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EV residential charging station with renewable energy sources

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ABSTRACT

The rapid growth of electric vehicles (EVs) has created an urgent need for reliable and sustainable charging infrastructure, as conventional grid-powered stations contribute to greenhouse gas emissions and increase grid dependency. This study investigates the design and performance of a residential EV charging station in Hai-Alandalus, Libya, powered by renewable energy sources. Using HOMER Pro software, three microgrid configurations were simulated: a grid-connected PV–wind hybrid, an autonomous microgrid with PV and one wind turbine, and an autonomous microgrid with PV and two wind turbines. The analysis incorporated local solar and wind resources, household demand, EV charging patterns, and battery storage performance. The results show that the grid-connected system is the most cost-effective, with a renewable fraction of 78.9% and the ability to export surplus electricity, although it remains partially reliant on the grid. In contrast, the autonomous systems achieved renewable fractions up to 89.3% and eliminated operational emissions but required higher capital investments and exhibited significant levels of excess electricity. Overall, the findings confirm that renewable-powered EV charging stations are technically feasible and environmentally beneficial in regions with high solar–wind potential. While grid-connected hybrids provide the most economical pathway, autonomous systems deliver full decarbonization. Future research should focus on smart charging strategies, vehicle-to-grid integration, and optimization methods to enhance efficiency and economic viability.

1. Introduction

Electric vehicle (EV) production relies upon a few factors: the purchase price of the EV, self-rule, charging operation, and charging infrastructure. This project is focused on the design of EV residential charging stations with renewable energy. The use of electric vehicles and renewable energy has many benefits, such as reducing oil consumption, reducing emitted gases, and integrating renewable energy sources into the power grid [1]. The installation of charging stations for electric vehicles (EVCSs) is important to promote large-scale acceptance of electric vehicles (EVs), which will minimize range anxiety about the distance the EV will cover until the battery runs out.

Renewable energy or clean energy is a common concept utilized to depict energy extracted from indefinitely renewable natural sources that can be replenished in a short period, including energy from the sun, wind, water, and biomass. These resources are compared with fossil fuels, which consist largely of oil, coal, and natural gas and are nonrenewable, meaning that a finite quantity of such resources is available.

Renewable energy sources originate from solar radiation (solar energy), wind energy, and geothermal heat (the Earth's abdomen). Tapping only a small portion of it would, in principle, be sufficient to convey all vitality administrations that humankind needs. Most renewable energy sources can be transformed into electricity. Only a few of them can be utilized to directly generate solid, liquid, or gaseous fuel, as well as heat. A portion of the

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Significant sources are discontinuous, which can pose difficulties in the implementation of these sources while preserving the accuracy of the aggregate energy supply, which relies on how widely used they are.

Sources for producing renewable energy emit almost no greenhouse gases or contaminants into the environment. This implies a lesser carbon impression and a generally positive influence on the natural environment. During the combustion process, fossil fuels release large concentrations of greenhouse gases, which have been shown to intensify global temperature increases and the frequency of severe weather events. The utilization of nonrenewable energy sources not only emits greenhouse gases but also other harmful pollutants, which leads to problems in respiratory and cardiac health. They require less by and more upkeep than generators that utilize conventional fuel sources do. This may be because innovations such as solar panels and wind turbines do not have many or no moving parts and do not rely on flammable sources of fuel for operation [2].

The case study of this project is located in Hai-Alandalus, Libya, where this region has a hot semiarid climate with hot summers and wet winters. An electric vehicle charging station (EVCS) design that uses renewable energy will be developed by considering electric energy production, electric energy consumption, greenhouse gas emissions, and cost. The cases studied in this project are an EVCS connected to the grid, an isolated microgrid EVCS with one turbine, and an isolated microgrid EVCS with 2 turbines, where renewable energy sources such as solar energy and wind energy are considered to supply the electric vehicle charging station. To obtain the simulation results, the hybrid optimization of multiple energy resources (HOMER Pro) software is used for modeling the electric vehicle charging station using renewable energy and is designed on the basis of actual input data regarding physical, operational, and economic characteristics.

2. Methods

The simulation of the EV residential charging station with renewable energy sources has been performed via HOMER PRO. The 3 situations for the EV charging station discussed in this chapter are a microgrid with EVCSs, an isolated microgrid EVCS with one turbine, and an isolated microgrid with an EVCS with 2 turbines, where renewable energy sources such as solar energy and wind energy are considered to supply the electric vehicle charging station. The location for this simulation was in Hai-Alandalus, Libya, with different charging intervals for the EV. Different charging intervals were considered in this simulation for the 3 cases. Table 1 shows the charging intervals for the EV.

Table 1 Charging intervals for the EV.

Case	Charging intervals for the EV
1	02am-04am
2	08am-10am
3	12pm-14pm
4	16pm-18pm
5	20pm-22pm

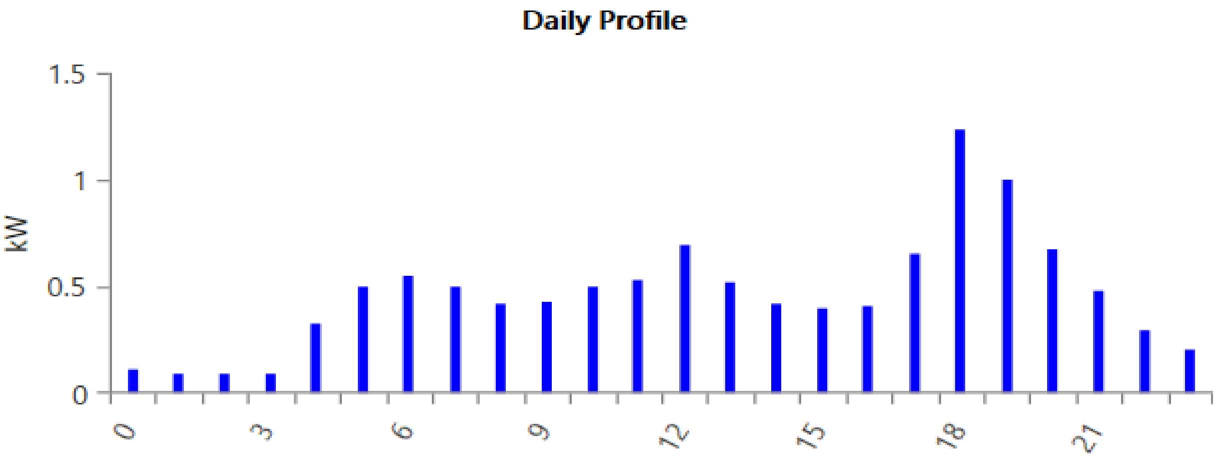

Figure 1 Daily profile of EV charging.

The annual average household electricity load in Hai-Alandalus is estimated at approximately 4 kWh/day, reflecting the modest yet consistent demand typical of residential settings in the region. Figure 1 shows the daily load profile, whereas Figure 2 presents the seasonal variation, both of which highlight how household energy use fluctuates throughout the day and across different times of the year. Understanding these consumption patterns is critical for designing efficient and reliable residential charging stations, as they define the baseline energy demand that must be met by either renewable sources or supplementary grid supplies.

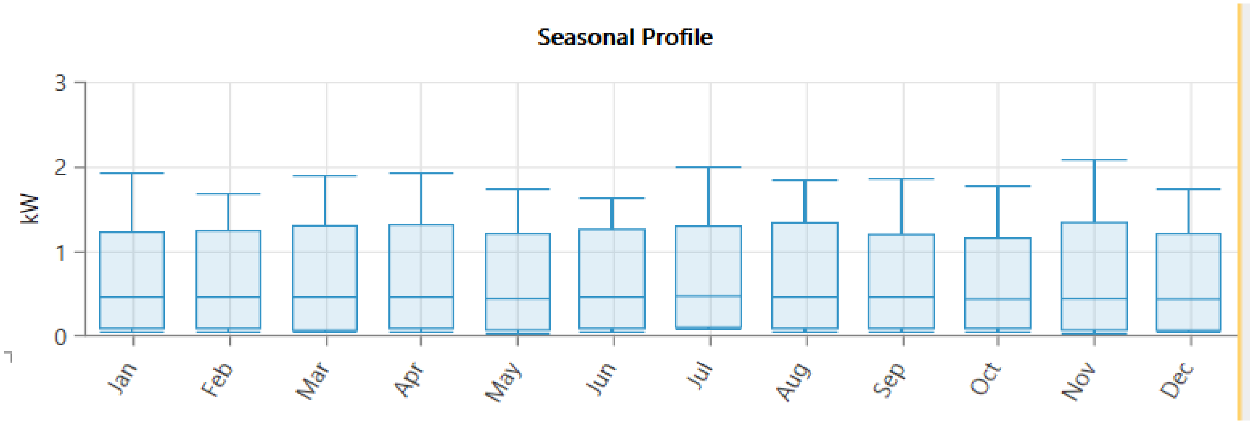

Figure 2 Seasonal profile of EV charging.

In parallel, renewable resource availability was assessed to evaluate the potential of solar and wind energy in the area [3]. According to the NASA Surface and Solar Energy Database, Hai-Alandalus receives an average annual solar radiation of 5.11 kWh/m²/day, underscoring the region's strong solar potential (Figure 3). Similarly, the average annual wind speed is recorded at 5.31 m/s, which is also derived from NASA data, with the wind profile shown in Figure 4. Together, these figures confirm that Hai-Alandalus benefits from abundant renewable energy resources, making it a suitable candidate for integrating solar and wind power into residential energy systems and electric vehicle charging infrastructure [4].

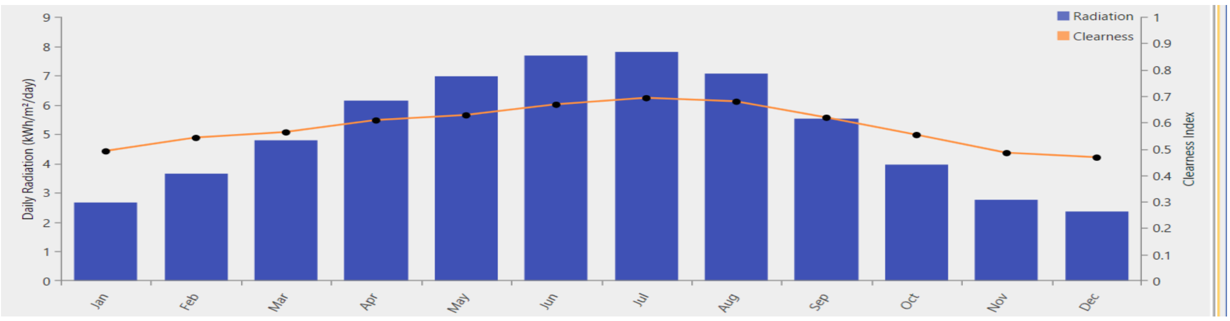

Figure 3 . Solar radiation profile.

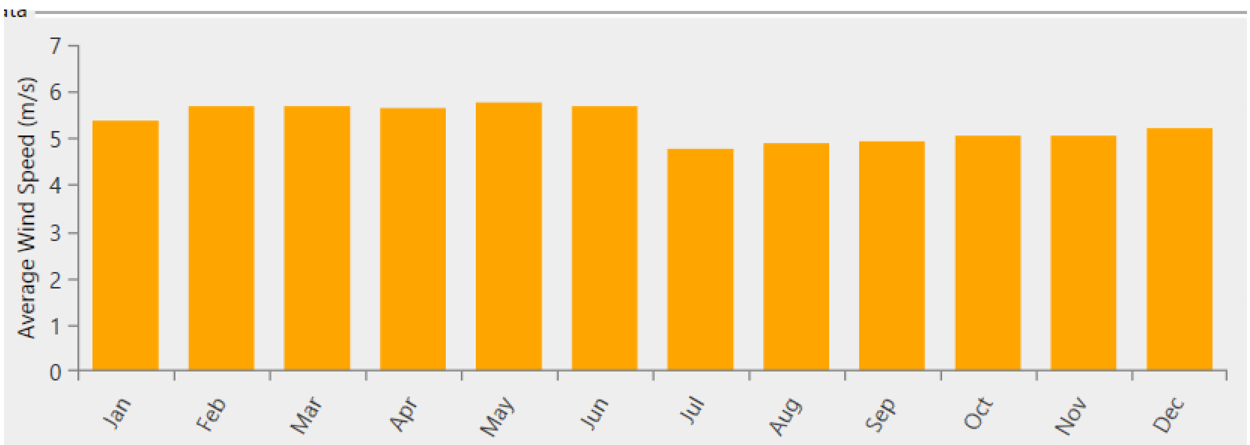

Figure 4 Wind speed profile.

3. Results

3.1. Case 1: Grid-connected with PV panels and a wind turbine

In this situation, the loads are supplied with the necessary power via renewable energy sources while being grid-connected. The system uses renewable energy sources such as solar energy and wind energy, which depend on the weather conditions. For the power produced by the PV system and the wind system, if not needed by the local loads, the surplus flows into the grid. When the load capacity is greater than the power produced by the PV panel and wind turbine, the grid will support the additional demand for the loads [5-7].

A schematic of the microgrid electric vehicle charging station (EVCS) is presented in Figure 5. This configuration relies on a 4 kW photovoltaic (PV) array and a 1 kW wind turbine operating while connected to the grid. The average daily EV load is 3 kWh/day, which is typically consumed between 02:00 and 04:00 in the morning. The monthly energy balance is shown in Figure 6, where the system generates 76.5% of its electricity from PV panels, 3.72% from the wind turbine, and the remaining 19.8% from the grid, indicating that the system is heavily dependent on solar power. The overall renewable energy penetration reaches 85.6% (Figure 7), confirming the dominant contribution of renewable sources to the microgrid's performance.

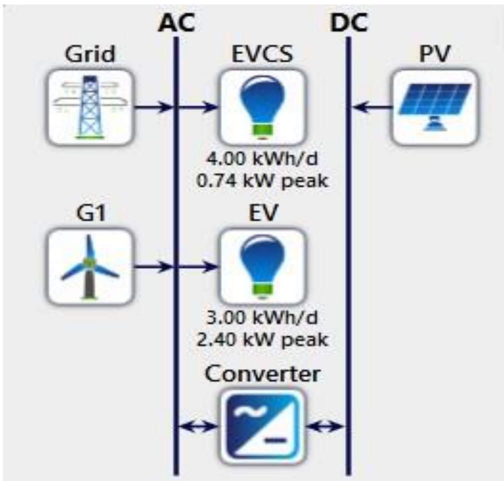

Figure 5 EVCS configuration.

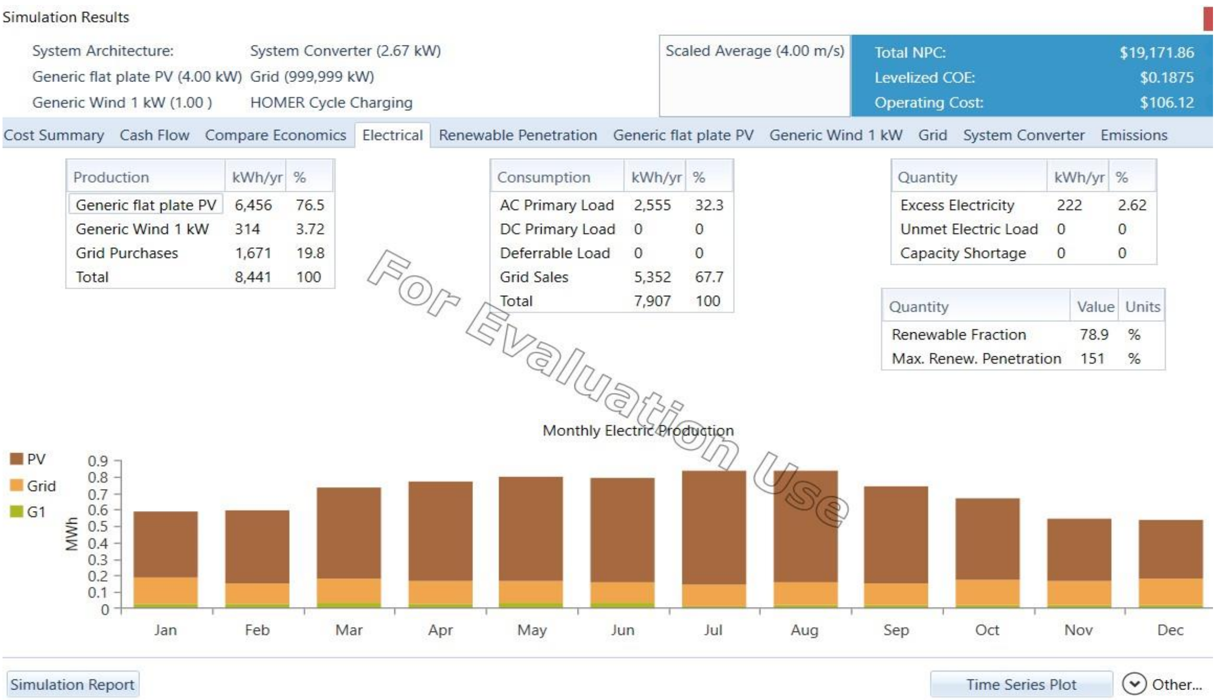

Figure 6 Electric energy production and consumption for the EVCSs.

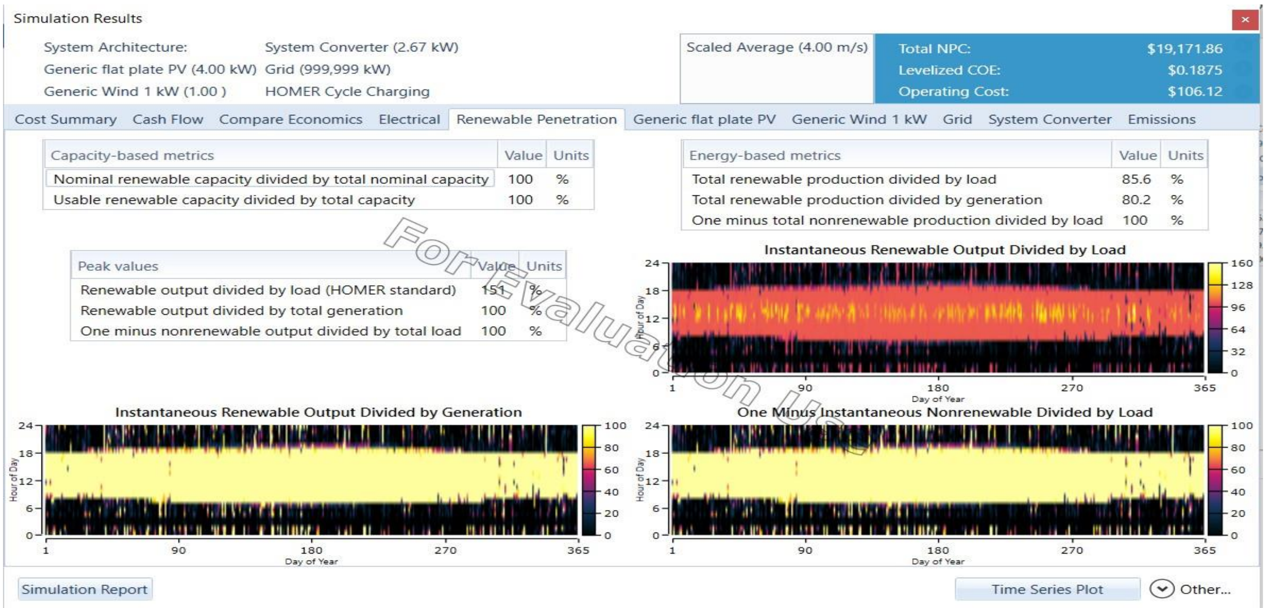

Figure 7 Renewable Penetration.

The renewable components were analyzed individually. The generic flat-plate PV array has a rated capacity of 4.06 kW and produces approximately 6,456 kWh/year. The wind turbine, rated at 1 kW, contributes an additional 314 kWh/year. While renewable energy provides the majority of the supply, the system remains grid-tied to ensure reliability during periods of low resource availability. Any surplus energy from the PV and wind systems is exported to the grid. A converter with a capacity of 2.67 kW ensures the conversion between alternating current and direct current. Conversion losses are estimated at 312 kWh/year, with 6,234 kWh/year entering the inverter and 5,922 kWh/year being delivered to the loads.

Economic and environmental assessments were also conducted. The total net present cost of the grid-connected microgrid is approximately $19,171.86 (Figure 8). Capital investments are largely attributed to the PV panels and wind turbine, whereas the system converter incurs replacement costs after 15 years and the wind turbine after 20 years. Routine PV maintenance is also required throughout the lifetime of the system. From an environmental perspective, although emissions are not fully eliminated due to grid connections [8], the integration of renewables significantly reduces greenhouse gases compared with a purely grid-supplied scenario. As shown in Table 2, the system lowers the emissions of carbon dioxide, sulfur dioxide, and nitrogen oxides, demonstrating the effectiveness of renewable integration in reducing the environmental footprint of residential EV charging [9].

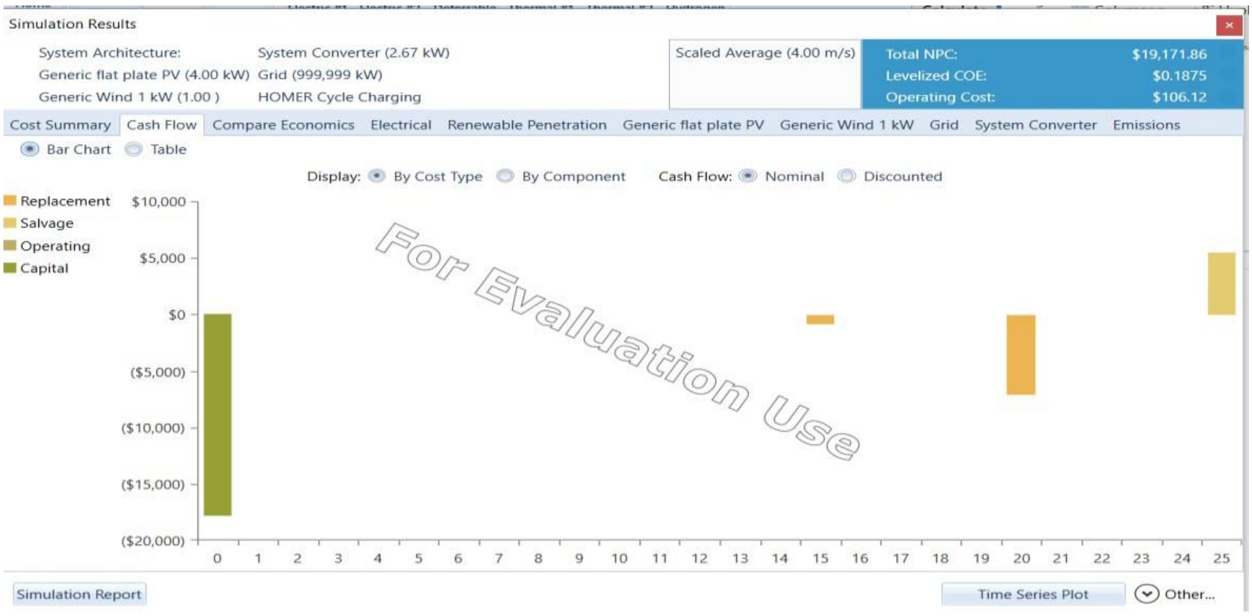

Figure 8 Cash flow.

Table 2 Effects of EVCS analysis on environmental emissions.

Quantity	Value	Units
Carbon Dioxide	1056	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	4.58	kg/yr
Nitrogen Oxides	2.24	kg/yr

3.2. Case 2: Autonomous system with PV panels and a wind turbine

The electric vehicle charging station was designed as an autonomous microgrid powered exclusively by renewable energy sources. The configuration, shown in Figure 9, consisted of a 4 kW photovoltaic (PV) array, a 1 kW wind turbine, and a battery storage system. This setup enables a continuous supply, with energy stored during periods of surplus production and drawn from batteries when solar and wind resources are insufficient. The average EV load remained 3 kWh/day and was typically charged between 08:00 and 10:00.

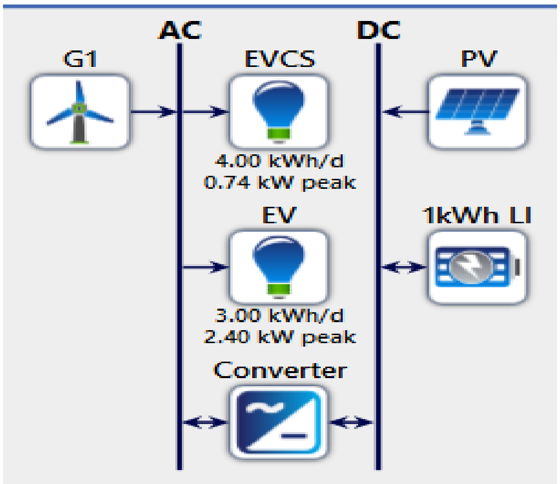

Figure 9 EVCS configuration.

The simulation results demonstrate that this system is heavily PV-dominated, with 87.6% of the energy provided by solar panels and 12.4% by the wind turbine (Figure 10). The PV array achieved an annual production of approximately 6,456 kWh/year, whereas the wind turbines contributed approximately 910 kWh/year. Battery storage played a central role in ensuring autonomy, with a total of 24 lithium-ion batteries (48 V bus voltage) storing surplus energy. Over one year, approximately 1,084 kWh was fed into the battery system, whereas 982 kWh was discharged for use, with storage losses of 109 kWh (Figure 11). The conversion efficiency also influences performance, with 2,125 kWh/year entering the inverter and 2,018 kWh/year being delivered to the loads, resulting in conversion losses of approximately 106 kWh/year.

Figure 10 The electric energy production and consumption for the EVCS.

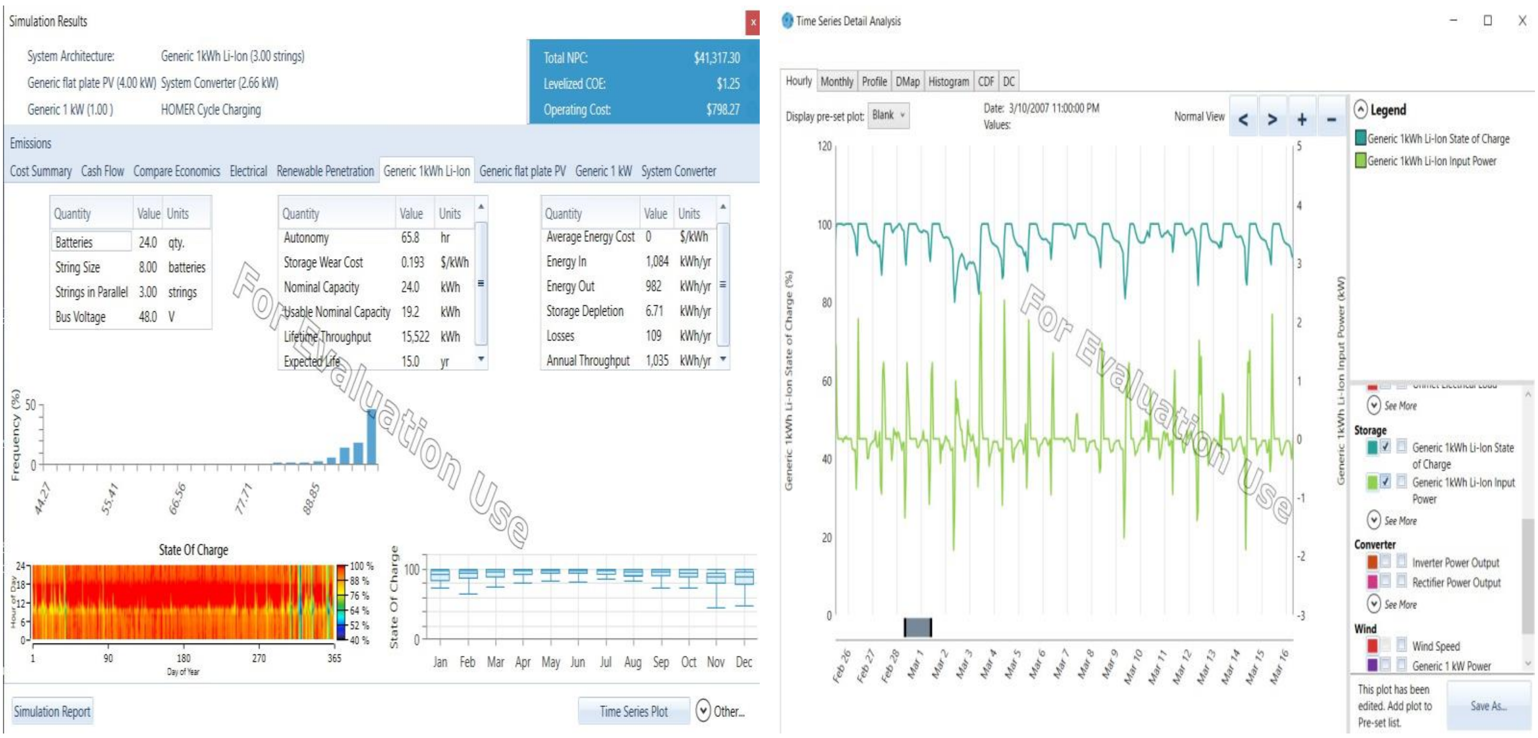

Figure 11 Generic 1 kWh lithium-ion battery: configuration, state of charge profile, and input power flow.

A notable advantage of this autonomous system is its environmental performance. Since it operates independently from the grid and relies solely on renewable sources, it achieves zero greenhouse gas emissions. As summarized in Table 3, no carbon dioxide, sulfur dioxide, nitrogen oxides, or other pollutants are emitted. This finding positions the autonomous PV–wind–battery system as a clean and sustainable alternative for residential EV charging that is capable of significantly reducing the environmental footprint of transportation in regions with strong solar and wind potential, such as Hai-Alandalus.

Table 3 Effects of EVCS analysis on environmental emissions

Quantity	Value	Units
Carbon Dioxide	0	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr

Particulate Matter	0	kg/yr
Sulfur Dioxide	0	kg/yr
Nitrogen Oxides	0	kg/yr

3.3. Case 3: Autonomous with PV panels and 2 wind turbines

The electric vehicle charging station was designed as an autonomous microgrid powered by a 4 kW photovoltaic array and two 1 kW wind turbines, supported by battery storage (Figure 12). The average EV load of 3 kWh/day was scheduled between 12:00 and 14:00. Energy is generated from solar and wind resources and stored in batteries, ensuring a continuous supply during periods of low production.

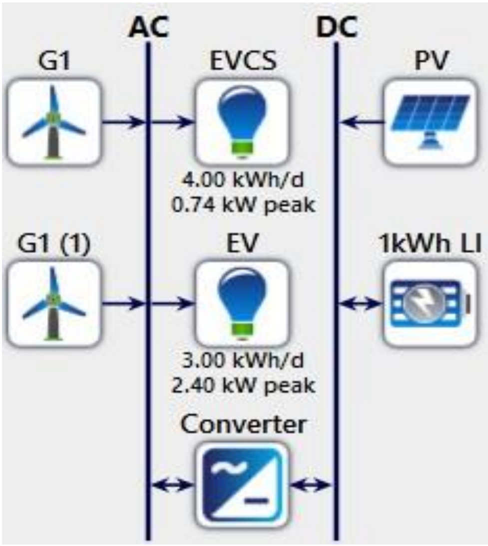

Figure 12 EVCS configuration

The simulation results revealed that the system remained PV-dominated, with 78% of the annual electricity generated from solar panels and 22% from wind turbines (Figure 13). The PV array produced 6,456 kWh/year, while each wind turbine contributed 910 kWh/year, providing a combined output of approximately 1,820 kWh/year. The battery storage system was composed of 16 lithium-ion batteries (48 V bus voltage) connected in two parallel strings. Over one year, 624 kWh was charged into the batteries, and 565 kWh was discharged, with total storage losses of approximately 62.6 kWh/year (Figure 14). The conversion efficiency also affected performance: 1,851 kWh/year entered the inverter, and 1,758 kWh/year was delivered to the loads, corresponding to conversion losses of approximately 92.5 kWh/year. The renewable penetration of the system reached 324% (Figure 53), confirming the substantial surplus of renewable generation relative to the local load demand.

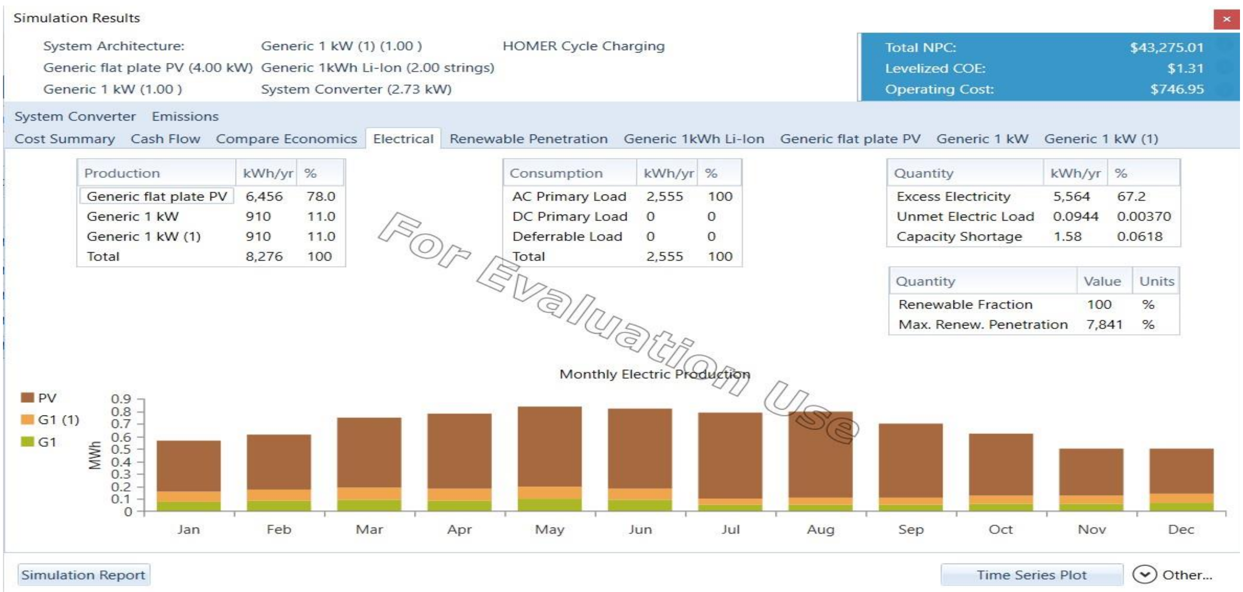

Figure 13 Electric energy production and consumption for the EVCSs

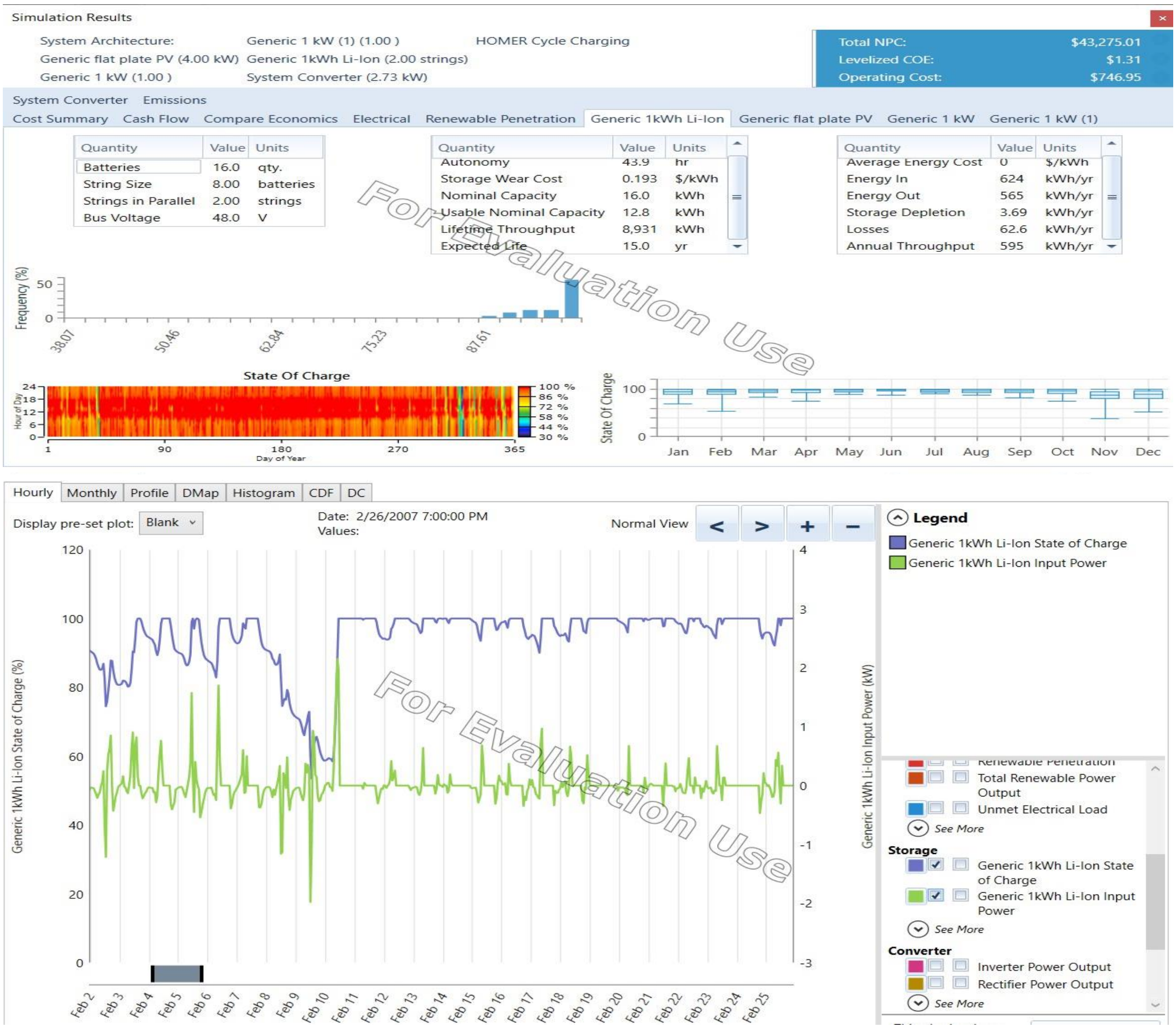

Figure 14 Generic Li-Ion batteries, Generic 1 kWh Li-Ion state of charge and input power.

From an economic perspective, the system was the most capital-intensive configuration among those analyzed. The total net present cost was estimated at $43,275.01, reflecting the investment in two wind turbines, PV panels, battery storage, and the inverter system. The maintenance and replacement costs are also significant: lithium-ion batteries and the converter require replacement at year 15, whereas both wind turbines must be replaced after 20 years. Routine PV panel maintenance is expected throughout the system's operational lifetime. Despite its higher cost, this system provides complete energy autonomy and ensures zero greenhouse gas emissions, positioning it as a sustainable but expensive solution for residential EV charging in regions with strong solar and wind potential.

4. Discussion

The results demonstrate that increasing renewable integration systematically improves autonomy and reduces utility dependence in residential EV charging microgrids. Case 1 (grid-connected PV–wind) achieved a renewable fraction of 78.9%, whereas the autonomous configurations in Case 2 and Case 3 reached 85.4% and 89.3%, respectively (see Table 4). Grid purchases fell from 1,671 kWh/yr (Case 1) to 744 kWh/yr (Case 3), indicating greater self-sufficiency as the wind capacity and storage strategy were adjusted. These outcomes align with prior reports that PV-dominant designs perform well in high–insolation regions, whereas incremental wind support smooths variability and lifts the renewable share. They also support the prevailing theory that hybridization (PV + wind) reduces the probability of coincident low-generation events, thereby lowering grid reliance. A minor tension with expectations is the still modest role of wind in Cases 2–3, suggesting that site-specific wind regimes and turbine sizing remain critical determinants of yield.

Table 4 Comparative performance of cases in terms of the renewable fraction, grid purchases, grid sales, and excess electricity.

Parameter	Case 1	Case 2	Case 3
Excess electricity kWh/yr	222	222	222
%	2.62%	2.83%	2.95%
Renewable fraction %	78.9%	85.4%	89.3%
Grid purchases kWh/yr	1671	1069	744
%	19.8%	13.6%	9.90%
Grid Sales kWh/yr	5352	4751	4426
%	67.7%	65%	63.4%

Battery behavior further clarifies system dynamics. Case 1 cycled 1,808 kWh/yr in and 1,634 kWh/yr out, whereas the throughput decreased to 1,084/982 kWh/yr (Case 2) and 726/659 kWh/yr (Case 3) as the renewable share increased (see Table 5). This finding supports storage-sizing theory: as onsite generation better aligns with the load, the required battery energy exchange and associated losses decline. The slight rise in excess electricity from 2.62% (Case 1) to 2.95% (Case 3) indicates growing seasonal or midday surpluses—consistent with PV-led portfolios—and underscores the importance of curtailment management or productive use of surplus (e.g., thermal loads or flexible appliances).

Table 5 Battery charging and discharging energy flows with excess electricity

Parameter	Case 1	Case 2	Case 3
Excess electricity kWh/yr	4523	4599	4634
%	61.4%	62.4%	62.9%
Battery energy IN kWh/yr	1808	1084	726
Battery energy OUT kWh/yr	1634	982	659

A complementary view of surplus and storage confirms these trends. Across the alternative dataset, excess electricity grows modestly across the three cases (to ~67% of annual load equivalents in the most autonomous option), whereas battery IN/OUT again diminishes with a higher renewable fraction (see Table 6). Practically, this means that beyond a certain point, adding generation capacity shifts the challenge from adequacy to utilization: without smart demand shaping or export channels, additional renewable capacity yields diminishing returns to autonomy but increases curtailed energy.

Table 6 Alternative dataset of battery energy input/output and excess electricity.

Parameter	Case 1	Case 2	Case 3
Excess electricity kWh/yr	5447	5529	5564
%	65.8%	66.8%	67.2%
Battery energy IN kWh/yr	1692	961	624
Battery energy OUT kWh/yr	1527	869	565

These findings have several implications for the field and for practice. First, in sunny, coastal climates, PV-led designs with modest wind support appear to be the most effective route to high renewable fractions for residential EV charging, with Case 3 offering the strongest technical outcome and Case 2 a near-optimal, simpler alternative. Second, where policy enables net metering or time-varying tariffs, a grid-tied hybrid analogous to Case 1 can monetize midday surpluses, albeit with higher indirect emissions; conversely, autonomous systems eliminate operational emissions but require greater capital and careful surplus management. Third, smart charging (shifting EV charging toward the solar peak) and load flexibility can substantially reduce storage cycling and curtailment, improving lifetime economics.

Limitations temper these conclusions. This study relies on simulations with assumed load shapes, fixed EV charging windows, and site-specific resource data; real-world behavior (driver arrival times, seasonal mobility, appliance use) could increase the results. Cost modeling and component replacements follow standard assumptions and may not capture degradation pathways or emerging price trends. Generalizability is strongest for regions with similar solar–wind regimes and grid conditions. Future work should (i) validate with measured load and resource data; (ii) test smart charging and vehicle-to-grid (V2G) controls; (iii) run sensitivity and uncertainty analyses (prices, degradation, resource variability); (iv) evaluate demand–response tariffs and export constraints; and (v) explore multiobjective optimization (cost–emissions–reliability) and neighborhood-scale coordination. Overall, the results strongly support the study’s aim: renewable-powered residential EV charging is technically feasible and, with targeted controls and sizing, can achieve very high autonomy and zero operational emissions.

5. Conclusion

This study aimed to evaluate the feasibility of renewable-powered residential electric vehicle charging stations in Hai-Alandalus, Libya, with the goal of identifying technically and economically viable microgrid configurations. Three scenarios were simulated via HOMER Pro: a grid-connected PV–wind hybrid, an autonomous system with a PV and one wind turbine, and an autonomous system with a PV and two wind turbines.

The key findings show that the grid-connected hybrid system is the most economical solution, providing a balance between renewable contribution and reliability while enabling surplus energy exports. In contrast, the autonomous systems achieved higher renewable fractions and zero emissions but required greater capital investment and more frequent component replacements. The results confirm that renewable-powered EV charging is technically feasible and environmentally beneficial while also highlighting the trade-offs between cost, autonomy, and sustainability.

These findings are significant for both research and practice. They provide evidence that hybrid PV–wind configurations can play a crucial role in reducing transport-related emissions and supporting sustainable energy transitions in regions with high solar and wind potential. Moreover, the high levels of excess electricity observed in autonomous systems point to the need for improved demand-side management, storage optimization, or flexible applications to maximize efficiency.

Limitations of this study include reliance on simulated load profiles, assumed charging intervals, and generalized cost models, which may differ from real-world conditions. Future research should validate these results with empirical data, explore smart charging and vehicle-to-grid integration, and assess system performance under varying policy and market conditions.

In conclusion, renewable-powered EV charging stations represent a practical and sustainable pathway for decarbonizing both the transport and electricity sectors. As electric vehicle adoption accelerates, hybrid renewable microgrids can provide clean, reliable, and scalable infrastructure, contributing to a cleaner and more resilient energy future.

Conflicts of interest

The authors declare that there are no potential conflicts of interest or that no conflicts of interest exist.

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Generative AI statement

The author(s) declare that no generative AI was used in the creation of this manuscript.

Data availability statement

The data supporting the findings of this study are included within the article and/or its supplementary materials. Additional information or further inquiries can be obtained from the corresponding author upon reasonable request.

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References

[1] Wim Turkenburg (Utrecht University, the Netherlands), Renewable Energy ,https://iiasa.ac.at/web/home/research/Flagship-Projects/Global EnergyAssessment/GEA_Chapter11_renewables_hires.pdf

[2] Kumar, A., Bansal, R. C., Yan, D., & Kumar, P. (Eds.). (2025). *Microgrid handbook: Planning to practices* (1st ed.). CRC Press. https://doi.org/10.1201/9781003219439

[3] Balaguer Vich, R. (2020). *Sustainable energy communities. Feasibility for today or long term? Case Analysis* [Master's thesis, Universitat Politècnica de Catalunya]. UPCommons Repository. https://upcommons.upc.edu/server/api/core/bitstreams/4035ef03-6be0-4ac8-bb10-f2283ffb8064/content

[4] El Mokhi, C., Hachimi, H., & Nayyar, A. (Eds.). (2025). *The future of urban living: Smart cities and sustainable infrastructure technologies. Proceedings of the 1st International Conference on Advanced Sustainability Engineering and Technology (ICASET'25)* (Vol. 1). Springer Cham. https://doi.org/10.1007/978-3-031-98334-4

[5] El Fathi, A., & Outzourhit, A. (2021). Assessment of the levelized cost of electricity for a standalone power plant in Morocco: A case study. Clean Energy and Environmental Sustainability, 2(1), Article e13216. https://doi.org/10.1002/2050-7038.13216

[6] Than, S. S., & Swe, W. (2023). Economic analysis of PV-utility grid hybrid electric vehicle charging station in Mandalay City. *International Journal of Communication Systems*, *13*(2). https://doi.org/10.33022/ijcs.v13i2.3912

[7] Jenkins, N., & Thornycroft, J. (2018). Grid connection of photovoltaic systems: Technical and regulatory issues. In S. Kalogirou (Ed.), *McEvoy's handbook of photovoltaics: Fundamentals and applications* (3rd ed., pp. 847-876). Academic Press. https://doi.org/10.1016/B978-0-12-809921-6.00022-7

[8] Hamidi, A., Weber, L., & Nasiri, A. (2013). EV charging station integrating renewable energy and second–life battery. In *Proceedings of the International Conference on Renewable Energy Research and Applications* (ICRERA 2013) (pp. 1217–1221). IEEE.

[9] Tahara, H., Urasaki, N., Senjyu, T., & Funabashi, T. (2016). EV charging station using renewable energy. In Proceedings of the 2016 IEEE First International Conference on Control, Measurement and Instrumentation (CMI) (pp. xx-xx). IEEE.