# RENEWABLE-POWERED TRANSITION: ANALYZING ELECTRIC VEHICLE CHARGING SOLUTIONS ACROSS SEVEN TURKISH CITIES

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## ABSTRACT
This study addresses the rising global demand for energy and the consequent increase in fossil fuel consumption, particularly in the transportation sector, by proposing off-grid hybrid energy systems powered by renewable sources for electric vehicle charging stations in seven Turkish cities: Adıyaman, Antalya, Balıkesir, Bayburt, Karaman, Muğla, and Van. These systems, evaluated using the HOMER Pro simulation program, aim to minimize fossil fuel use and maximize the environmental benefits of electric vehicles. The study identifies the most suitable system configuration for each city through economic and environmental analysis, offering a viable design to reduce reliance on fossil fuels and enhance sustainable energy use in Turkey's transportation sector.

**Keywords:** Electric Vehicle Charging Station, Hybrid Renewable Energy Systems, Turkey's Energy Potential, HOMERPro software.

## 1. INTRODUCTION
In today's world, where energy demand is continuously increasing, the risks of depletion and environmental impacts of fossil fuels are creating growing concerns. The use of these fuels has become a significant trigger for climate change by increasing greenhouse gas emissions(Wahedi and Bicer, 2022) . As part of climate action plans, the importance of clean and efficient energy usage, especially in the transportation sector, is emphasized. In this context, the growing interest in electric vehicles signals a shift towards sustainable energy sources as alternatives to fossil fuels (Ampah et al. 2022).
Electric vehicles offer a cleaner alternative to internal combustion engine vehicles; however, the need for a robust charging infrastructure to support their effective use presents new challenges in meeting energy demand. Therefore, the use of hybrid renewable energy systems is seen as key to sustainably and eco-friendly meeting the energy needs of electric vehicle charging stations (Chen et al. 20224). The aim of this study is to reduce fossil fuel use in the transportation sector, encourage the transition to electric vehicles, and develop off-grid hybrid systems that will meet the energy needs of charging stations from renewable energy sources. These systems aim to support the charging needs of electric vehicles, taking a significant step towards a sustainable future.
The motivation behind this study stems from the need to combat the environmental and health impacts caused by fossil fuel consumption. The proliferation of electric vehicles, while reducing dependency on fossil fuels and potentially reducing exhaust emissions to zero when charging stations are powered by renewable sources, is central to this effort. Drawing on existing examples in the literature, this study focuses on the design of hybrid systems composed of diesel generators, wind turbines, photovoltaic panels, and battery storage systems. These systems are designed to meet the energy needs under different weather conditions, utilizing electricity generated from solar and wind energy for charging electric vehicles. This approach can enhance energy efficiency and sustainability while playing a crucial role in combating climate change (Elkholy et al. 2024).
This study, aiming to evaluate the solar and wind energy potential in various cities of Turkey, has analyzed the technical and economic performance of hybrid systems using the HOMER software developed by the National Renewable Energy Laboratory (NREL). These analyses will guide the development of sustainable and efficient energy solutions.

## 2. MATERIAL AND METHODS
Our hybrid system is engineered to harness renewable energy through the integration of solar panels and wind turbines, complemented with a converter, batteries for energy storage, and a diesel generator for backup support. The detailed descriptions of the system components and their functionalities within our proposed setup are as follows:
**Converters** serve a pivotal role in our system by enabling the conversion between alternating current (AC) and direct current (DC). This conversion is essential for both the charging needs of the batteries and the operational requirements of the overall system (Khaled, et al. 2024) . The initial investment for the converter is set at $300, with no additional costs for operation and maintenance, achieving an efficiency rate of 95%.
**Solar Panels** are deployed to convert solar radiation into electrical energy, representing the most cost-effective renewable energy source available. Considering Turkey's substantial solar energy potential, our system

incorporates 1 kW solar panels. These panels are associated with an initial cost of $750, a renewal cost of $750, and an annual operation and maintenance cost of $10.

**Wind Turbines** are utilized to transform wind energy into mechanical and subsequently electrical energy. The selection process for an appropriate wind turbine is critical, given their high initial costs. After evaluating various models, a Generic 1 kW wind turbine was selected, with an initial and renewal cost of $500, and an annual operation and maintenance cost of $10. This turbine has a hub height of 17 meters.

**Batteries** play a crucial role in storing the generated electrical energy, making it available for conversion back into electricity when needed. The impact of batteries on the overall system cost is significant, necessitating careful selection of the type and number of batteries. Our analysis favored the Generic 1 kWh Lithium-Ion battery, with both initial and renewal costs at $600, and an annual operation and maintenance cost of $10.

**The Diesel Generator** is designed to convert thermal energy, obtained during combustion, into mechanical energy and then into electrical energy. It is intended for use solely when necessary due to its high fuel consumption at peak output levels. The fuel cost is determined at $1.2 per liter.

To evaluate the cost-effectiveness and efficiency of our hybrid system in supplying renewable energy, the HOMER software was employed. This software simulates scenarios for selected cities across seven different regions, taking into account techno-economic parameters for each configuration. The cities included in our analysis are Karaman (37°11.1'N, 33°14.0'E) from the Central Anatolia region, Antalya (37°8.9'N, 31°12.2'E) from the Mediterranean region, Balıkesir (39°39.2'N, 27°53.4'E) from the Marmara region, Muğla (37°14.2'N, 28°17.8'E) from the Aegean region, Adıyaman (37°46.0'N, 38°13.9'E) from the Southeastern Anatolia region, Bayburt (40°15.5'N, 40°12.9'E) from the Black Sea region, and Van (38°28.3'N, 43°23.5'E) from the Eastern Anatolia region.

The HOMER software conducts hourly calculations to ascertain whether the renewable energy sources can meet the electrical demand at any given hour throughout the year (Zhang et al. 2023). The electricity demand is predominantly met by energy produced from the solar panels and wind turbines. In addition to the commercial load profile, temperature values, solar radiation data, and wind speed values for the selected regions have been inputted into HOMER, sourced from the NASA database (Khan et al. 2024). This comprehensive methodology ensures a detailed and accurate evaluation of our hybrid system's performance across a variety of Turkish locales. Fig. 1 illustrates the elements of the hybrid renewable energy system (HRES), namely the photovoltaic panel (PV), wind turbine (WT), batteries (BT), diesel generator (DG), dual converter, electrical load and electrical vehicles load components.

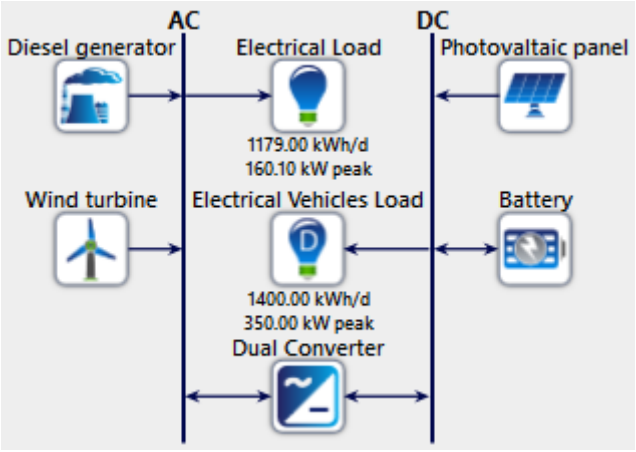


Fig.1. Hybrid renewable energy systems.

## 3. RESULTS AND DISCUSSION

Our environmentally friendly project, designed to rely on clean energy sources, is in line with climate action plans. Our hybrid system, intended as an alternative to diesel generators that increase fossil fuel consumption at base stations, can be independently installed on the grid without harming aquatic or terrestrial habitats (Li et al. 2022). On the contrary, this project aims for a healthy and high-quality life by contributing to green energy while reducing greenhouse gas emissions. Energy production is entirely from clean and sustainable sources, using panels and turbines that are harmless to the ecosystem and easy to maintain (Oladigbolu et al. 2023). This approach helps to reduce our country's dependency on external energy sources and aids in the preservation of its natural wealth.

Table 1. Results of hybrid system change based on renewable energy.

| Cities | Solar Panel (kW) | Wind Turbine (kW) | Battery (kWh) | Converter (kW) | Total Net Present Cost ($) | Levelized Cost of Energy ($/kWh) |
|---|---|---|---|---|---|---|
| Adıyaman | 650 | 741 | 577 | 268 | 2,007,613.00 | 0.110 |
| Antalya | 779 | 471 | 658 | 176 | 1,959,547.00 | 0.107 |
| Balıkesir | 542 | 558 | 398 | 308 | 1,566,163.00 | 0.0855 |
| Bayburt | 1,117 | 928 | 758 | 165 | 2,756,169.00 | 0.151 |
| Karaman | 957 | 502 | 625 | 159 | 2,108,795.00 | 0.115 |
| Muğla | 511 | 1,102 | 437 | 199 | 1,976,711.00 | 0.108 |
| Van | 1,202 | 547 | 757 | 169 | 2,533,418.00 | 0.139 |

In this study, an off-grid hybrid energy system was designed to meet the electricity needs of electric vehicle charging stations in seven provinces across Turkey, each selected for their varying solar and wind potential. The system's lifecycle was analyzed using the HOMER Pro simulation software and determined to be 25 years. To identify the most suitable system configuration, comparative analyses of the results from the seven different regions were conducted, leading to the selection of the optimal province based on economic and environmental analysis outcomes.

The analysis revealed that the off-grid hybrid system implemented in Balıkesir was the most cost-effective option, with a net present cost of $1,566,163 and a levelized cost of energy of $0.0855 per kWh. Solar radiation data for the seven provinces are presented in Appendix 2, showing Balıkesir's average daily solar radiation per square meter as 4.19 kWh, which is comparatively low in the regional context. However, Balıkesir was found to have a relatively high average wind speed of 5.90 m/s, making it an advantageous location for wind energy production. The annual electricity production from wind turbines in Balıkesir was calculated at 1,229,619 kWh, indicating a high production capacity compared to the other provinces.

Table 1 displays the component power outputs and economic parameters for the seven provinces, with Balıkesir having the lowest levelized cost of energy at $0.0855 per kWh, underscoring its suitability. A closer examination of the renewable energy-based hybrid system for Balıkesir reveals a capital investment cost of approximately $1.02 million and a net present cost of $1,566,163. At the end of the 25-year period, the system's salvage value is estimated at $209,233. However, components such as wind turbines, batteries, and converters are expected to require replacement within the 25-year lifespan, with total renewal costs calculated at $455,601.

## 4. CONCLUSIONS

The analysis reveals that the annual electric energy generated from renewable sources totals 1,959,566 kWh, with 1,025,265 kWh designated as surplus energy stored in batteries. In the warmer seasons, solar energy production increases due to higher solar irradiation, while wind energy is more abundant during the cooler seasons, illustrating the complementary nature of these power sources in a hybrid system. Solar panels achieve maximum output during midday and the longer daylight hours of summer, though their generation halts at night. Wind turbines, on the other hand, provide a consistent energy supply throughout the year, with enhanced output in the winter months.

The capacity factors for solar and wind energy are calculated to be 15.4% and 25.2%, respectively. These figures are essential for evaluating the efficiency of the energy generated. Analysis of the Lithium-Ion battery storage indicates a practical capacity of 318 kWh from a nominal 398 kWh, due to the 80% depth of discharge limit, with an annual loss of 7,537 kWh and an input of 75,346 kWh. Seasonal fluctuations in the battery's charging levels are evident, with lower levels in June and July correlating with higher energy production during these months. The system design is conducive to supporting electric vehicle charging stations in areas with substantial solar or wind potential. Expanding the system to incorporate other renewable sources such as biomass and geothermal energy could further increase the reliance on renewable energies, although this may lead to higher production costs.

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