Research in Education, Technology, and Multiculture
ISSN: 3025-6763 | Journal's DOI: 10.61436/rietm
Homepage: https://imrecsjournal.com/journals/index.php/rietm

Optimizing Performance of Electric Vehicle Charging Systems Using Solar PV Tree Models

Aris Ansori[1,*], Priyo Heru Adiwibowo[1], Indra Herlamba Siregar[1], Grummy Wailanduw[1], Saiful Anwar[1], Edy Herianto Majlan[2]

[1]Department of Mechanical Engineering, Universitas Negeri Surabaya, Indonesia
[2]Fuel Cell Institute, The National University of Malaysia, Malaysia

ARTICLE INFO
Article History:
Received: 24 May 2026
Accepted: 21 July 2026
Published: 01 September 2026

Keywords:
Solar PV trees;
EV charging;
Electric vehicles;
Renewable energy.

Corresponding Author:
arisansori@unesa.ac.id

ABSTRACT
The transition to electric vehicles in the transportation sector has had a positive impact on reducing carbon emissions. However, the availability of electricity from renewable energy sources to charge electric vehicles (EVs) remains very limited in both rural and urban areas. The abundant potential of renewable energy sources, such as solar energy, presents challenges in their application as a power source for charging electric vehicles. This study aims to design and analyze the performance of electric vehicle charging using a solar PV tree model. The solar PV installation uses a 152.4 mm diameter iron pipe, with four solar PVs installed in a circle at 90° intervals and a tilt angle of 15°. Eight solar PV trees are installed in a row on the side of the road in the city of Surabaya, geographically located at latitude south 7°9′-7°21′ and longitude east 112°36′-112°54′. The solar PV tree performance measurement method uses IEC 61724-1. The measured electrical parameters consist of voltage, current, power, and solar PV energy efficiency. Electrical energy measurement is divided into two measurements: electrical energy directly used to charge electric vehicles using a kWh meter, and electrical energy stored in energy storage batteries. Solar PV performance testing uses two types of EV loads: an electric car with a charging capacity of 37.9 kWh and an electric bicycle with a charging capacity of 1.75 kWh. Solar PV testing with a tree model can increase sunlight capture with a leaf-like installation model, and it is easy to place in a park or along the roadside. A solar PV system with a capacity of 8 kWp can produce an average of 18.9718 kWh/day, with an efficiency of 2.63% when the sky is clear and sunlight lasts 8 hours. This solar power plant can charge electric bicycles with 1.22 kWh from a full capacity of 1.75 kWh, and electric cars with 14.31 kWh from a full capacity of 37.9 kWh, with an energy loss of approximately 11.5% during charging. Meanwhile, in terms of economic feasibility, with an electricity price of IDR 2,950/kWh, charging electric vehicles (EVs) is economically feasible with a Benefit Cost Ratio (BCR) of 1.23. The solar power plant's investment capital will be returned in eleven years and two months.

To cite this article:
Ansori, A., Adiwibowo, P. H., Siregar, I. H., & Wailanduw, G. (2026). Optimizing performance of electric vehicle charging systems using solar pv tree models. *Research in Education, Technology, and Multiculture*, *5*(3), 280-292. doi: https://doi.org/10.61436/rietm/v5i3.pp280-292

■ INTRODUCTION

The transportation sector is the second largest contributor to CO_2 pollution after the industrial sector. Elevated CO2 levels affect environmental health and contribute to global warming. Fossil-fueled vehicle emissions significantly contribute to greenhouse gases, ozone depletion, and acid rain, and cause respiratory health problems and skin irritation in humans. Vehicle emissions can be reduced by lowering CO_2 emissions in the transportation sector. Replacing fossil-fuel vehicles with electric vehicles is an effective way to reduce CO_2 emissions (Zhao et al., 2021; Krause et al., 2020). Electric vehicle technology has advanced significantly in vehicle design and control systems since 1900 (Himani Bhatt et al., 2022; Asaad et al., 2018).

However, electric vehicles remain underused in the transportation sector, with estimates suggesting they will reach 130 million worldwide by the end of 2030. Factors contributing to the low use of electric vehicles in the transportation sector include high initial investment costs, limited availability of electric vehicle charging stations, battery damage levels, vehicle mileage, and government regulations (Bunsen et al., 2018). Several countries have enacted regulations to increase electric vehicle use through financial incentives and policies that accelerate the transition to electric transportation. Electric vehicles are powered by the electrical energy stored in the battery. Therefore, the battery storage system uses a lithium-ion (Li-ion) rechargeable battery, which is the most widely used due to its high energy density. In addition, Li-ion batteries still have limitations such as limited energy density, decreased battery cell performance, and limited charging rate due to electrochemical processes (Ahmed et al., 2017; Keyser et al., 2017).

Electric vehicle charging can be connected to the power grid to recharge the battery. Therefore, electric vehicle charging stations are needed. The Indonesian government is targeting the construction of 4,300 Public Electric Vehicle Charging Stations (SPKLU) by the State Electricity Company (PLN) by the end of 2025. This step supports the transition to electric vehicles and reduces carbon emissions. The ease of use of electric vehicles encourages people to use them for transportation. Electric vehicle charging facilities must be easily accessible and available in sufficient quantities. However, increased CO_2 emissions occur if electric vehicle charging stations still use electricity from fossil-fueled power plants. This situation does not reduce carbon emissions; instead, it increases carbon pollution. For example, a fossil-fueled power plant with a diesel engine can produce 266.76 g of CO_2 per 1 kWh. Meanwhile, power generation emissions in Sweden are low, producing 18 g CO_2 per kWh of electricity, with 73% renewable energy (Energy production data source: ENTSO-E, 2025), while power generation in China produced 5,455 Mt of CO2 in 2025 (International Energy Agency, 2025). According to PLN, power plants in Indonesia still contribute 14% of total national carbon emissions. Therefore, implementing a solar photovoltaic-based electric vehicle charging system can be an appropriate alternative solution to reduce CO_2 pollution.

Using clean, renewable energy sources provides a more sustainable alternative. However, some constraints in renewable energy-based electric vehicle charging systems require large areas to harvest the renewable energy. One of the renewable energy sources that has been applied in several countries as a source of electrical energy for solar electric charging stations, such as in California, United States, The implementation of an electric vehicle charging system with a 100 kW photovoltaic capacity and a 635 KWH energy storage system can simultaneously charge 16 electric vehicles (Yap et al., 2022); (Ekren et al., 2021); (Ullah et al., 2023); (Nishanthy et al., 2022); (Fretzen et al., 2021); (Bishla et al., 2024).

Furthermore, further research is underway to optimize solar-powered electric vehicle charging systems, including improvements to energy storage systems and the use of MPPT systems to maximize the power generated by solar panels. This approach can increase the profitability of the charging system, reduce investment costs, and enable faster battery charging (Goswami & Sadhu, 2021). The strategy to optimize the electric vehicle (EV) charging system with photovoltaic (PV) solar panels cannot be separated from the solar PV installation model, such as conventional solar PV installations (installed on the ground) with adjustments to the tilt angle of the solar panels, and settings with Maximum Power Point Tracking (MPPT) to increase the reception of solar radiation. Meanwhile, installing four solar PV panels in a tree model, arranged in a 360° circle with each panel tilted 15°, can receive optimal solar radiation throughout the day without being affected by the sun's hour angle. Meanwhile, an EV charger system with battery storage can optimize solar PV energy storage when the system is not being used for EV charging. An EV charger system with a storage battery is shown in Figure 1.

A renewable energy hybrid electric

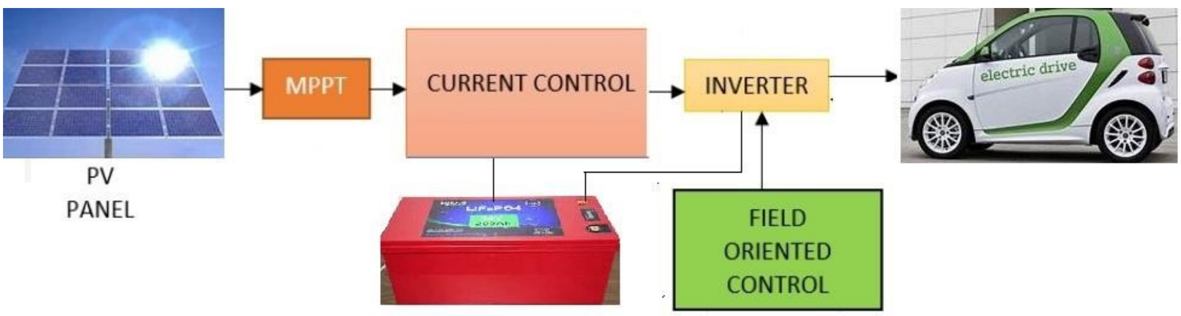

Figure 1. Ev charger model with battery storage

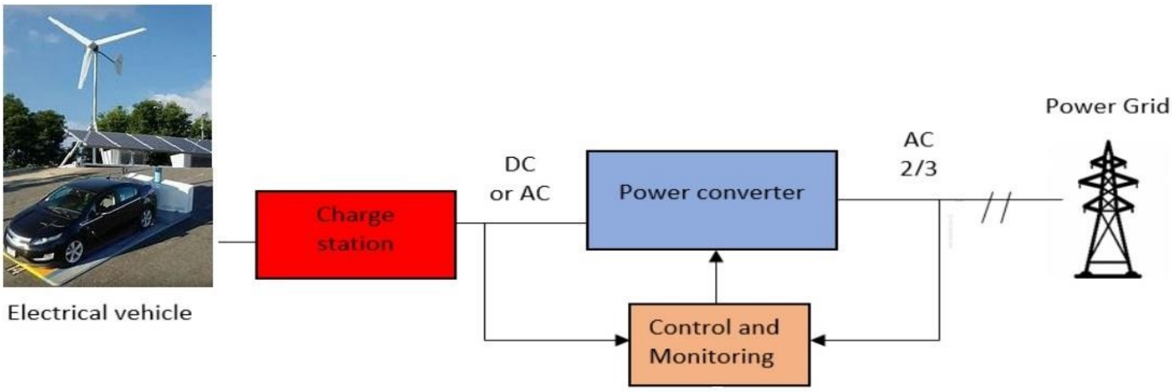

Figure 2. Electric vehicle charger hybrid model

vehicle charging system uses more than one energy source to improve the stability of electric vehicle charging power, such as electricity from wind turbines and solar photovoltaic energy. The hybrid renewable energy system configuration generates electric vehicle chargers using a multi-criteria process that integrates a renewable energy electricity demand system and a local electric vehicle charging system (Bastida-Molina et al., 2021; Kumar et al., 2022; Ray et al., 2021).

Meanwhile, an intelligence-based control system has been developed to optimize the operating system of a renewable-energy electric vehicle charger system. The DC microgrid electric vehicle charging system uses a battery charging control system that determines the battery charging mode used to maintain the current supply level used for charging. Solar PV and batteries are ideal power sources for EV charging, supported by an adaptive interactive power management controller. Power is drawn from the grid if the solar panel and battery power are insufficient to meet demand. Excess power from the solar panel system is fed back into the grid when it is generated and the battery system is fully charged (Viswa Teja et al., 2023; Ramasamy et al., 2023; Singh et al., 2024; Afzal et al., 2023; Adedeji, 2023).

Several studies have highlighted the utilization of solar energy as a source of electrical energy for electric vehicle charging. However, few in-depth technological and economic analyses remain. Technological and economic studies of solar energy utilization with rooftop solar for lighting applications (Reddy et al., 2024). From a techno-economic perspective, renewable energy electric vehicle charging systems show effectiveness and economic value in application (Ansori et al., 2023).

Several models of solar PV EV charging systems have been developed, such as rooftop solar PV systems, which use rooftops to house solar panels and generate electricity for EV charging. These rooftop solar PV systems still face challenges in solar radiation due to the angle of the solar PV panels, which must be adjusted to the shape and slope of the roof (Yadav et al., 2026). Additionally, installing solar PV panels on the roofs of electric vehicle parking lots can simplify EV charging while parked. However, the surface area of the solar panels and the one-way mounting angle result in suboptimal solar radiation (Shaheen et al., 2026). A rooftop solar PV system integrated with battery energy storage can supply EV charging power under various climate conditions and support the energy transition (Sanda et al., 2027). In addition, charging EVs with a solar PV roof that also serves as an EV parking area in an integrated transportation-distribution network can address energy supply (Nareshkumar, 2025).

Meanwhile, integrating rooftop solar panels and battery electric vehicles into residential energy systems can provide EV charging power (Nadimi et al.,2026). The combined integration of rooftop solar PV installations and electric vehicle charging can reduce the risk of damage to distribution transformers (Gaikwad & Mehta, 2025). Integrating solar PV, battery storage, and electric vehicle charging in a residential complex with a stochastic MPC-based energy management system can optimize electric vehicle charging performance (Saleem et al., 2024).

However, a major challenge in placing rooftop solar PV on homes or parking lots for residential electric vehicle (EV) charging systems is the solar radiation reaching the panel surface, which is affected by the roof's shape, slope, and position and thus impacts solar PV energy production. Previous researchers have integrated solar PV and electric vehicles and demonstrated the ability to meet EV charging

Table 1. Solar PV-inverter power clipping ratio

Parameter	Inverter power Input	Inverter power Output	Inverter power loss (5%-15%)	MCB-DC specifications
Voltage	48 Volt DC	220-230 Volt AC		
Current	119.79 Ampere	22.75	15%	120 MCB-DC
Power	5.75 kW	5 kW		

needs. However, how to optimize solar PV placement and AC and DC charging has not been fully elucidated. Therefore, this study focuses on solar PV placement and charging models for distributing electricity to EVs. A solar PV tree design model is expected to address solar radiation capture issues and provide more stable power to EVs. Results show an average daily electricity production of 18.8514 kWh with an average system energy loss of 1.61 kWh. Implementing this tree-shaped solar PV panel charging system can reduce household electricity bills.

■ METHOD

Equipment and Instruments

Specifications of the equipment used, such as: solar PV Monocrystalline type SOL-24250 W; specifications: power (Pmax) = 250 Wp, voltage (Vmp) = 30.3 V, current (Imp) = 8.25 A, VOC = 36. 3 Volt, ISC = 8.75 A, module efficiency = 15,37%, Temperature = 45 ºC - 80 ºC, dimensions = 1640 x 992 x 35 mm, maximum system voltage = 1000 Volt DC, maximum series fuse rating = 15 Ampere, prime inverter DC/AC 5kW (48VDC/180 - 380 Volt AC), Eight solar PV trees with a capacity of 8 kWp. One solar PV tree has a capacity of 1 kWp, arranged as two series PV panels (500 Wp) and two parallel PV panels (500 Wp). Solar Charge Controller (SCC) of type MPPT (Maximum Power Point Tracking) 48/160 A is used to regulate energy charging to the battery and limit the amount and rate of battery charging. The SCC automatically stops power flow from the solar PV to the battery and prevents battery performance degradation.

MPPT (Maximum Power Point Tracking) tracks the solar panel's maximum power point in real time and converts excess voltage into additional current. This can increase energy efficiency by up to 30%. The SCC system channels excess peak power to the battery and maintains a stable power supply to the inverter. Meanwhile, to maintain the safety of a 5 kW inverter powered by an 8 kW solar PV source during peak conditions, a power clipping ratio is applied. The solar PV-to-inverter clipping ratio is based on the inverter's input and output specifications (48 VDC/220 VAC, 5 kW) and an inverter power-loss rate of 5%-15%. The clipping ratio determines the installation of a Miniature Circuit Breaker (MCB-DC) to limit the electric current entering the inverter to maintain the safety and stability of the inverter's output power. The inverter uses a 120°C MCB-DC to limit the maximum power entering the inverter and functions as an automatic circuit breaker to prevent inverter damage due to overload. The clipping ratio values are presented in Table 1. The schematic of the solar tree system is presented in Figure 3.

Figure 3. Schematic of solar photovoltaic trees for an electric vehicle charger

Measurement Techniques

The solar PV tree system consists of a 152,4 mm diameter iron pipe for the solar PV trees, with a solar photovoltaic installation arranged in a circle at 90° intervals, with 4 solar PV at the top and 4 at the bottom in a cross configuration. Each solar PV tree has a capacity of 1 kWp, for a total of eight trees. The solar PV tree installation is adapted to the research location in Surabaya City, Indonesia,

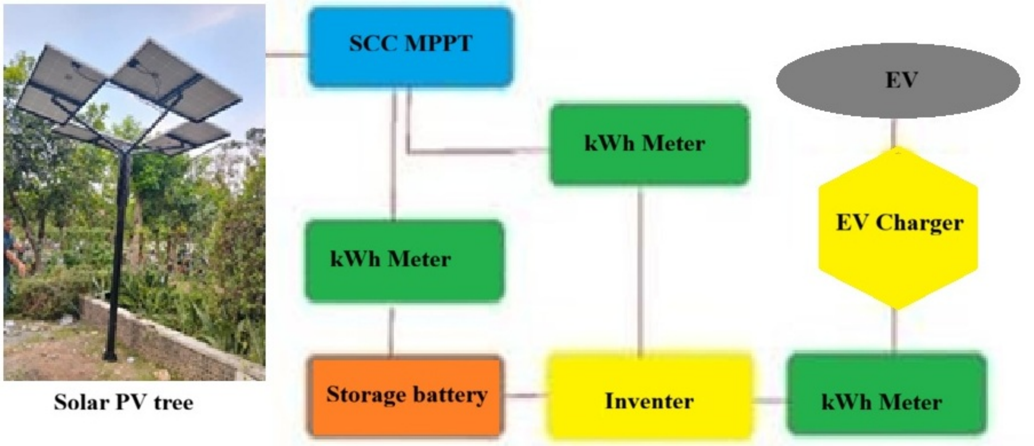

Figure 4. Techno-analysis system of the solar photovoltaic tree

which is located at 7° 9′ - 7° 21′ South Latitude and 112° 36′ – 112° 54′ East Longitude. Solar PV tilt angle: 15 °.

The standard for measuring solar PV performance uses IEC 61724-1: Solar PV system performance. The parameters measured to measure solar PV performance include: 1) Environmental parameters: solar irradiation hitting the solar PV surface, solar PV ambient temperature using a solar meter, and wind speed measured with an anemometer. 2) Measuring electrical parameters: DC and AC power, voltage, current, and energy efficiency. 3) Measuring the actual solar PV efficiency performance compared to theoretical efficiency under reference conditions. 4) Operating time. The electrical energy generated by solar PV trees/day is measured using a kWh meter. The electrical energy generated by solar PV trees is input into the MPPT solar charger controller, where the electrical energy measurement is divided into two measurements, namely, measuring the electrical energy directly used to charge electric vehicles using a kWh meter, and measuring the electrical energy generated by solar photovoltaics stored in the battery pack. The total electrical energy used to charge electric vehicles is measured using a kWh meter. The total electrical energy consumption equals the energy used directly and the energy stored in the battery. Meanwhile, the electrical load includes two types of EV loads: an electric car with a charging capacity of 37.9 kWh and an electric bicycle with a charging capacity of 1.75 kWh. The performance measurement system scheme of the solar PV tree is presented in Figure 4.

■ RESULT AND DISCUSSION

Solar PV Power Production

The power generated by solar PV trees was measured using two measurement techniques: first, by measuring the electricity production generated by the solar PV trees and measuring the energy loss of the grid system, and the second technique was by measuring the electricity consumption of electric vehicles and the energy loss in the EV charging system. Solar radiation and ambient temperature measurements were taken every minute and averaged every 15 minutes around the solar PV to determine the power generated by the solar PV. Solar PV power production is affected by sunshine duration and solar radiation levels. Solar radiation measurements in Surabaya City ranged from 137.77 W/m² to 928.10 W/m². Solar radiation during clear skies at 07.00 AM was 139.50 W/m². The highest value at 11.30 AM was 928.10 W/m². This indicates that solar PV electrical energy production is strongly influenced by solar irradiation, as shown in Figure 5.

Analysis based on solar irradiation values, solar irradiation intensity, and duration of irradiation from the Meteorology, Climatology, and Geophysics Agency in Juanda, Surabaya, shows that solar PV energy production can be estimated, with the highest average clean energy production of solar PV in September at 18.9718 kWh/day during the dry season. The lowest was in December during the rainy season at 3.1981 kWh/day, with energy production of 8,331,955 kWh/year. Increasing temperature on the solar PV surface can reduce solar PV efficiency. This condition can decrease solar PV efficiency by 1.47%–3.94%. Solar PV efficiency analysis can be performed using Equation 1.

$$\eta = \frac{P_{out}}{P_{in}\,x\,A}\,x\,100\% \qquad (1)$$

η is the solar PV efficiency, $P_{ou}t$ is the solar PV output power, P_{in} is the solar input power, and A is the area of the PV panel module. When the

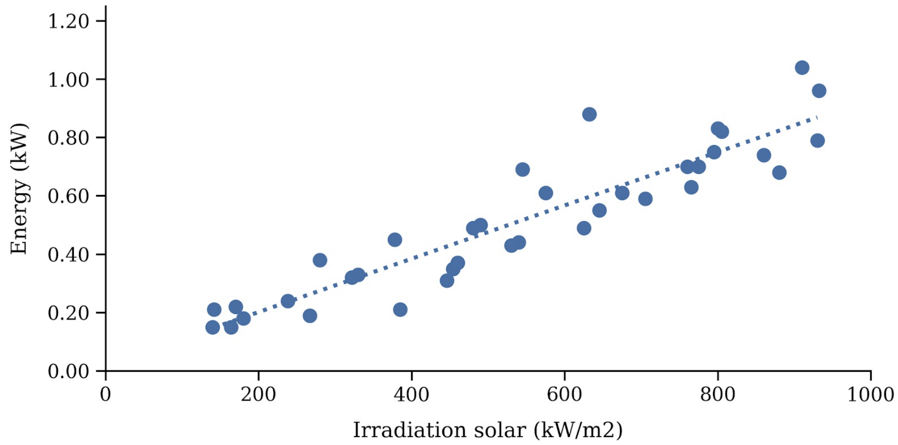

Figure 5. Solar PV power production in Surabaya

sky is clear, with a solar radiation range of 137.77 W/m² to 928.10 W/m², and the radiation duration is 8 hours (07:00 AM–04:00 PM). The solar PV tree generates an average daily electrical energy production of 18.9718 kWh/day, with an efficiency of 2.63%.

The overall system efficiency reduction from solar energy input power to electric vehicle battery charging power is caused by inverter power loss of 8.5%, power loss in electrical conductor cables of about 1.5% of system capacity, battery charging power loss with the MPPT solar cell controller of 1.49%, and power loss due to solar PV temperature increase, which can reduce panel output power of about 1.25%. Several parameters affect the change in the sun's hour angle by 1 degree every 15 minutes. This affects the radiation value received on the surface. Solar PV electrical energy production is presented in Figure 6.

Vehicle Charging Efficiency

To maintain EV battery performance and longevity, EV charging is carried out before the EV battery reaches the 30% limit. Therefore, EV charging is carried out at 70% of the EV's full capacity. For an electric car type EV is 70% of the 37.9 kWh full capacity of the EV battery is 26.52 kWh. An electric bicycle is 70% of its 1.75 kWh full capacity of 1.31 kWh. The charging model uses single-phase AC charging at 220-230 volts. The charging power flow diagram is presented in Figure 7.

The EV charging per-day results are presented in Figure 8 and 9. Electric bicycle charging can reach 1 unit/day, with a charging capacity of 69.83% of the full capacity of 1.75 kWh (1.22 kWh). The electric car type EV charging, on the other hand, reaches 45.83% of the full capacity of 3.9 kWh, or 1.79 kWh. Meanwhile, the energy stored in the energy storage battery is 3.5755 kWh.

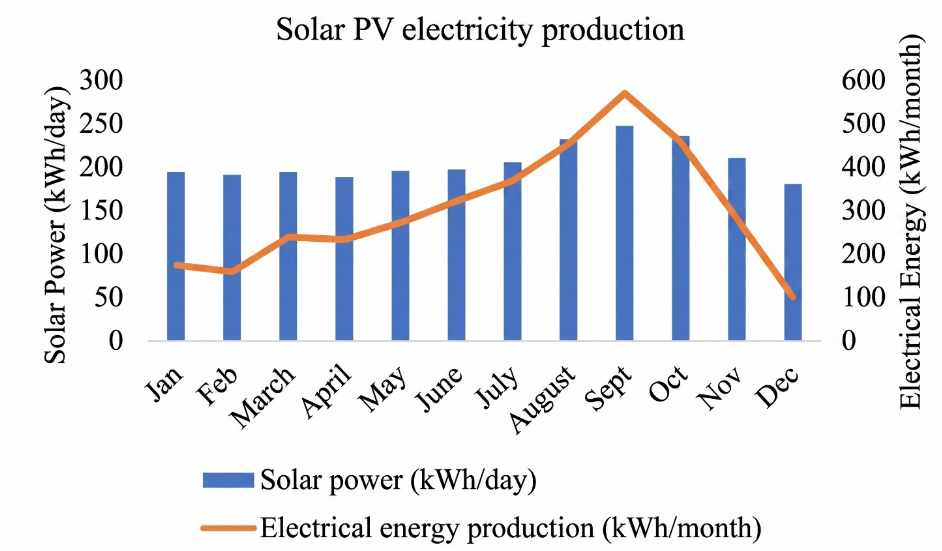

Figure 6. Monthly energy production

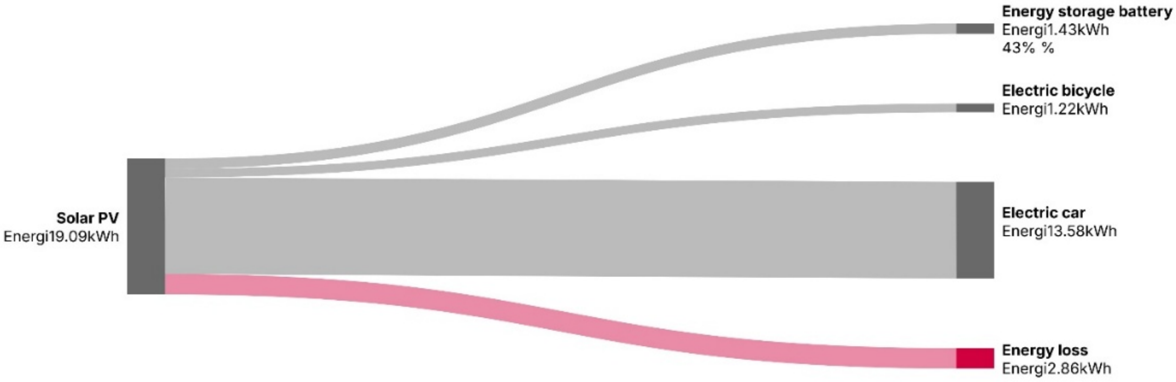

Figure 7. Solar PV distribution of energy

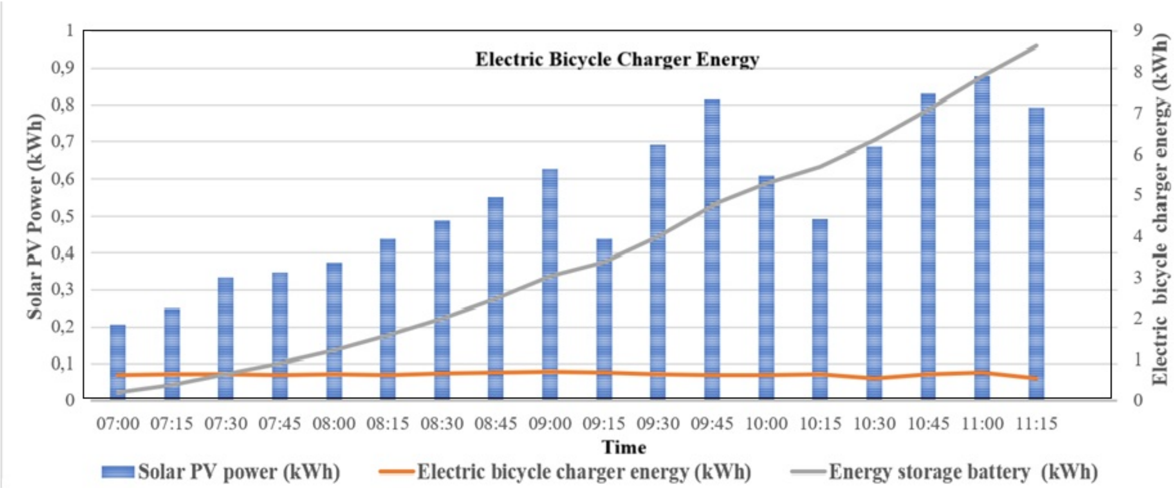

Figure 8. EV charger of the electric bicycle

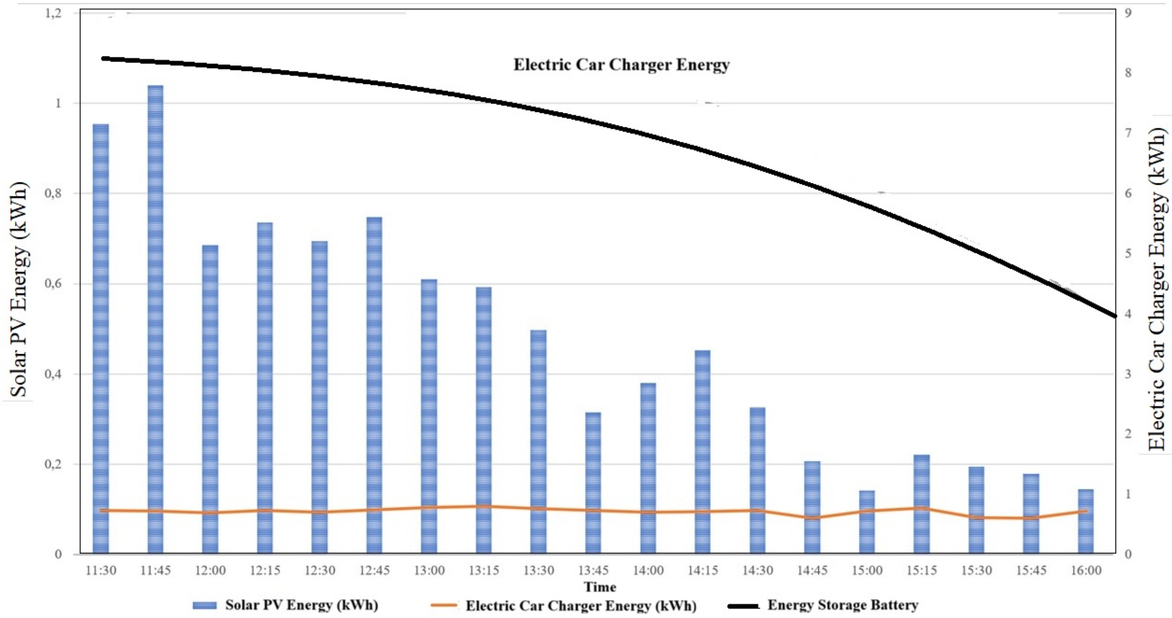

Figure 9. EV charger of the electric cars

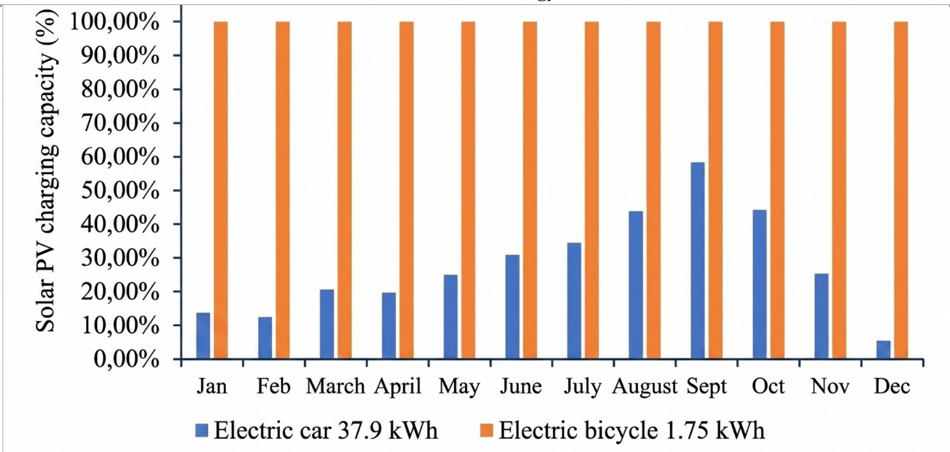

Figure 10. Charger EV capacity

EV charging efficiency is divided into two parts: the efficiency of the solar PV system in producing electrical energy (2.63%) and the efficiency of EV charging from DC to the AC charging system (88.47%). These results align with research on solar energy utilization carried out in several previous studies, such as the implementation of a renewable energy source management system for charging electric vehicles (Engelhardt et al., 2022). Renewable energy utilization strategy to improve electric vehicle mobility. (Schuller et al., 2014) EV charging with smart grid renewable energy in Germany increases charging costs (Corsetti et al., 2024). Renewable energy management and storage for electric vehicle charging can reduce costs (Huang et al., 2023). Renewable energy systems with diverse energy sources can improve electric vehicle charging systems. This can increase the electricity supply for electric vehicle charging (Gönül et al., 2024).

The ratio of electric bicycle to electric car charging capacity shows that electric bicycle charging can reach 100% of the required charging capacity each month; the charging capacity is presented in Figure 10. However, solar PV capacity can only meet an average of 27.84%. Solar PV's capacity to provide electric car charging power was highest in September (58.41%) and lowest in December (5.57%). This is strongly influenced by surface solar irradiation, driven by the dry season in September and the rainy season in December.

Economic feasibility

An economic feasibility analysis of a solar PV system is needed to assess the investment cost of solar PV for EV charging, including the costs of the solar PV, inverter, battery, power grid installation, and construction. The solar PV inventory costs are presented in Table 3. Meanwhile, the annual

Table 3. Solar pv investment costs

Number	Component	Amount	Price (IDR)
A.	**Equipment investment**		
1	Solar PV	32 unit	40,000,000
2	Energy storage battery	10 unit	21,000,000
3	Inverter	1 unit	4,500,000
4	Control unit	1 unit	2,300,000
5	Construction and installation costs	1 packet	3,000,000
	Total Equipment investment		70,800,000
B.	**Operations and maintenance**		
1	Maintenance costs	1 packet	2,000,000
	Total investment costs		72,800,000

Table 4. Electric energy price

Component	Electric energy price
Solar PV capacity	8 kWp
Electric energy price (IDR)	IDR 2950/kWh
Electric energy from Solar PV (kWh/year)	3,622.31 kWh
Charger system losses (kWh)	413.40 kWh
Charger EV from Solar PV	3,165.71 kWh
Electric energy price for solar PV (IDR)	IDR 9,338,839.85
Electric energy consumption (kWh)/year	
Changer EV (kWh)	3,165.71 kWh
Electric energy price (IDR)	IDR 9,338,839.85
Energy in a power storage battery (kWh)	43.2 kWh
Electric energy price (IDR)	IDR 127,440.00
Benefit	Rp 9,466,279.85

solar PV energy production is presented in Table 4.

The Indonesian government's policy on electric vehicle charging providers is regulated in the Minister of Energy and Mineral Resources Regulation Number 1 of 2023. The standard electric charging tariff at the Public Electric Vehicle Charging Station (SPKLU) owned by the State Electricity Company is set at IDR 2.950/ kWh (ESDM, 2023).

The economic feasibility of a household-scale EV charging system using solar PV by integrating the PLN electricity network can be calculated by calculating the Net Present Value (NPV) which is the first year's investment value, the Benefit Cost Ratio (BCR) to analyze the feasibility of investing in EV charging using solar PV, and the Payback Period (PP) to calculate the time period required for the investment funds put into the EV charging investment to be fully returned (Ansori, A et al., 2023). The calculation values are presented in Table 3.

The Net Present Value (NPV) can be calculated using equation 2.

$$NPV = PWB - PWC \tag{2}$$

If the NPV > 0, it means that the investment is feasible, and if the NPV < 0, it means that the investment is infeasible. Where present worth of benefit (PWB) is the cash flow taking into account the benefits and can be calculated by equation 2. Feasibility analysis of solar PV for EV charging: investment is feasible if NPV > 0, and investment is not feasible if NPV < 0.

$$PWB = \sum_{t=0}^{n} Cfb_t \; x \; (Pif)_t \tag{3}$$

Meanwhile, Present Worth of Cost (PWC) is a cash flow that accounts for cost and can be calculated using equation 4.

$$PWC = \sum_{t=0}^{n} Cfc_t \; x \; (Pif)_t \tag{4}$$

Where the investment period is n, and the time period is t, the cash flow benefit is Cfb, the cash flow cost is Cfc, and Pif is the current interest rate. Meanwhile, to analyze the feasibility of investing in photovoltaic solar panels for electric vehicle chargers, the benefit-cost ratio (BCR) is calculated using Equation 5.

$$BCR = \frac{PWB}{PWC} \tag{5}$$

To determine the feasibility of an investment with a BCR value, the investment is considered feasible if BCR > 1, and an investment is not feasible if BCR < 1. If the profit value varies each year, the payback period can be calculated using equation 6.

$$\mathrm{PP} = \mathrm{n} + \frac{(\mathrm{a-b})}{(\mathrm{c-b})} \mathrm{x}\ 1\ \mathrm{Year} \tag{6}$$

n = the required return period for the investment or the final year of cash flow that still falls short of covering the initial investment capital, a = the initial investment amount, b = the cumulative total cash flow in the nth year, c = the cumulative total cash flow in the nth year

$$PP = \sum_{t=0}^{n} Cf_t \; \geq 0 \tag{7}$$

Table 5. The levelized cost of energy (lcoe)

Item Name	Value
Equipment investment costs (IDR)	70,800,000.00
Maintenance costs (IDR)	2,000,000.00
Total investment cost (IDR)	72,800,000.00
Maintenance growth rate (%)	2
Electricity output (kWh)	3622.31
Solar PV lifespan (years)	20
Discount factor (%)	8
Total costs	
Investment cost (IDR)	70,800,000.00
Maintenance costs (IDR) over 20 years	18,688,440.00
Present value costs (IDR)	70,800,000.00
NPV of total costs (IDR)	89,488,440.00
Total energy output	
Yearly output	3,622.31
Present value costs (kWh)over 20 years	33,183.98
NPV of total output (kWh)	36,806.29
LCOE	IDR 2,431.335/kWh

To determine the feasibility of an investment with a PP value, if the PP value ≥ 1, then the investment is considered feasible.

Table 4. Economic feasibility analysis

Method	Value
Present Worth of Benefit (PWB)	IDR 92,941,330.96
Present Worth of Cost (PWC)	IDR 72,800,000
Net Present Value (NPV)	IDR 20,141,330.96
Benefit Cost Ratio (BCR)	1.23
Payback Period (PP)	11.16 (11 Years 2 Months)

Based on the analysis, the Net Present Value (NPV) is positive, and the ratio of the Present Value of Benefits (PWB) to the Present Value of Costs (PWC) is greater than one. Therefore, investing in solar photovoltaic (PV) power for electric vehicle (EV) charging is economically feasible. The solar PV application will pay back the investment within eleven years and two months. The Average Total Cost of a solar PV Per Unit of Total Electricity Generated. The Levelized Cost of Energy (LCOE) is the constant price per unit of energy that will yield the net present value (NPV) for a solar PV system. The LCOE is the ratio of the NPV of the total costs over the lifetime to the NPV of the electrical energy produced over the lifetime. The Levelized Cost of Energy (LCOE) of solar PV can be calculated using Equation 8. The LCOE value of solar PV is IDR 2,431.335/kWh, as presented in Table 8.

$$\text{LCOE} = \frac{\text{NPV of total costs over lifetime}}{\text{NPV of electrical energy produced over lifetime}} \tag{8}$$

CONCLUSION

Using solar photovoltaic (PV) panels in the transition to electric vehicles can help address rising electricity loads and household electricity bills by providing power for EV charging. The PV tree model can address the challenges faced by electric vehicle users who charge at home. The power capacity of the solar PV panel largely determines the electrical energy produced for charging electric vehicles. A solar PV tree with a capacity of 8 kWp can produce 3622.309 kWh/year, with an energy loss of 11.5% during charging (413.40 kWh/year). The solar PV system can charge electric bicycles at 69.83% and electric cars at 45.83%.

Meanwhile, from an economic feasibility perspective, the solar PV tree system for electric vehicle charging is economically feasible, with a payback period of eleven years and two months.

■ ACKNOWLEDGEMENTS

Research funding is supported by the Institute for Research and Community Service of Surabaya State University (UNESA) through UNESA's Non-APBN funds with the Faculty of Engineering policy research scheme in 2025.

■ AUTHOR CONTRIBUTIONS

Aris Ansori (Author 1) is the researcher who formulated the research topic, designed the research instrument, research framework, compiled the data collection plan, and conducted data analysis; Priyo Heru Adiwibowo (Author 2) conducted data analysis and drafted the paper; Indra Herlamba Siregar (Author 3) conducted data collection; Grummy Wailanduw (Author 4) validated the data; and Saiful Anwar (Author 5) Data Curation; Edy Herianto (Author 6) compiled the data collection plan, and conducted data analysis.

■ REFERENCES

Adedeji, B. P. (2023). Electric vehicles survey and a multifunctional artificial neural network for predicting energy consumption in all-electric vehicles. *Results in Engineering*, *19*, 101283.

Afzal, M. Z., Aurangzeb, M., Iqbal, S., Pushkarna, M., Rehman, A. U., Kotb, H., ... & Bereznychenko, V. (2023). A novel electric vehicle battery management system using an artificial neural network-based adaptive droop control theory. *International Journal of Energy Research*, *2023*(1), 2581729.

Ahmed, S., Bloom, I., Jansen, A. N., Tanim, T., Dufek, E. J., Pesaran, A., ... & Zhang, J. (2017). Enabling fast charging–A battery technology gap assessment. *Journal of Power Sources*, *367*, 250–262.

Ansori, A., Arsana, I. M., Siregar, I. H., Adiwibowo, P. H., & Haryuda, S. I. (2023). Techno-Economic Analysis of Triangular Rooftop Solar Pv Model/Pln on-Grid Household Scale in Indonesia. *ASEAN Eng. J*, *13*(4).

Asaad, M., Shrivastava, P., Alam, M. S., Rafat, Y., & Pillai, R. K. (2018, April). Viability of xEVs in India: A public opinion survey. In *ISGW 2017: Compendium of Technical Papers: 3rd International Conference and Exhibition on Smart Grids and Smart Cities* (pp. 165–178). Singapore: Springer Singapore.

Bastida-Molina, P., Hurtado-Pérez, E., Gómez, M. C. M., & Vargas-Salgado, C. (2021). Multicriteria power generation planning and experimental verification of hybrid renewable energy systems for fast electric vehicle charging stations. *Renewable Energy*, *179*, 737–755.

Beiron, J., Normann, F., & Johnsson, F. (2022). A techno-economic assessment of CO2 capture in biomass and waste-fired combined heat and power plants–A Swedish case study. *International Journal of Greenhouse Gas Control*, *118*, 103684.

Bishla, S. (2024). A survey of fast charging systems in electrical vehicles using solar and grid sources. *J. Electrical Systems*, *20*(7s), 4084–4105.

Bunsen, T., Cazzola, P., Gorner, M., Paoli, L., Scheffer, S., Schuitmaker, R., ... & Teter, J. (2018). Global EV Outlook 2018: Towards cross-modal electrification.

Corsetti, A., Castro, R., Geyken, C., & Mohan, A. (2024). Commercial EV fleet smart charging for cost reduction and renewables integration: A case study in Germany. *Journal of Energy Storage*, *100*, 113765.

Ekren, O., Canbaz, C. H., & Güvel, Ç. B. (2021). Sizing of a solar-wind hybrid electric vehicle charging station by using HOMER software. *Journal of Cleaner Production*, *279*, 123615.

Engelhardt, J., Zepter, J. M., Gabderakhmanova, T., & Marinelli, M. (2022). Energy management of a multi-battery system for renewable-based high power EV charging. *ETransportation*, *14*, 100198.

Eom, D., Choi, J., Song, J., Park, B., Kim, S. J., & Park, S. (2025). Techno-economic analysis of grid-connected highway solar EV charging station. *International Journal of Precision Engineering and Manufacturing-Green Technology*, *12*(2), 573–590.

Fretzen, U., Ansarin, M., & Brandt, T. (2021). Temporal city-scale matching of solar photovoltaic generation and electric vehicle charging. *Applied Energy, 282*, 116160.

Gaikwad, S., & Mehta, H. (2025). Mitigating distribution transformer loss of life through combined integration of rooftop solar photovoltaic installations and electric vehicle charging. *e-Prime-Advances in Electrical Engineering, Electronics and Energy*, *11*, 100867.

Gönül, Ö., Duman, A. C., & Güler, Ö. (2024). Multi-objective optimal sizing and techno-economic analysis of on-and offgrid hybrid renewable energy systems for EV charging stations. *Sustainable Cities and Society*, *115*, 105846.

Goswami, A., & Sadhu, P. K. (2021). Stochastic firefly algorithm enabled fast charging of solar hybrid electric vehicles. *Ain Shams Engineering Journal*, *12*(1), 529–539.

Himani Bhatt; Nikunj Patel. Examining the Potential of Renewable Energy Sources to Help Promote the Adoption of Electric Vehicles in A Smart Grid Setting. J. Electrical Systems 18-4(2022):520–531.

Huang, Q., Yang, L., Zhou, C., Luo, L., & Wang, P. (2023). Pricing and energy management of EV charging station with distributed renewable energy and storage. *Energy Reports*, *9*, 289-295.

International Energy Agency. (2025). Retrieved 05 April, 2026, https://www.iea.org/data-and-statistics/charts/co2-emissions-from-electricity-generation-in-china-2014-2026

Juanda Meteorology, Climatology, and Geophysics Agency (2025). Retrieved 10 january, 2025, https://stamet-juanda.bmkg.go.id/home/pages/pelayanan/prosespelayanan.php

Krause, J., Thiel, C., Tsokolis, D., Samaras, Z., Rota, C., Ward, A., ... & Verhoeve, W. (2020). EU road vehicle energy consumption and CO2 emissions by 2050–Expert-based scenarios. *Energy Policy*, *138*, 111224.

Keyser, M., Pesaran, A., Li, Q., Santhanagopalan, S., Smith, K., Wood, E., ... & Markel, A. (2017). Enabling fast charging–Battery thermal considerations. *Journal of Power Sources*, *367*, 228–236.

Kumar, N., Kumar, T., Nema, S., & Thakur, T. (2022). A comprehensive planning framework for electric vehicles fast charging station assisted by solar and battery based on Queueing theory and non-dominated sorting genetic algorithm-II in a co-ordinated transportation and power network. *Journal of Energy Storage*, *49*, 104180.

Nadimi, R., & Goto, M. (2025). Analyzing incentivized self-consumption and integration of rooftop solar and battery electric vehicles in residential energy systems. *Renewable Energy*, 124937.

Nareshkumar, K., & Das, D. (2025). A novel planning and operation strategy of solar rooftop EV parking lots in a coupled transportation-distribution network considering uncertainties. *Sustainable Energy, Grids and Networks*, 101988.

Nishanthy, J., Charles Raja, S., Praveen, T., Jeslin Drusila Nesamalar, J., & Venkatesh, P. (2022). Techno-economic analysis of a hybrid solar wind electric vehicle charging station on highway roads. *International journal of energy research*, *46*(6), 7883–7903.

Nowtricity. (2025). *Current emissions in Sweden*. Retrieved 05 April, 2025 from https://www.nowtricity.com/country/sweden/

Ramasamy, L., Soundirarajan, N., & Varsha, R. J. (2024). Artificial neural network based bidirectional converter control for electric vehicle charging. In *Proceedings of the First International Conference on Science, Engineering and Technology Practices for Sustainable Development (ICSETPSD)*.

Ray, P., Bhattacharjee, C., & Dhenuvakonda, K. R. (2022). Swarm intelligence-based energy management of electric vehicle charging station integrated with renewable energy sources. *International Journal of Energy Research*, *46*(15), 21598–21618.

Reddy, Y. M., Prasad, P. V., Mustare, N., Ananda, M. H., Devi, S. C., & Prabagaran, S. (2024). Integrating IoT and Artificial intelligent for Enhanced Electric Vehicle Charging and Autonomous Driving for sustainable transportation. *J. Electr. Syst*, *20*, 893–900.

Regulation of the Minister of Energy and Mineral Resources Number 1 of 2023 concerning the Provision of Electric Charging Infrastructure for Battery-Based Electric Motor Vehicles, 09 January 2023.

Saleem, M. I., Saha, S., Izhar, U., & Ang, L. (2024). A stochastic MPC-based energy management system for integrating solar PV, battery storage, and EV charging in residential complexes. *Energy and Buildings*, *325*, 114993.

Sanda, M. G., Abdullahi, M., Umar, B. A., Maibugu, T. J., & Shirputda, J. J. (2026). Design and performance assessment of a grid-connected rooftop solar photovoltaic system integrated with battery energy storage for electric vehicle charging across varied climatic conditions to enhance energy transition. *Unconventional Resources*, 100449.

Schuller, A., & Hoeffer, J. (2014). Assessing the impact of EV mobility patterns on renewable energy oriented charging strategies. *Energy Procedia*, *46*, 32–39.

Shaheen, S., Saini, V. K., Allouhi, A., & Al-Sumaiti, A. S. (2026). Energy and economic assessment of solar PV on stadium parking rooftops: Case study of football stadiums in Qatar. *Sustainable Energy Technologies and Assessments*, *87*, 104896.

Singh, A. P., & Kumar, Y. (2024). Artificial neural network based active power management controller for electric vehicle charging station. *International Journal of Ambient Energy*, *45*(1), 2268102.

Ullah, Z., Wang, S., Wu, G., Hasanien, H. M., Rehman, A. U., Turky, R. A., & Elkadeem, M. R. (2023). Optimal scheduling and techno-economic analysis of electric vehicles by implementing solar-based grid-tied charging station. *Energy*, *267*, 126560.

Viswa Teja, A., Razia Sultana, W., & Salkuti, S. R. (2023). Performance explorations of a PMS motor drive using an ANN-based MPPT controller for solar-battery powered electric vehicles. *Designs*, *7*(3), 79.

Yadav, B. K., Pokharel, N., Yadav, L., Yadav, R., & Yadav, N. K. (2026). Rooftop solar PV for green campus and EV charging hub. *Research in Transportation Business & Management*, *67*, 101717.

Yap, K. Y., Chin, H. H., & Klemeš, J. J. (2022). Solar Energy-Powered Battery Electric Vehicle charging stations: Current development and future prospect review. *Renewable and Sustainable Energy Reviews*, *169*, 112862.

Zhao, J., Xi, X. I., Na, Q. I., Wang, S., Kadry, S. N., & Kumar, P. M. (2021). The technological innovation of hybrid and plug-in electric vehicles for environment carbon pollution control. *Environmental Impact Assessment Review*, *86*, 106506.