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Design and Optimization of Renewable Energy-Based Electric Vehicle Charging Stations: A Case Study in Yalova

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Abstract Energy consumption in the transportation sector has become a significant issue involving the sustainable use of global energy resources. Environmental concerns related to fossil fuel consumption and the need for energy efficiency have made the transition from traditional internal combustion engine vehicles to electric vehicles (EVs) imperative. Along with the widespread adoption of EVs, improving charging infrastructure and supporting this infrastructure with environmentally friendly energy sources have become crucial.
In this study, a renewable energy-based charging station design and optimization for EVs at a shopping center in Yalova was conducted. Simulation models were created using HOMER Grid software, and four different scenarios with different components were developed. Among these scenarios, scenario 4 was chosen as the optimal solution in terms of energy efficiency and cost-effectiveness. In this scenario, the net present cost of the charging station was $1.18 million, with an initial cost of $1.05 million, and the renewable energy usage rate reached 97%. The results demonstrate that renewable energy-based charging stations offer significant environmental and economic benefits.

Keywords: *Renewable Energy, Electric Vehicle Charging Stations, Energy Optimization, HOMER Grid Simulation, Sustainable Transportation*

I. INTRODUCTION

Energy is a fundamental element of economic growth, sustainability, and social welfare in modern societies [1]. As global energy demand rapidly increases and fossil fuel resources become increasingly limited, energy management and efficient utilization have become more critical than ever [2]. Carbon emissions and climate change caused by fossil fuels have made the transition to renewable energy sources (RES) a global necessity [3]. In this context, the use of renewable energy sources and energy-efficient systems plays a crucial role in ensuring future energy security and promoting environmental sustainability.

The transportation sector is a major contributor to global energy consumption, and the environmental impacts of fossil fuel-powered vehicles pose significant challenges [4]. Electric vehicles (EVs) are emerging as an innovative solution that reduces the dependency on fossil fuels and offers significant opportunities to improve energy efficiency. Research shows that EVs have much higher energy-conversion efficiency than traditional internal combustion engine vehicles and significantly reduce carbon emissions. However, the widespread adoption of EVs also requires the development of charging infrastructure. The proliferation of fast-charging stations is crucial for providing reliable and user-friendly solutions for EV owners while promoting sustainable transportation [5].

Several studies in the literature have focused on developing charging infrastructure for EVs.

Rigas et al. developed a charging station design using the EVLibSim library to simulate and analyze various charging station scenarios, examining factors such as charging capacity, demand, and grid load [6]. Wang et al. proposed an off-grid solar- and hydrogen-based charging station that can provide electricity to electric and hydrogen vehicles. Their design included a water electrolyzer powered by solar systems to generate and store hydrogen with a backup diesel generator. The system's solar capacity was increased from 1612 to 1818 kW, while the diesel generator capacity was raised from 48 to 64 kW [7].

Bicer designed a charging station that utilizes H2 and NH3 fuel cells in combination with concentrated photovoltaics (CPV) and wind turbines, highlighting increased system efficiency, especially in space-constrained areas. The system employs two fuel cells for greater flexibility in electricity generation and storage, with the main energy contribution coming from the fuel cells, which account for about 80% of the system's output [8]. Çobanoğlu et al. analyzed the economic feasibility of grid-connected solar-assisted charging stations in İzmir by using MATLAB/Simulink to simulate various configurations. Their findings indicated that systems without battery storage could amortize their costs in five years, whereas those with battery storage contributed to grid stability by reducing load fluctuations [9]. Li et al. explored the optimization of EV charging infrastructure using renewable energy and battery storage systems by applying Monte Carlo simulations and multi-objective genetic algorithms to minimize total costs and carbon emissions [10].

In Morocco, Allouhi et al. applied HOMER Grid software to design an optimal hybrid renewable energy system (HRES) for supermarkets in three cities. The design integrated solar PVs, wind turbines, and battery storage to achieve a renewable energy fraction of 71.66% in Dakhla, resulting in a COE of $0.0841/kWh and annual operating costs of $0.124M [11]. Similarly, Chisale et al. examined the energy challenges in Malawi, where only 15% of the population had reliable access to electricity. They proposed a hybrid system that combined solar panels, biogas, wind, and battery storage to reduce school grid demand and electricity costs. The system achieved a cost of $0.095/kWh, lower than Malawi's average of $0.11/kWh, with biogas being primarily generated from human waste [12].

In the study by Güven, the integration of HRES into electric vehicle (EV) charging infrastructure is explored. Using solar panels, wind turbines, and battery storage, this research focuses on designing sustainable energy systems for university campuses and nearby electric vehicle stations. This study demonstrates that the system significantly reduces energy costs and carbon emissions while supporting EV charging. Simulations conducted with MATLAB 2022b indicated that the proposed system can meet both the university's energy demands and EV charging needs effectively [13]. Joseph et al. explored renewable energy storage systems in EV charging stations, focusing on the integration of solar panels. They designed a hybrid forward converter to improve the power transfer efficiency under fluctuating energy conditions, achieving a maximum overall efficiency of 95% [14]. Atawi et al. developed a photovoltaic-powered standalone charging station employing a closed-form design equation for the system components. The system was modeled in MATLAB/Simulink, and the experimental results showed that the system exhibits stable charging performance under various solar irradiance levels [15]. Kurtz et al. used HOMER to optimize hydrogen-powered microgrids for data centers and identified scenarios for integrating RESs to achieve carbon-free power solutions [16]. In Bangladesh, Karmaker et al. addressed the rapid rise in EV demand by proposing hybrid solar/biogas EV charging stations to reduce the load on the national grid, with an energy cost of $0.1302/kWh and a total net present cost (NPC) of $56,202 [17]. Singh et al. conducted a study in India using PVsyst software to design a solar-powered EV charging station. The system, equipped with 8.1 kWp of PV capacity and two days of battery autonomy, reduced CO2 emissions by 7,950 kg annually while achieving an optimal performance ratio [18]. Narasipuram et al. provided a comprehensive review of various EV charging station designs, categorizing stations by power levels and examining optimization algorithms for improved design efficiency [19]. Ebrahimi et al. used Monte Carlo methods and queueing theory to address uncertainties in renewable energy supply for EV charging stations, minimize total costs, and improve grid performance [20]. Güven et al. extended the research into hybrid microgrid systems by optimizing EV charging infrastructure using RESs. Their work emphasized the potential of vehicle-to-grid (V2G) and grid-to-vehicle (G2V) models in reducing grid stress. Using a range of optimization algorithms, including the Coati Optimization Algorithm (COA) and Turbulent Flow of Water-based Optimization (TFWO), their simulations demonstrated a 69.87% reliance on renewable energy [21]. Güven et al. also investigated the use of HRES at Yalova University, finding that a system that utilizes 73% renewable energy could significantly reduce carbon emissions with a 5.7-year payback period [22]. In another study, Güven et al. analyzed the integration of RES into EV charging stations and evaluated seven different scenarios. Scenario 3, which combined photovoltaic systems, batteries, and biodiesel generators, was identified as the most efficient method, reducing CO2 emissions by 29.40% [23]. In addition, their research in Manisa showed that optimized EV charging stations had an annual energy generation capacity of 3,049,337 kWh and lower energy costs than fossil fuels [24]. These findings underscore the importance of renewable energy systems for environmental sustainability and cost-effectiveness.

In summary, these literature reviews highlight the significant potential of renewable energy-based EV charging infrastructure in reducing energy costs, improving energy efficiency, and promoting environmental sustainability.

This study focuses on the design and optimization of a renewable energy-based electric vehicle charging station for a shopping center in Yalova, and examines its cost-effectiveness and environmental sustainability. Shopping centers, due to their high visitor traffic flows, are strategic locations for charging stations, playing a key role in promoting sustainable transportation.

II. MATERIAL AND METHOD

A. Homer Grid Software

HOMER Grid is a software application used for designing and analyzing systems that generate electricity from RES. The proposed model shares the same mathematical foundation as HOMER Pro for calculating energy production but is specifically designed for grid-connected applications and can handle more complex tariff structures. This software is particularly useful for configuring EV charging stations and connecting them to HRES.

HOMER Grid offers users a comprehensive set of tools for analyzing energy demands and sources, balancing energy production and consumption, and optimizing the use of energy storage systems. This allows for the design of the most efficient system by considering multiple RESs (e.g., solar, wind) and energy storage options (e.g., batteries). Through advanced optimization algorithms, HOMER Grid enables users to model various energy scenarios and design systems that minimize costs while maximizing efficiency. It is especially useful for providing strategic decisions regarding the proper sizing and management of EV charging stations, ensuring that energy demands are met while reducing environmental impact.

B. System Design

The proposed renewable energy-based electric vehicle charging station was designed using HOMER Grid software. In this design process, four different scenarios were created using various system components. The schematic diagrams of these scenarios are presented in Figure 3. The main objective of the design was to create a system that operates at the lowest NPC and cost of energy (COE). As shown in Figure 1, the methodological framework comprises three main steps: initial assessment, design optimization, and results analysis.

In the initial stage, the available energy sources and meteorological data (such as solar radiation, wind speed, and ambient temperature) for the study area were thoroughly examined. This examination was conducted to understand the potential of energy sources and to accurately evaluate the system components. Using HOMER Grid, several scenarios were created to determine the optimal system design.

Finally, among the four scenarios, the most cost-effective and environmentally friendly system was selected and analyzed. Figure 2 schematizes the scenarios tested in the program. Based on the evaluation of these scenarios, the system that offered the best balance between cost and environmental sustainability was selected as the optimal solution.

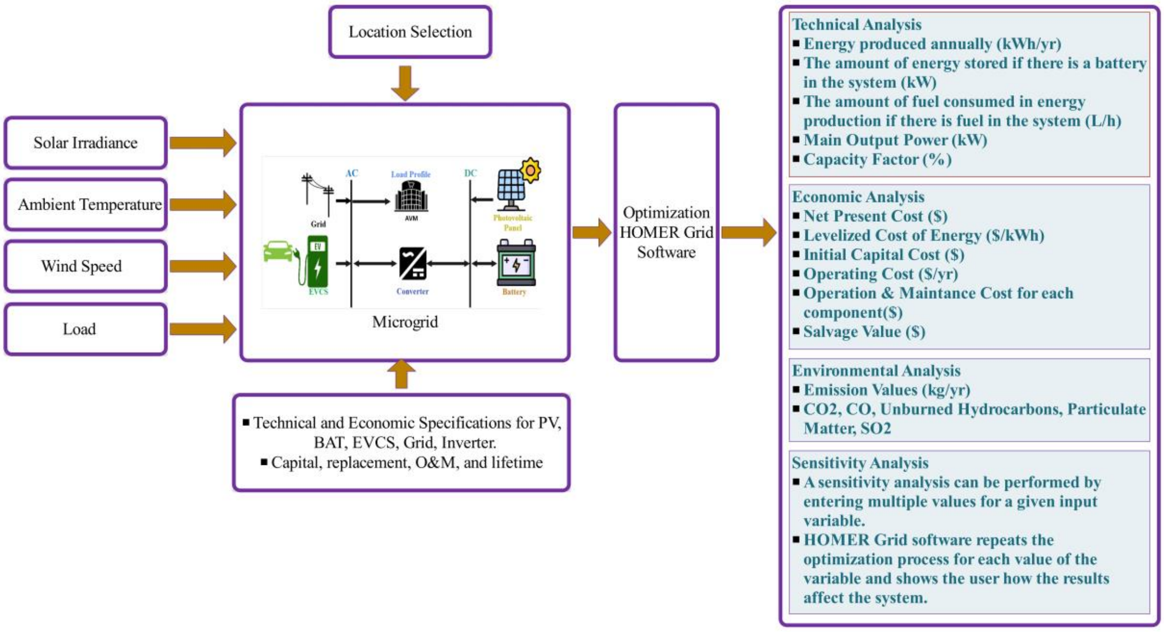

Fig. 1. Schematic representation of study techniques.

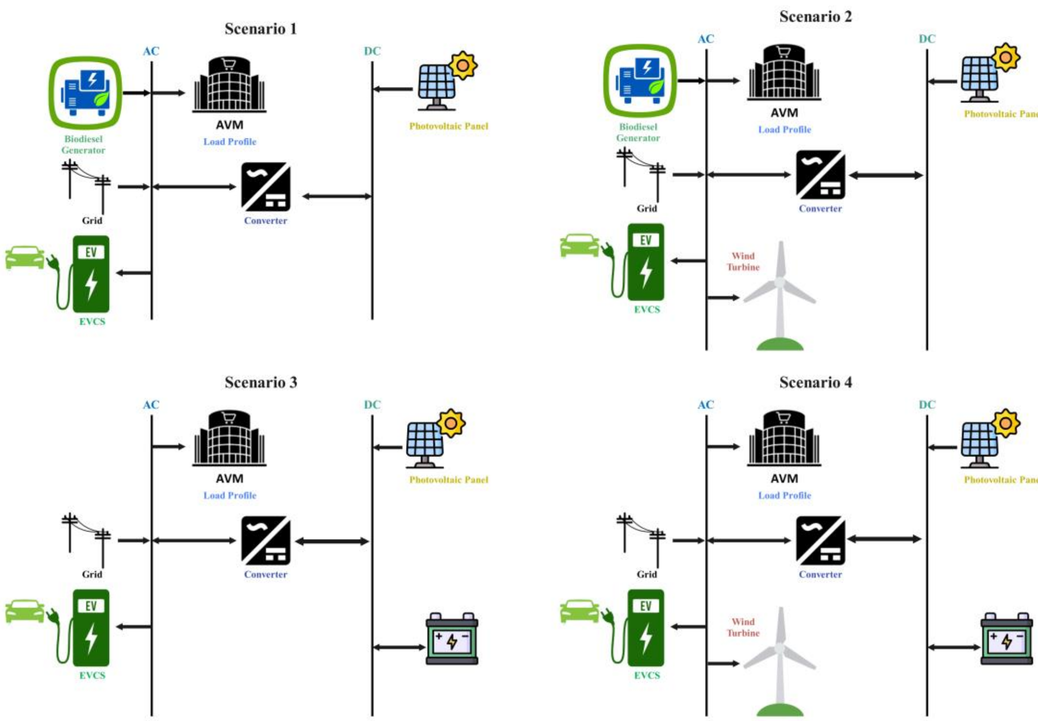

Fig. 2. Schematic diagrams of the four scenarios.

C. Location Selection

The study area is a shopping center located in the central district of Yalova. To meet the energy demand of the charging stations planned for shopping centers, a grid-connected hybrid energy system comprising RES was evaluated. Meteorological data used in this study were provided by the Turkish Meteorological Service. To create a detailed profile of the study area, annual wind speed, solar radiation, ambient temperature, and load data were collected.

Figure 3 presents the hourly solar radiation profile over the course of a year, while Figure 4 shows the monthly wind speed profiles at 10 m above ground level. Figure 5 illustrates the monthly ambient temperature profiles in the form of time series graphs. As shown in Figure 3, the solar energy potential of the study area is higher during summer than during winter. Wind turbines can serve as supplementary energy sources when solar energy is insufficient during the winter months, thus complementing solar power. These two energy sources are the most preferred in hybrid systems.

The annual, daily, and seasonal load demand profiles are also presented in Figure 6. The economic analysis, a nominal discount rate of 25% and an inflation rate of 20% were considered. The project lifespan of the HRES was set to 25 years [25].

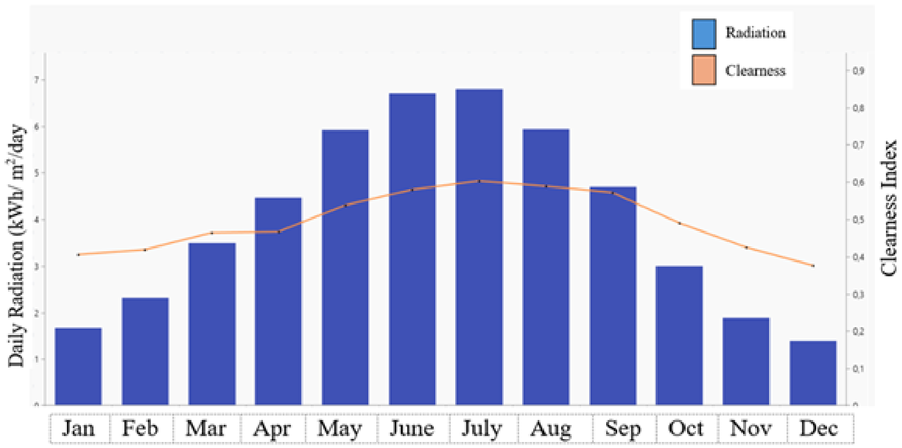

Fig. 3. The radiation profile of the study area.

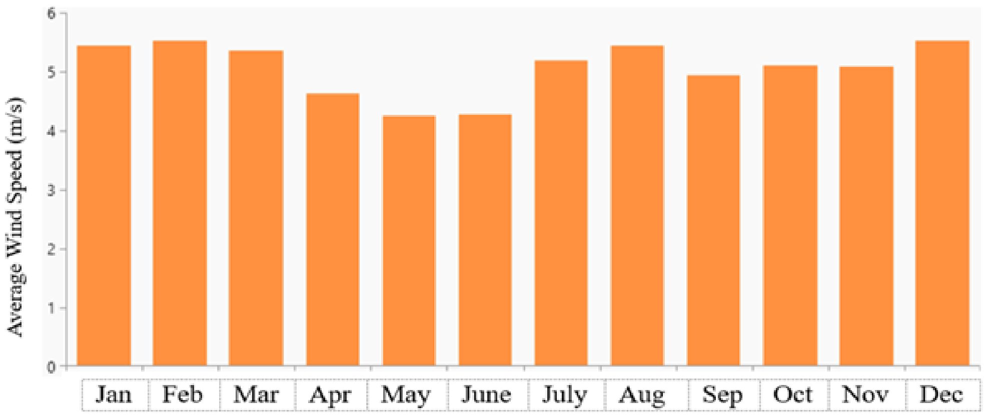

Fig. 4. Wind speed in the study area.

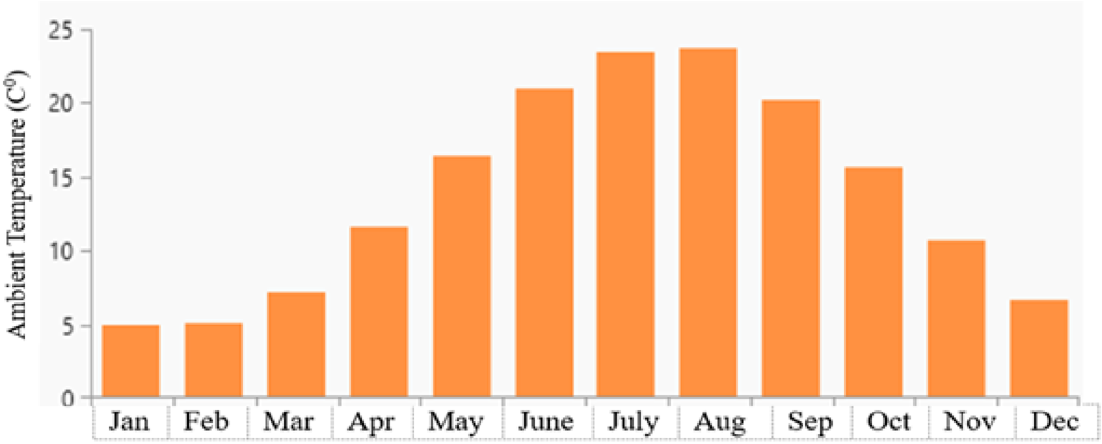

Fig. 5. Ambient temperature of the study area.

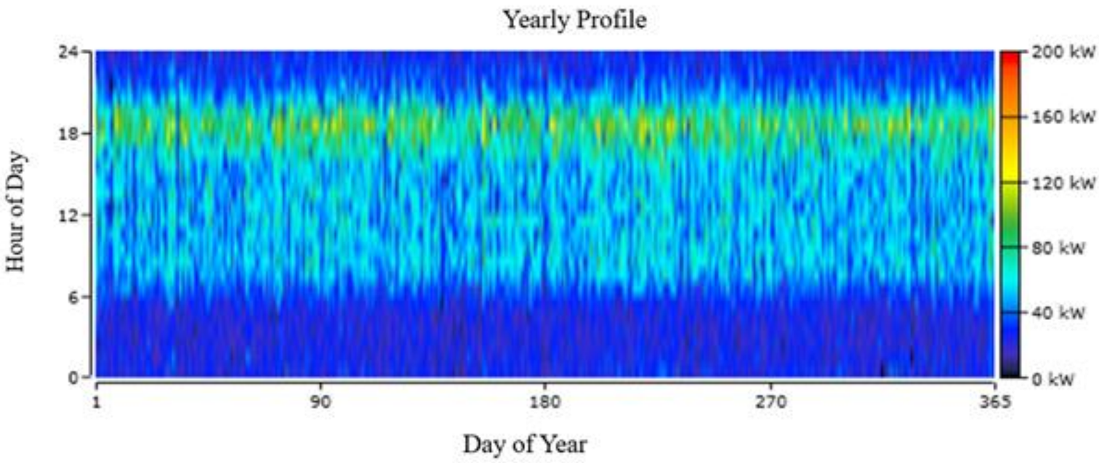

Fig. 6. Load profile of the study area

D. Grid

To supply power to electric vehicle charging stations, a connection to the grid is typically established. This step is essential for evaluating the economic costs associated with the system based on the proportion of renewable energy production and for analyzing the carbon emissions in each scenario. In all scenarios considered, a grid connection was used. The electricity cost varies depending on the time of day, with a rate of \$0.40/kWh during the day (06:00-17:00), \$0.35/kWh during peak hours (17:00-22:00), and \$0.30/kWh during nighttime (22:00-06:00). Additionally, electricity sold back to the grid is priced at \$0.15/kWh [26].

E. Solar Panels

Solar energy is one of the most important RES due to its inexhaustible nature. Given Turkey's high solar energy potential, solar power is considered one of the best renewable sources for hybrid energy systems. Solar radiation reaches its peak in March and April, and drops to its lowest in December and January. Solar panels convert the heat energy they collect from the sun into direct current (DC) electricity stored in batteries. The solar panel output power can be calculated using the following equation [27]:

$$P_{PVout} = Y_{PV} * f_{PV} * \frac{G_T}{G_{T,STC}} * \left[1 + \alpha_P * \left(T_c - T_{c,STC}\right)\right] \quad (1)$$

where P_{PVout} represents the output power of the solar panel in watts, Y_{PV} is the rated capacity of the solar panel under standard test conditions, and f_{PV} is the derating factor of the panel. G_T is the solar radiation incident on the panel at any given time, while $G_{T,STC}$ is the radiation under standard test conditions. α_P is the temperature coefficient of power, T_c is the cell temperature, and $T_{c,STC}$ is the cell temperature under standard test conditions. The installation cost of a 1-kW solar panel is approximately $700, with the same amount for the replacement cost, and the annual maintenance cost is estimated to be $70. The expected lifespan of a solar panel is 25 years.

F. Wind Turbine

The wind turbine selected for this study was an XANT M21 with a nominal power of 100 kW. This model was chosen because it can be constructed using the essential engineering parts principle, thereby reducing manufacturing costs, and is portable. The wind turbine has a starting speed of 3 m/s, nominal speed of 11 m/s, and cut-off speed of 20 m/s. It was installed at a height of 31.8 m, and the rotor had a diameter of 21 m. The installation and replacement costs were $250,000 each, and the annual maintenance cost was $62.5. The expected lifespan of a wind turbine is 20 years [28].

HOMER analyzes wind turbine electricity generation on an hourly basis four steps. To estimate wind speed, the following power law equation was used:

$$U_{hub} = U_{anem} * \left(\frac{Z_{hub}}{Z_{anem}}\right)^{\propto} \tag{2}$$

HOMER adjusts the calculated power values to match real-life conditions by multiplying the calculated power values by the air density ratio. The air density was measured at standard temperature and pressure (1.225 kg/m³). The equation is as follows:

$$P_{WTG} = \left(\frac{\rho}{\rho_0}\right) * P_{WTG,STP} \tag{3}$$

where P_{WTG} is the power generated by the wind turbine, ρ is the air density at the site, ρ_0 is the air density under standard temperature and pressure (1.225 kg/m³), and $P_{WTG,STP}$ is the power generated by the wind turbine under standard test conditions.

G. Converter

The converter connects the DC and alternating current (AC) components of the system. It operates bidirectionally, depending on the energy flow, and ensures smooth energy conversion between DC and AC systems. The installation cost of the converter was approximately $400, with the same cost for replacement, and the annual maintenance cost was $50. The lifespan of the converter is estimated to be 15 years. The power output of the converter can be calculated using the following equation:

$$P_{inv} = \frac{PV_{ic}}{n_{inv} * N_{inv}} \tag{4}$$

where P_{inv} represents the output power of the converter, PV_{ic} is the installed capacity of the solar panels, n_{inv} is the efficiency of the inverter, and N_{inv} is the number of inverter units [29].

H. Battery

Batteries, which store electrical energy in chemical form, are crucial components of hybrid energy systems. They are used to store excess energy produced when generation exceeds consumption. The installation and replacement costs for a 1-kW battery are approximately $550, and the annual maintenance cost is $55. The lifespan of the battery is expected to be 15 years. The state of charge (SOC) of the battery during charge and discharge modes can be calculated using the following equation [30]:

$$SOC\ (t) = (1 - Q) * SOC(t-1) + \frac{P_{cd} * \Delta(t) e_{cd}}{E} \tag{5}$$

where Q represents the hourly discharge rate, P_{cd} is the charge and discharge power, e_{cd} is the charge and discharge efficiency, and E is the total energy stored in the battery.

İ. *Electric Vehicle Charging Station*

The charging station planned for the shopping center is designed to accommodate various EV types. The charging characteristics of the vehicles to be charged are presented in Table 1. Although the electric vehicle market is rapidly growing, there are still limited data on the actual operation of charging stations. Therefore, the system was modeled based on probable data regarding vehicle charging requirements and population estimates.

TABLE I

CHARGING CHARACTERISTICS OF THE VEHICLES

Vehicle type	Population	Maximum charging power per vehicle (kW)	Required charging energy per vehicle (kWh)
SUV EV	30	150	260
Small EV	70	50	260

The data used in this study assume a growing EV population, and the charging station design reflects a realistic mix of different vehicle types. As the global adoption of EVs continues to increase, the chosen vehicle population and charging characteristics parameters are in line with industry expectations for future EV charging demands.

III. RESULTS AND DISCUSSION

Using HOMER Grid software, four scenarios were generated to evaluate the economic and environmental performance of a renewable energy-based EV charging station. The results summarized in Table 2 show that Scenario 4 emerges as the optimal solution, exhibiting the lowest NPC of $1.18M and renewable energy fraction 97%. This high renewable fraction indicates that the majority of the station's energy is sourced from renewable resources, minimizing the dependency on fossil fuels and significantly reducing carbon emissions.

In comparison, Scenario 4 also achieves the lowest operating cost of $8,398 and an initial cost of $1.05M, making it the most financially sustainable option. While Scenario 2 records a slightly lower COE of $0.0554/kWh, its higher initial and operational expenses make it less favorable than Scenario 4. On the other hand, Scenario 1, with an NPC of $2.06 million and the lowest renewable fraction of 87.6%, ranks as the least efficient in terms of both cost and environmental sustainability.

Ultimately, Scenario 4 is the ideal implementation choice, offering an optimal balance between cost efficiency and environmental performance. The scalability and reliance on renewable energy make it a suitable model for future projects, especially in urban areas such as shopping centers. As the demand for electric vehicle charging infrastructure grows, Scenario 4 can be replicated or expanded to meet these needs while contributing to long-term environmental sustainability and financial savings.

TABLE II

COST OPTIMIZATION RESULTS.

	NPC($)	COE($)	Operating Cost($)	Initial Cost($)	Renewable Fraction (%)
Scenario1	2.06M	0.0818	60.339	1.14M	87.6
Scenario2	1.53M	0.0554	9.641	1.39M	93.3
Scenario3	1.47M	0.0653	15.970	1.22M	97.3
Scenario4	1.18M	0.0628	8.398	1.05M	97

The various scenarios for installing charging stations in shopping centers in Yalova are presented in Table 2. Among the systems created with different components, Scenario 4, which includes photovoltaic (PV) panels, wind turbines, batteries, and a converter, as shown in Figure 8, is the most suitable system in terms of NPC, initial cost, and renewable energy fraction.

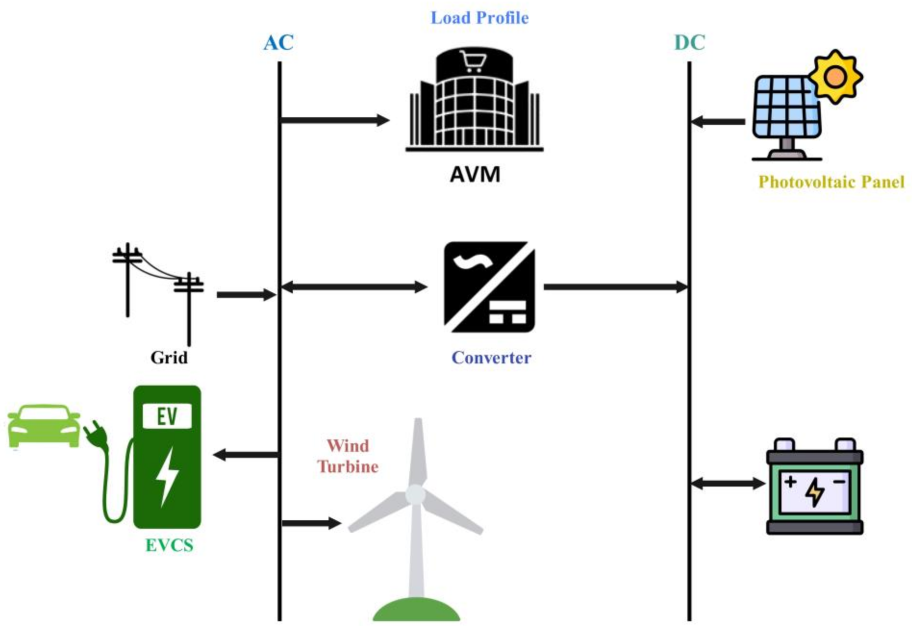

Fig. 7. Diagram of the selected system.

The monthly and annual performance of the optimized system is depicted in Figure 8, and the respective contributions of wind, grid, and solar panel electricity production are illustrated in Figure 9. The system consumes 1,424 kWh of energy per day, with a peak demand of 164 kW, and predominantly relies on RES for its electricity needs. As shown in the figures, combined electricity generation from solar panels and wind turbines exceeds the grid's contribution. Specifically, the system generates 1,062,698 kWh/year from PV panels and 244,794 kWh/year from wind turbines, covering 97.2% of the total energy demand.

In the proposed system, the nominal capacity of solar PVs is 795 kW, with an average daily output of 2,912 kWh/day. As shown in Figure 10, solar PV production occurs between 06:00 and 18:00. Figure 11 highlights the daily performance of wind turbines, which serve as complementary energy sources, particularly during periods when solar energy is insufficient.

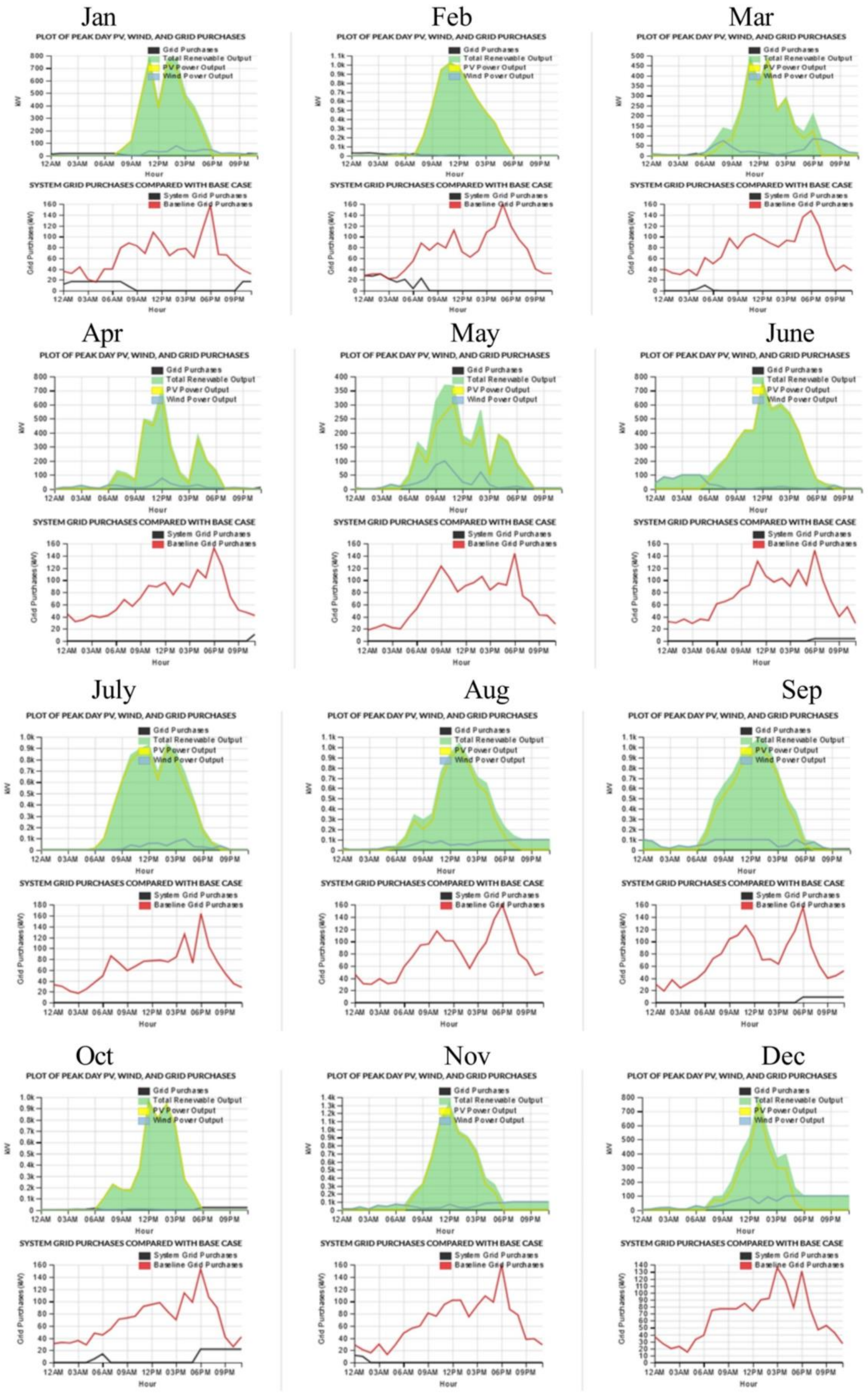

Fig. 8. Monthly load profile of electricity consumption.

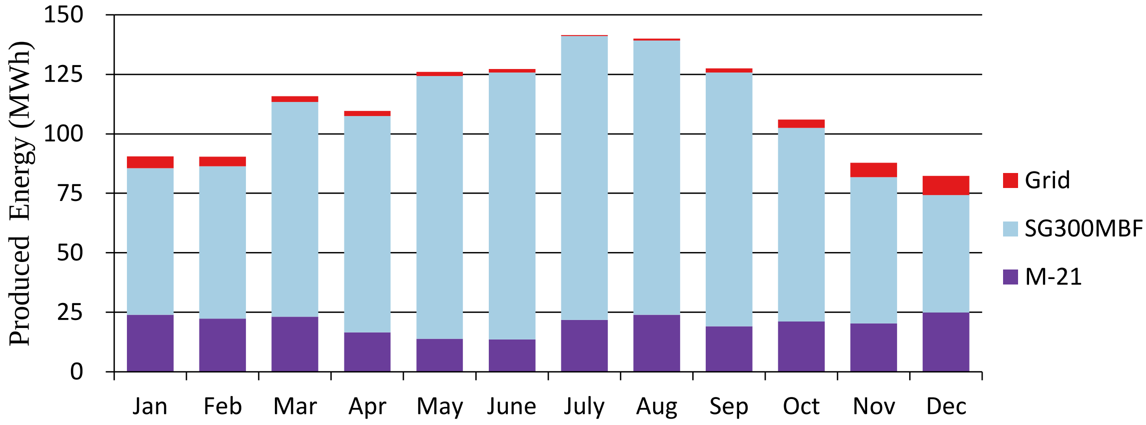

Fig. 9. Monthly electricity production of solar, wind and grid.

The monthly electricity production from solar panels (SG300MBF), wind turbines (M-21), and the grid for the system are shown in Figure 9. It can be observed that solar energy generation is the dominant source across all months, with peak production occurring during the summer months of June, July, and August. The wind energy production, shown in purple, remains relatively constant throughout the year, providing supplementary power. The grid represented by the red section contributes only a small portion of the total electricity, demonstrating the system's heavy reliance on renewable energy sources. This highlights the effectiveness of integrating solar and wind energy sources to meet energy demands while minimally relying on grid electricity.

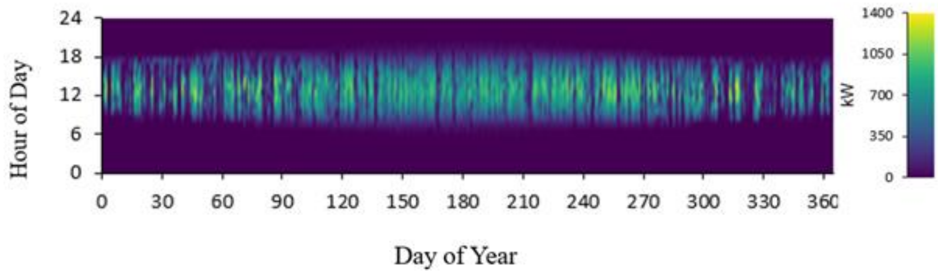

Fig. 10. Daily PV performance.

Figure 10 illustrates the daily performance of the solar PV system over the course of a year. The graph displays the solar output in kilowatts (kW) at various hours of the day across the 365 days of the year. The color gradient indicates the intensity of solar power generation, where darker areas represent low production and lighter shades indicate higher energy generation. As expected, the highest solar output occurs during the daytime, typically between 6:00 AM and 6:00 PM, with peak production around noon. Consistent horizontal energy production bands suggest reliable daily electricity generation throughout the year, with minor fluctuations due to seasonal changes and weather variations.

Figure 11 illustrates the daily performance of the wind turbine system over the course of a year. The graph shows the power output in kW at different hours of the day plotted against the 365 days of the year. The color scale indicates the intensity of wind power generation, with darker colors representing lower production levels and lighter colors indicating higher output. Unlike solar energy, wind energy production does not follow a fixed daily pattern because wind speeds fluctuate throughout the day and across different seasons. The graph shows that wind energy production is more sporadic, with noticeable variations occurring throughout both day and night. However, despite these fluctuations, wind power provides a consistent source of energy throughout the year.

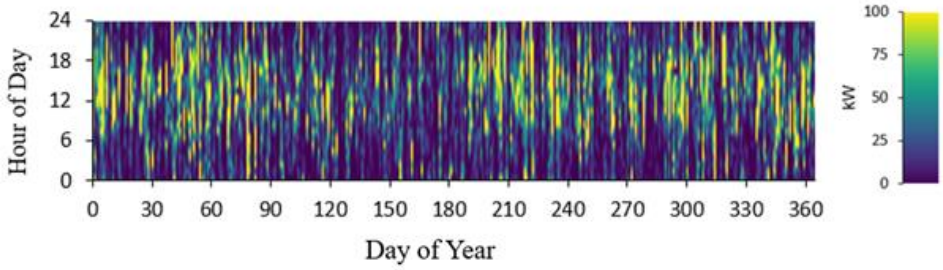

Fig. 11. Daily wind turbine performance.

The converter in the system has a capacity of 480 kW, with an average output power of 110 kW and a maximum output power of 480 kW. Based on the simulation results, the converter's capacity factor was found to be 22.9%, with a total annual operation time of 7,385 hours. Annually, the converter processes 17,311 kWh of energy, with an output of 16,446 kWh, resulting in an energy loss of 866 kWh. As shown in Figure 13, the converter's performance is closely linked to solar PV generation. The graphical representation shows that the converter's peak output generally aligns with the daily solar production hours, highlighting its reliance on solar energy for efficient operation.

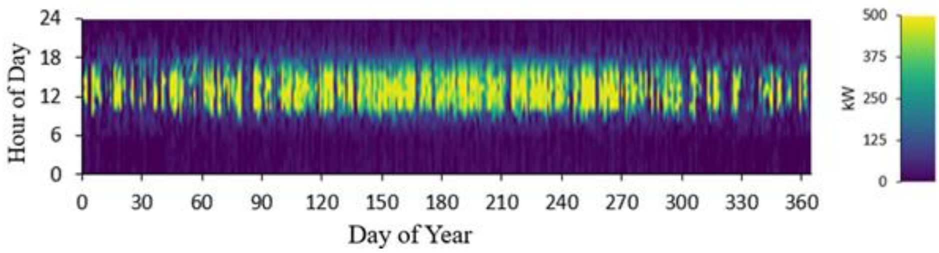

Fig. 12. Daily converter performance.

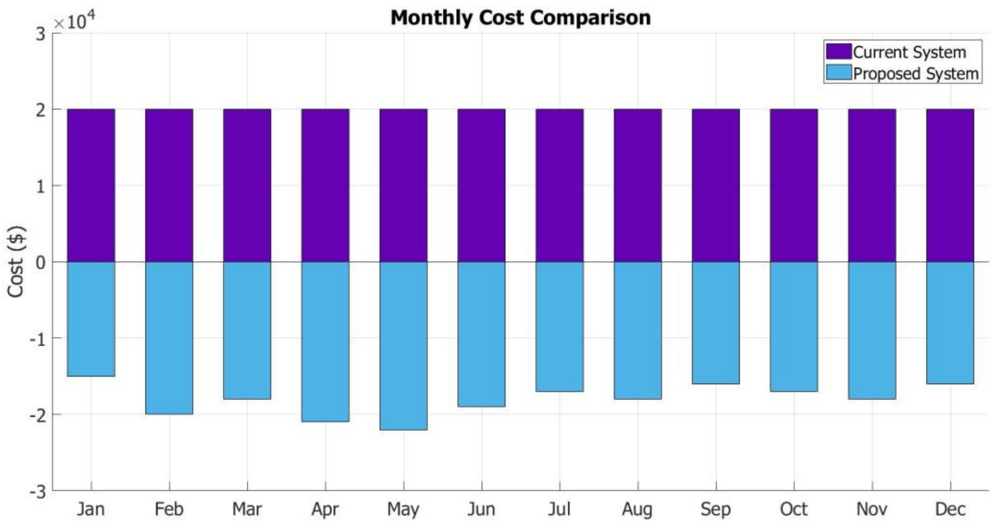

Fig. 13. Monthly cost comparison between the current and proposed systems.

The economic performance of the hybrid energy charging stations designed using RESs was evaluated through a techno-economic analysis. This analysis considered all costs incurred over the system's lifespan. To identify the most cost-effective system, the NPC was prioritized in HOMER Grid software, and the system with the lowest NPC was selected as optimal. Other key parameters included the renewable fraction and the COE, which were also vital for determining the optimal system configuration. Figure 13 displays the monthly electricity bill savings of the proposed system compared to the existing one. As the chart indicates, the proposed system offers significant cost savings across all months, with the most notable reductions occurring during the spring and summer periods. This highlights the economic advantage of integrating renewable energy into the system.

As shown in Table 3, the proposed system resulted in an annual emission of 23,554 kg of carbon dioxide (CO_2), 102 kg of sulfur dioxide (SO_2), and 49.9 kg of nitrogen oxides (NO_x). Notably, the emissions of carbon monoxide (CO), unburned hydrocarbons, and particulate matter (PM) were zero, indicating a significant reduction in the harmful pollutants. This environmentally friendly system helps reduce atmospheric gas emissions, which can contribute to mitigating global warming and improving air quality.

TABLE III
EMISSION RESULTS

	Emission value (KG/YEAR)
Carbon Dioxide	23,554
Carbon Monoxide	0
Unburned Hydrocarbons	0
Particulate Matter	0
Sulfur Dioxide	102
Nitrogen Oxides	49.9

Reductions in emissions are especially important in the context of climate change mitigation, as lower CO_2 levels contribute to slowing down the greenhouse effect, while reduced NO_x and SO_2 levels minimize acid rain formation and respiratory health risks. Overall, the proposed renewable energy system offers both economic and environmental advantages by significantly cutting emissions.

IV. CONCLUSION

HRES have been proven to offer reliable and uninterrupted electricity despite the intermittent nature of RES. This study focused on the design of an EV charging station for a shopping center using RES, addressing both energy reliability and cost efficiency. The system's goal was to reduce energy costs while utilizing clean, sustainable energy sources. The study modeled four scenarios, each incorporating various combinations of RES, and evaluated their performance using HOMER Grid software.

Among the modeled scenarios, Scenario 4, which combines solar energy, wind energy, battery storage, and converters within a grid-connected hybrid energy system, emerged as the optimal solution. This scenario exhibited a NPC of $1.18 million, an initial cost of $1.05 million, and achieved a renewable fraction of 97%, making it the most cost-effective and environmentally friendly option compared to the other models.

The simulation results demonstrate that the proposed hybrid energy system can generate significantly more energy from renewable sources than from the grid. Specifically, the system is expected to deliver 97% of its energy from renewable sources, thus reducing reliance on fossil fuels and minimizing environmental impacts. The use of renewable energy not only decreases the carbon footprint of EV charging stations but also contributes to long-term energy security and cost savings.

1. **Key Findings and Recommendations:**

2. **Environmental Benefits**: The transition to renewable energy significantly reduces carbon emissions, as shown by the system's ability to cut annual CO_2 emissions by over 23,554 kg. This will support global efforts to combat climate change and promote sustainable development.
3. **Economic Efficiency**: Scenario 4, with its optimized combination of solar, wind, and battery storage, provides the lowest NPC and initial investment and demonstrates the financial viability of adopting HRES in EV charging infrastructure.
4. **Scalability and Adaptability**: The success of this model in a commercial shopping center setting indicates that similar systems can be scaled up and adapted for broader applications, such as industrial zones, residential complexes, or even entire city districts, where renewable energy can meet growing energy demands.
5. **Policy Implications**: Policymakers should consider incentivizing the integration of renewable energy systems into EV charging networks to significantly reduce dependency on non-renewable energy, lower energy costs, and contribute to national and international sustainability targets.
6. **Future Work and Recommendations:**

- **Technological Advancements**: Further research should focus on integrating emerging technologies, such as V2G solutions, which can enhance system flexibility and efficiency by allowing stored energy in EVs to be fed back into the grid.
- **Extended Sensitivity Analysis**: Conducting a more detailed sensitivity analysis under various weather and market scenarios can provide deeper insights into system resilience and financial outcomes.
- **Expansion to Other Locations**: Future studies should also explore the potential of hybrid renewable systems in regions with different climatic conditions and energy demands to assess the scalability and adaptability of the proposed solutions across diverse geographies.

This study demonstrates that HRES are not only feasible but also crucial in supporting the transition to cleaner energy, especially for EV charging infrastructure. Implementing such systems will significantly contribute to environmental sustainability, energy security, and economic benefits, aligning with global renewable energy and decarbonization goals.

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