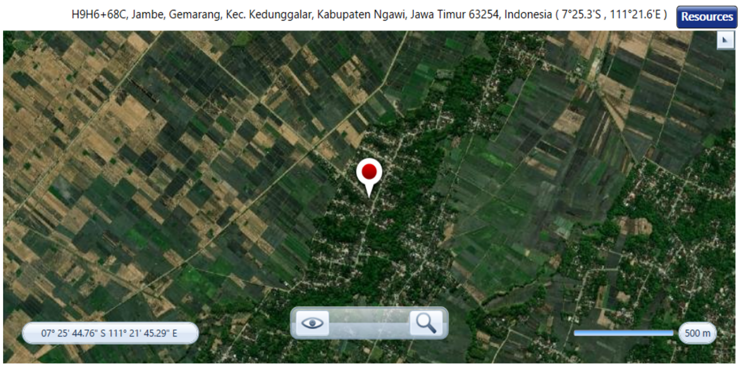

Figure 3. PLTS EV Charging Station location

2.3 Potential for Utilizing Solar Energy in Ngawi Regency

Ngawi Regency in East Java presents a considerable potential for harnessing solar energy as a renewable resource. The feasibility of employing solar energy for the PLTS in this region is substantiated by data regarding solar radiation intensity and local temperature parameters, accessible through the NASA website. Table 3 provides detailed information on the solar radiation intensity observed in Ngawi Regency.

Table 3. Data on radiation intensity in Ngawi Regency

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Des	Mean	Min
2.68	2.69	3.36	3.62	4.2	4.33	4.85	5.35	5.26	4.16	3.26	2.71	3.87	2.68

The efficiency of the PLTS in terms of output power is directly proportional to the solar radiation intensity. Notably, the month of August records the highest solar radiation intensity in Ngawi Regency, with a measurement of 5.35 kWh/m^2/day, while the average radiation intensity across the year stands at 3.87 kWh/m^2/day.

2.4 Design of PLTS Component Specification

2.4.1 Economy

The economic parameters of the project, including project duration, currency, discount rate, and inflation rate, are crucial for the economic feasibility analysis. Given the project's location in Indonesia, the Indonesian rupiah is the designated currency. Drawing from Bank Indonesia's data, the project is envisaged to span a 25-year period. The discount and inflation rates applied are 5.75% and 4.97%, respectively, aligning with the current economic indices.

2.4.2 Total expense

The foundational step in this design involves calculating the total daily load. The average daily load for a household employing a solar circuit home system, as illustrated in Table 4, serves as the basis for these calculations. For the EV Charging Station, the load is determined considering operational hours from 8 a.m. to 5 p.m. Beyond these hours, electricity usage is confined to lighting and auxiliary support systems.

Table 4. Data on daily total load

Afternoon (07.00 - 17.00)		**Evening (17.00-07.00)**	
O'clock	Load (kW)	O'clock	Load (kW)
7	10	18	13
8	26.7	19	10
9	26.7	20	3
10	26.7	21	3
11	26.7	22	3
12	26.7	23	3
13	26.7	0	3
14	26.7	1	3
15	26.7	2	3
16	26.7	3	3
17	26.7	4	3
		5	3
		6	3
Total (kW)	277		56
Load increases by 30%, so total power (kW)	285.31		57.68
Total load per day (kW)		342.99	

2.4.3 Solar panel

The PLTS system incorporates the Peimar SG370M solar panel. The performance of these solar panels is subject to various environmental and operational factors. A key determinant of their efficiency is the derating factor, which accounts for non-ideal conditions such as adverse weather, elevated temperatures, aging of solar cells, variations in solar radiation, among other factors that could affect system output. Figure 4 and Table 5 detail the specifications and visual representation of these solar panels.

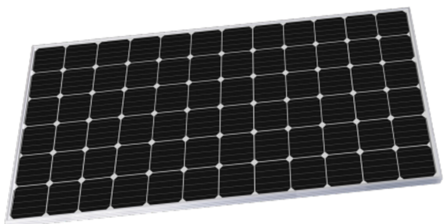

Figure 4. Solar panel peimar SG370M

Table 5. Specifications for solar panels

Type of Technical Specification	**Mark**
Maximum power (Pmax)	370 Wp
Maximum voltage (Vmp)	40.1 V
Maximum current (Imp)	9.23 A
Open circuit voltage (Voc)	48.93 V
Short circuit current (Isc)	9.81 A
Frequency	50 Hz
Module efficiency	19.07%
Derating factors	80%

To ascertain the requisite total capacity of solar panels for powering the EV charging station, a comprehensive calculation encompassing several factors is imperative. These include determining system losses, the total energy output of the PV module, and the module's capacity, with an emphasis on the specified nominal power of 370 Wp per module. System losses, which occur during the operation of solar panels, represent the energy not converted into usable electricity. These losses are a crucial consideration and are typically quantified based on established industry assumptions and practices. The specifics of these system losses, reflecting the energy efficiency reduction in the operational setting, are presented in Table 6.

Table 6. Specifications for solar panels

Types of Losses	Percentage
PV Module	11.5%
Network inverter	3%
Battery inverter	6%
Wiring	2%
Battery	15%
Total losses during the night	37.5%
Total losses during the day	22.5%

The capacity of the solar module is derived by summing the total energy output per performance and then subtracting the quantified system losses to obtain a net effective capacity:

$$\begin{aligned}\text{Total module energy } &= \frac{\text{Night energy}}{100\% - \text{ loses at night}} + \frac{\text{Daytime energy}}{100\% - \text{ loses at daytime}} \\ &= \frac{57.68\text{kWh}}{62.5\%} + \frac{285.31\text{kWh}}{77.5\%} = 460.43\text{kWh}\end{aligned} \tag{1}$$

The calculation for the required number of solar panels for the system incorporates several key factors. These include the total daily load demand, the duration of peak sunlight hours per day, characterized by an intensity of 1000 W/m^2/h, and the average potential solar radiation, estimated at 4.80 kWh/m^2/h. Additionally, the capacity of each solar panel, specified at 370 Wp, is integral to this calculation. To determine the necessary quantity of solar panels, a comparison is made between the total energy output required by the system and the individual capacity of the solar panels. Utilizing the following formula allows for a prompt and accurate estimation of the number of solar panels needed to meet the system's energy demands effectively:

$$\text{Total PV } = \frac{\text{Total module energy}}{\text{Capacity of solar panel}} = \frac{460430}{370} = 1244.4 \text{ or } 1245\text{PV} \tag{2}$$

To meet the load requirements of the EV charging station, 1245 units of PV modules, each with a standard of 370 Wp, are required. The financial implication for procuring 1245 units of 370 Wp solar panels totals IDR 4,980,000,000.00, with an additional IDR 50,000,000.00 allocated for operation and maintenance. With a projected lifespan of 30 years, the PV modules are not expected to necessitate replacement within this period.

2.4.4 Inverter

Table 7. Specifications for the Dynapower IPS–500

Type of Technical Specification	Mark
Output power	500 kW
Maximum power	500 kW
Output frequency	50/60 Hz
Input dc voltage	100 – 1500 V
Efficiency	98.2%

The inverter plays a critical role in the PLTS system, serving as the device that converts direct current (DC) generated by the solar panels into alternating current (AC), which is suitable for powering common household appliances. The selection of the inverter type and capacity is dictated by the total load of the electrical equipment, based on the assumption that all components are operational simultaneously. For this system, a Dynapower IPS-500 inverter has been chosen to accommodate the total electrical demand of 342.99 kW. Table 7 details the specifications of the selected inverter, and Figure 5 provides a visual representation of the inverter model.

Consequently, the calculation for the number of inverters required is conducted by dividing the total electrical demand by 125% of the output power of a single inverter.

Figure 5. Dynapower IPS–500

$$P_{\text{inverter}} = \frac{\text{Total electrical demand} \times 125\%}{\text{Output power of inverter}} = \frac{342990 \times 125\%}{500000} = 0.857 \text{ or } 1 \text{ inverter} \tag{3}$$

This methodology ensures that the inverter can handle occasional surges in power demand, maintaining system reliability. According to this approach, the HOMER analysis indicates the necessity of only one inverter with a capacity of 500 kW. The financial implication for acquiring a single unit of this inverter is IDR 7,187,501.00, with an additional IDR 500,000.00 allocated for operation and maintenance. Given the estimated lifespan of a secondhand inverter at 15 years, a future replacement cost for the inverter would also be IDR 7,187,501.00.

2.4.5 Battery

The battery is an essential component of the PLTS system, acting as the storage unit for energy harnessed by the solar panels. Without the incorporation of batteries, the PLTS would be limited to functioning only during daylight hours or under sufficient lighting conditions. For this system, the EnerSys PowerSafe SBS 3900 battery has been selected. This particular model is a lead-acid battery, characterized by its capacity to store 51.6 kWh of power. It operates at a voltage of 12 V and has a current rating of 4300 Ah. Figure 6 visually illustrates this battery model, while Table 8 details the specific characteristics of the battery as implemented in this system setup.

Figure 6. Battery EnerSys PowerSafe SBS 3900

Table 8. Specifications for the EnerSys PowerSafe SBS 3900 battery

Type of Technical Specification	Mark
Normal voltage	2 V
Internal holding capacity	0.18 mΩ
Nominal capacity	4300 Ah

The calculation for the required number of batteries is conducted by dividing the total electrical demand of the system by the power capacity of a single battery, thus providing a straightforward formula to ascertain the precise quantity of batteries necessary for the system.

$$\text{Battery} = \frac{\text{Total electrical demand}}{\text{Power capacity of the battery}} = \frac{342990}{51600 \times 80\%} = 8.31 \text{ or } 9 \text{ battery} \tag{4}$$

As a result of the calculation, it is determined that the HOMER system necessitates a total of nine batteries. The financial implication for procuring these nine units of the EnerSys PowerSafe SBS 3900 battery amounts to IDR 412,200,000.00. Additionally, the system incurs annual operating and maintenance costs of IDR 500,000.00 per battery. Considering the battery's estimated lifespan of 15 years, a future replacement for all nine batteries would entail an expenditure of IDR 412,200,000.00.

3 Results and Discussion

3.1 HOMER Simulation Results

The primary objective of the simulation process was to leverage HOMER's optimization capabilities to ascertain the most efficient system configuration. This involved modeling and designing a specific system configuration, followed by applying an optimization technique to identify the optimal configuration. The results from the HOMER simulation, as detailed in Tables 9-11, indicate the system comprises an off-grid setup, a 500 kW converter, solar panels with a total capacity of 460.65 kW, and nine batteries each offering 51.6 kWh capacity. This configuration is capable of adequately meeting the electric load demands of the EV charging station. Notably, the system is proficient in generating a surplus of electrical energy beyond its consumption needs, presenting an opportunity for financial gain through the sale of excess electricity. The total annual electricity generation achieved in this setup amounts to 562.227 kWh. Of this, 547.026 kWh represents the annual surplus electricity, while the annual unserved power load stands at 870.399 kWh.

Table 9. Electricity production

Production	kWh/yr	%
Peimar SG370M	562.227	100
Total	562.227	100

Table 10. Electricity consumption

Consumption	kWh/yr	%
AC primary load	14.453	100
DC primary load	0	0
Deferrable load	0	0
Total	14.453	100

Table 11. Excess electricity

Quantity	kWh/yr	%
Excess electricity	547.026	97.3
Unmet electric load	870.399	98.4
Capacity shortage	958.884	100

The aspect of excess electricity within the system metrics warrants particular attention. Excess electricity occurs when the electricity generated surpasses the consumption or requirement of an electrical system or grid at a given time. This contrasts with the unmet electricity load, which represents the shortfall in meeting the electrical energy demand. The relationship between excess electricity and unmet electricity load presents a notable challenge, as electrical systems typically have limited capacity for long-term energy storage. Addressing this issue effectively calls for practical strategies. These may include energy storage solutions, transferring excess energy to other grids in need, or employing intelligent automation systems. Such systems can dynamically redirect excess electricity to alternative applications, like battery charging or heating, thus optimizing energy utilization during periods of surplus generation.

3.2 NPC

The efficiency of the system design is principally gauged by the magnitude of the NPC, which quantifies the total cost of the system over a designated period. Consequently, HOMER software prioritizes the optimization results based on the principle of ascending NPC values, ranking configurations from the lowest to the highest NPC. This approach ensures that the most cost-effective system design is identified. Figure 7 graphically represents the NPC generated by this specific system arrangement. The computation of the total NPC encompasses all expenses associated with the project. This includes the costs of components, replacements, maintenance, and any applicable fuel expenses, along with the rates of borrowing.

Total NPC:	**Rp1,105,781,000.00**
Levelized COE:	**Rp3,364.63**
Operating Cost:	**Rp45,953,330.00**

Figure 7. NPC

3.3 Renewable Fraction

The analysis of the renewable fraction reveals a significant distinction between system configurations with and without battery storage. The inclusion of batteries, which serve as storage units for surplus power, introduces variability in the system's ability to manage excess electricity. This variation is critical in enhancing the system's overall renewable energy utilization. Table 12 provides a detailed presentation of the renewable fraction results across different system configurations.

Table 12. Renewable fraction

Quantity	Value	Units
Renewable fraction	100	%
Max renewable penetration	20.770	%

The achievement of a 100% renewable fraction is indicative of the total energy consumption being exclusively sourced from renewable energy. This outcome demonstrates the system's capability to effectively address electricity provision using renewable sources.

3.4 COE

The COE is a critical metric in evaluating the economic efficiency of the system. It is calculated by dividing the system's total yearly cost by its annual electricity production. For this system, the COE is determined using the yearly cost of IDR 131,541,394.00 and the annual electrical load usage of 562.227 kWh. Thus, the COE is derived by dividing the total NPC value by the total electricity production, providing a clear indicator of the cost-effectiveness of the energy generated by the system.

$$\text{COE} = \frac{\text{Total NPC}}{\text{Total electricity production}} = \frac{Rp1.105.781.000,00}{562.227} = Rp1.966,00/\text{kWh} \tag{5}$$

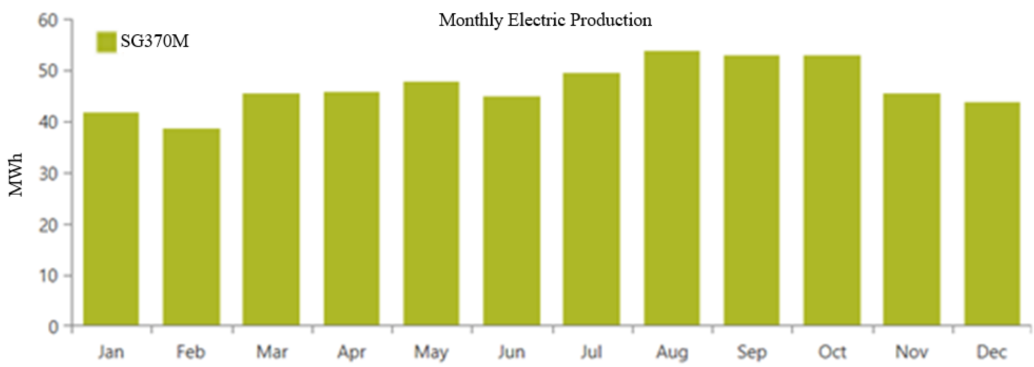

Figure 8. Monthly electric production

3.5 Monthly Electric Production

The monthly electric production of a photovoltaic module refers to its capacity to generate electricity over a monthly period. This metric is vital in understanding the system's performance across different times of the year. Figure 8 presents the results of the HOMER system simulation regarding monthly electric production. The simulation forecasts that the system will produce its highest electricity output in August, with an estimated generation of approximately 54 megawatt-hours. This peak in production correlates with the highest solar irradiance in August, which is about 5.35 kWh/m^2/day, demonstrating the direct impact of solar irradiance on the system's electricity generation capabilities.

4 Conclusions

This study conducted a comprehensive evaluation of the cost-effectiveness of on-grid PV systems for EV charging stations in Ngawi City. Utilizing the HOMER software for simulation purposes, the research encompassed an array of factors influencing the cost-effectiveness of the proposed designs. These included load requirements, renewable energy potential, system capacity, levelized cost of electricity, payback period, NPC, and COE. The techno-economic analysis combined utilization costs and payback periods to predict the time required for capital repayment.

The findings of this technical-economic analysis indicated that the PV-based power generation system is capable of fulfilling the electrical needs of EV charging stations. Furthermore, the system is able to generate surplus energy, offering the potential for profitable sales and thus enhancing its economic feasibility. The off-grid PLTS system, employing 1,245 PV modules each with a capacity of 370 watts, is capable of producing 562,227 kWh of electricity annually. This PLTS system model is adept at powering an electric vehicle charging station with a daily load requirement of 342.99 kWh.

The successful electricity production from the PV system, surpassing the electricity demands in this context, underscores the significant potential for EV infrastructure development in Indonesia. This aligns with the increasing demand for EV charging facilities, highlighting the viability of renewable energy solutions in meeting the emerging energy needs of the transportation sector.

Author Contributions

Conceptualization, S.D.P., F.J.R., and Z.A.; methodology, S.D.P., F.J.R., and M.S.M.; software, S.D.P. and F.J.R.; validation, S.D.P. and Z.A.; formal analysis, S.D.P. and F.J.R.; investigation, S.D.P., F.J.R., and M.S.M.; resources, S.D.P. and F.J.R.; data curation, S.D.P. and F.J.R.; writing—original draft preparation, S.D.P. and F.J.R.; writing—review and editing, S.D.P. and M.S.M; visualization, S.D.P. and F.J.R.; supervision, S.D.P. and Z.A.; project administration, S.D.P.; funding acquisition, S.D.P., M.S.M. and Z.A. All authors have read and agreed to the published version of the manuscript.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Acknowledgments

This research was fully supported by the PNBP grant from the Universitas Sebelas Maret, Indonesia (Grant No.: 228/UN27.22/PT.01.03/2023).

Confilict of interest

The authors declare that they have no conflicts of interest.

References

[1] W. E. Juwana, R. A. Rachmanto, N. F. Alfaiz, S. D. Prasetyo, and Z. Arifin, "Economic analysis of PV-generator hybrid off-grid systems in underdeveloped Indonesian regions," *J. Eur. Syst. Autom.*, vol. 56, no. 4, pp. 519–527, 2023. https://doi.org/10.18280/jesa.560401

[2] M. Rumbayan, A. Abudureyimu, and K. Nagasaka, "Mapping of solar energy potential in Indonesia using artificial neural network and geographical information system," *Renew. Sustain. Energy Rev.*, vol. 16, no. 3, pp. 1437–1449, 2012. https://doi.org/10.1016/j.rser.2011.11.024

[3] Z. Arifin, M. A. M. Rosli, Y. J. Prasojo, N. F. Alfaiz, S. D. Prasetyo, and W. Mulyani, "Economic feasibility investigation of on-grid and off-grid solar photovoltaic system installation in central Java," *Int. J. Energy Prod. Manag.*, vol. 8, no. 3, pp. 169–175, 2023. https://doi.org/10.18280/ijepm.080305

[4] Y. Fang, "Economic welfare impacts from renewable energy consumption: The China experience," *Renew. Sustain. Energy Rev.*, vol. 15, no. 9, pp. 5120–5128, 2011. https://doi.org/10.1016/j.rser.2011.07.044

[5] N. Bolson, P. Prieto, and T. Patzek, "Capacity factors for electrical power generation from renewable and nonrenewable sources," *Proc. Natl. Acad. Sci.*, vol. 119, no. 52, p. e2205429119, 2022. https://doi.org/10.1073/pnas.2205429119

[6] R. A. Rachmanto, W. E. Juwana, A. Akbar, S. D. Prasetyo, W. B. Bangun, and Z. Arifin, "Economic analysis of on-grid photovoltaic-generator hybrid energy systems for rural electrification in Indonesia," *Int. J. Sustain. Dev. Plan.*, vol. 18, no. 9, pp. 2967–2973, 2023. https://doi.org/10.18280/ijsdp.180935

[7] P. Suman, P. Sharma, and P. Goyal, "Analysing the effects of solar insolation and temperature on PV cell characteristics," *Mater. Today Proc.*, vol. 45, pp. 5539–5543, 2021. https://doi.org/10.1016/j.matpr.2021.02.301

[8] F. He and H. Fathabadi, "Novel standalone plug-in hybrid electric vehicle charging station fed by solar energy in presence of a fuel cell system used as supporting power source," *Renew. Energy*, vol. 156, pp. 964–974, 2020. https://doi.org/10.1016/j.renene.2020.04.141

[9] R. A. Rachmanto, F. J. Regannanta, Z. A. Ubaidillah, D. Widhiyanuriyawan, E. Yohana, and S. D. Prasetyo, "Analysis development of public electric vehicle charging stations using on-grid solar power plants in Indonesia," *Int. J. Transp. Dev. Integr.*, vol. 7, no. 3, pp. 215–222, 2023. https://doi.org/10.18280/ijtdi.070305

[10] A. Hu, S. Levis, G. A. Meehl, W. Han, W. M. Washington, K. W. Oleson, B. J. Van Ruijven, M. He, and W. G. Strand, "Impact of solar panels on global climate," *Nat. Clim. Change*, vol. 6, no. 3, pp. 290–294, 2016. https://doi.org/10.1038/nclimate2843

[11] M. Muratori, M. Alexander, D. Arent *et al.*, "The rise of electric vehicles—2020 status and future expectations," *Prog. Energy*, vol. 3, no. 2, p. 022002, 2021. https://doi.org/10.1088/2516-1083/abe0ad

[12] R. R. Kumar, P. Guha, and A. Chakraborty, "Comparative assessment and selection of electric vehicle diffusion models: A global outlook," *Energy*, vol. 238, p. 121932, 2022. https://doi.org/10.1016/j.energy.2021.121932

[13] A. D. Setiawan, T. N. Zahari, F. J. Purba, A. O. Moeis, and A. Hidayatno, "Investigating policies on increasing the adoption of electric vehicles in indonesia," *J. Clean Prod.*, vol. 380, no. P2, p. 135097, 2022. https://doi.org/10.1016/j.jclepro.2022.135097

[14] W. Strielkowski, L. Civín, E. Tarkhanova, M. Tvaronavičienė, and Y. Petrenko, "Renewable energy in the sustainable development of electrical power sector: A review," *Energies*, vol. 14, no. 24, p. 8240, 2021. https://doi.org/10.3390/en14248240

[15] O. A. Odetoye, P. K. Olulope, O. M. Olanrewaju, A. O. Alimi, and O. G. Igbinosa, "Multi-year techno-economic assessment of proposed zero-emission hybrid community microgrid in nigeria using HOMER," *Heliyon*, vol. 9, no. 9, p. e19189, 2023. https://doi.org/10.1016/j.heliyon.2023.e19189

[16] D. D. D. P. Tjahjana, Suyitno, R. A. Rachmanto, W. E. Juwana, Y. J. Prasojo, S. D. Prasetyo, and Z. Arifin, "Economic feasibility of a PV-wind hybrid microgrid system for off-grid electrification in Papua, Indonesia," *Int. J. Des. Nat. Ecodyn.*, vol. 18, no. 4, pp. 811–818, 2023. https://doi.org/10.18280/ijdne.180407

[17] Z. Arifin, Suyitno, D. D. D. P. Tjahjana, M. Muqoffa, S. D. Prasetyo, N. F. Alfaiz, and A. Sanusi, "Grid-connected hybrid PV-wind system simulation in urban Java," *J. Eur. Syst. Autom.*, vol. 55, no. 4, pp. 477–483, 2022. https://doi.org/10.18280/jesa.550406

[18] S. D. Prasetyo, F. J. Regannanta, A. R. Birawa, and M. S. Alfaridzi, "Techno-economic evaluation of hybrid photovoltaic-wind energy systems for Indonesian government buildings," *J. Sustain. Energy*, vol. 2, no. 3, pp. 132–144, 2023. https://doi.org/10.56578/jse020303