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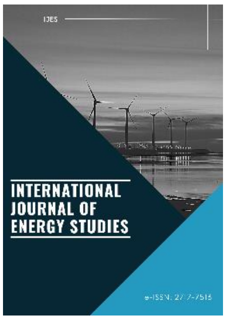

Research Article

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Application of HOMER in assessing and controlling renewable energy-based hybrid EV charging stations across major Turkish cities

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Highlights

- This study showcases the optimization and comparative analysis of hybrid and off-grid charging stations across six distinct regions in Turkey, aiming to support the swift transition to renewable energy.
- The research utilizes the HOMER program, a tool designed for optimizing renewable energy systems, to identify the most efficient positioning of these charging stations.
- The system of analysis adopted in the study bolsters Turkey's energy independence, positively impacts the economy, and reduces carbon emissions.

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ABSTRACT

Facing the global increase in population, escalating energy demands, environmental impacts of internal combustion engines, and potential depletion of fossil fuels, the urgency of developing renewable energy systems becomes more evident. This study takes place during a period of rapid electric vehicle adoption and escalating demand for renewable energy. It presents optimization and comparative analysis of hybrid and off-grid charging stations across six distinct regions. The process of establishing off-grid hybrid charging stations in each region is critically analyzed, using the HOMER program to determine the most efficient placement. HOMER, an optimization tool for renewable energy systems, enables lifecycle cost analysis. This method not only strengthens our energy independence but also supports the economy and reduces carbon emissions, positively impacting the environment. Comparative optimization analysis, based on technical and economic metrics across the provinces, identifies Manisa as the optimal location for the planned electric vehicle charging station. The station is expected to generate a total energy of 3,049,337 kWh per year, with a Net Present Value of 7.24 M$, a Levelized Cost of Energy of $0.441 per kWh, an annual operation cost of $175,795, and an initial capital cost of 3.69 M$. In conclusion, this study aims to improve environmental outcomes and contribute positively to the economy by reducing reliance on fossil fuels and fostering a quick transition to renewable energy.

Keywords: HOMERPro, Electric vehicle charging station, Hybrid energy system, Energy management

1. INTRODUCTION

Electric vehicles (EVs) have risen prominently in the global automotive landscape, evolving from niche eco-friendly alternatives to mainstream transportation options. This transformation is primarily driven by the significant benefits they offer in terms of reduced carbon emissions and superior energy efficiency, especially when compared to their fossil fuel-based counterparts [1]. As these vehicles gain popularity and receive wider acceptance from both consumers and governments, the establishment of a robust, effective, and efficient charging infrastructure becomes not only beneficial but vital.

In a bid to address the challenges of integrating renewable energy into the EV charging infrastructure and ensuring a continuous power supply, hybrid charging stations have emerged as potential game-changers [2]. Distinct in their design, these stations harness power from both renewable energy sources, such as solar and wind, and the traditional electric grid. This versatility assures a more reliable charging infrastructure and also presents opportunities for optimizing energy consumption, reducing grid congestion during peak hours, and fostering a greener and more sustainable urban environment [3].

Central to the EV evolution in major cities such as Istanbul, Ankara, Konya, Manisa, Mardin, and Mersin is the role played by these hybrid charging stations. The dense vehicle traffic and rapidly expanding electric vehicle market in these urban centers highlight the urgency to establish sophisticated charging solutions rooted in sustainable energy. This study delves into the architecture and operational strategies of hybrid charging stations, employing the HOMER program to explore various scenarios for energy source optimization. HOMER's analytical capabilities make it an essential tool, offering insights into integrating diverse energy sources seamlessly while prioritizing cost-effectiveness [4].

Our primary objective is to comprehensively address the energy demands of hybrid charging stations in these pivotal cities. We aim to develop advanced control strategies that streamline operations and emphasize sustainability. In essence, this research seeks to bolster the momentum of sustainable transportation by ensuring that the charging infrastructure for EVs is both efficient and environmentally responsible.

In conclusion, this research aims to make significant advancements in the design and management of hybrid charging stations based on renewable energy sources. The insights derived will serve as a valuable guide for energy policymakers, urban planners, and stakeholders in the energy sector, furthering the global shift towards sustainable transportation.

1.1. Literature Review

The existing literature on the optimization of energy systems and the analysis of hybrid energy systems encompasses comprehensive research conducted across many different geographies worldwide.

In Asia, studies have revealed significant insights into hybrid charging systems. For instance, research in Bangladesh examined the design of a low-cost charging station, where the utilization of solar and biogas energy resources showed both economic and environmental benefits [5]. Elsewhere, other studies have explored the roles of photovoltaic panels, wind turbines, and fuel cells in energy production, underscoring the pivotal role of photovoltaic panels [6]. Similarly, in Pakistan, an analysis of a hybrid energy system integrating photovoltaic panels, biomass, and fuel cells highlighted the major contribution of photovoltaic panels [7]. In India, an analysis of a hybrid charging station based on solar and biogas energy demonstrated reductions in CO_2 emissions and costs [8]. Middle Eastern examples include studies from Saudi Arabia and Qatar, where simulations of photovoltaic and wind turbine-based energy systems were conducted [10]. Another study from Qatar employed HOMER Pro to design and simulate a hybrid charging station integrating solar energy, wind energy, hydrogen production, electrolyzers, and batteries, identifying this scenario as the most efficient [11]. In Egypt, a study analyzed the design and feasibility of four charging stations in different regions, concluding that the most efficient scenarios involved the use of solar energy and biomass in three regions and solar energy with a diesel generator in another [12]. In Europe, a study in Romania utilized the TRNSYS program for the analysis of residential charging stations used in homes, acknowledging their considerable environmental and economic benefits [13]. In Turkey, two distinct studies tackled hybrid energy system analysis using HOMER Pro, integrating photovoltaic panels, wind turbines, biogas generators, and diesel generators [14], and an optimization of a grid-connected photovoltaic-based energy system using data from the Meteorological General Directorate, NASA, and PVGIS. The latter indicated a significant reduction in environmental pollutants with an annual average solar energy production of 160,000 kWh [15].

This broad spectrum of studies demonstrates global interest in the analysis and optimization of hybrid energy systems, showcasing various methods and tools in the field. Each study offers a unique perspective on optimizing hybrid energy systems based on specific geographic conditions and resource utilization.

Within the scope of this study, we delve into the standalone energy optimization of Electric Vehicle Charging Stations (EVCS) using HOMER Pro software in detail. Section 2 provides an in-depth look at our methodology and the system components used. A detailed evaluation of the analysis results and their economic, technical, efficiency, and environmental impacts are located in Section 3. General conclusions and an overall assessment of the study are presented in Section 4.

1.2. Originality and Contributions to the Literature

- Hybrid Charging Integration: By synergizing the areas of EVs and renewable energy, this research delves deeply into the operational intricacies of hybrid charging stations, contributing a novel perspective to sustainable transportation studies.

- City-specific Analysis: Taking into account the specific urban dynamics of cities like Istanbul, Ankara, Konya, Manisa, Mardin, and Mersin, this research delivers insights that cater to region-specific challenges and opportunities in the EV infrastructure domain.

- Pioneering Application of the HOMER Program: By utilizing the HOMER program for energy source optimization in hybrid charging stations, this study introduces an innovative methodological approach, setting a new standard for subsequent research in the field.

- Comprehensive Control Strategy Development: This research not only emphasizes the design and establishment of hybrid charging stations but also the critical post-establishment phase, focusing on control strategies that ensure operational efficiency.

- Broad Stakeholder Relevance: Positioned to influence a diverse set of stakeholders – from energy policymakers and urban planners to professionals in the energy sector – the findings of this study carry significant implications for the broader shift toward sustainable urban transportation.

2. MATERIAL AND METHOD

2.1. Selection of Location

In this study, the technical, economic, and environmental analyses of a grid-independent charging station using Renewable Energy Sources (RES) components have been carried out through the HOMER program. The study also emphasizes the importance of choosing locations with a high potential for renewable energy due to our increasing need for RES (solar, wind). Based on these criteria, six different provinces with high renewable energy potential in Turkey have been selected. These provinces are Istanbul, Ankara, Konya, Manisa, Mardin, and Mersin. The solar and wind potentials of these provinces are shown in Figures 3, 4, and 5.

For the province of Istanbul, an area situated near Maltepe University's Marmara Training Village in the Maltepe/Basıbüyük district (40°57'30.7" North, 29°11'37.6" East) has been selected. In Ankara, the chosen site is near the Ankara Forum Shopping Center (40°01'05.8" North, 32°49'38.0" East). For Konya, the selected area is near the Turkish Petroleum gas station in the İçeri Çumra neighborhood of Çumra (37°34'52.96" North, 32°38'44.82" East). In Manisa, a location within a farming field near the Manisa Bus Station (38°38'14.61" North, 27°26'46.00" East) has been chosen. In Mardin, the designated area is near the TUVTURK Vehicle Inspection Station in the city center (37°17'32.21" North, 40°42'42.98" East). Lastly, for Mersin, the selection is an area near the Kardeşler Rest Area in the Tarsus district (36°56'44.86" North, 34°47'41.25" East).

2.2. HOMERPro Software

HOMER Pro, standing for Hybrid Optimization of Multiple Energy Resources, is a cutting-edge microgrid simulation and optimization tool developed by HOMER Energy LLC, a wholly-owned subsidiary of Cummins Inc. Recognized globally, this software serves as a comprehensive techno-economic analysis tool that assists in designing and evaluating hybrid microgrid systems. Such systems might incorporate renewable energy sources, traditional generators, battery storage, and load management. Designed to assess the technical and economic feasibility of various energy system configurations, HOMER Pro simulates their operations under different conditions. It evaluates these configurations based on key performance indicators such as total net present cost, cost of energy, renewable fraction, and excess electricity, among others. This in-depth evaluation equips users with critical insights into the most cost-effective and reliable system configurations.

HOMER Pro demonstrates extensive versatility, extending its applicability to a broad array of power system types. This includes both off-grid and on-grid systems, as well as grid-tied systems with battery backup. The software enables users to compare the implications of various design decisions and technology options, thereby aiding in understanding how these choices affect overall system performance. The tool also offers the unique capability to account for potential future changes in fuel and electricity prices. This forward-thinking functionality makes it a powerful resource for resilience planning and energy system optimization. With its user-friendly interface and powerful capabilities, HOMER Pro has become a standard tool for energy system analysis and optimization within the global renewable energy sector.

Figure 1 depicts the process of optimization. In the single-line diagram of the system, the diesel generator, wind turbine, and base load are connected to the Alternative Current (AC) bus. The Direct Current (DC) bus connects the PV panel, battery, and electric charging station. The converter used is a bidirectional converter, connected to both the DC and AC bus. Prior to the optimization, meteorological data, technical and economic parameters of all system components, and the base load profile data (compiled over 8760 hours) are included in the optimization process. As a result of the optimization, we obtain outcomes that can be technically, economically, and environmentally evaluated.

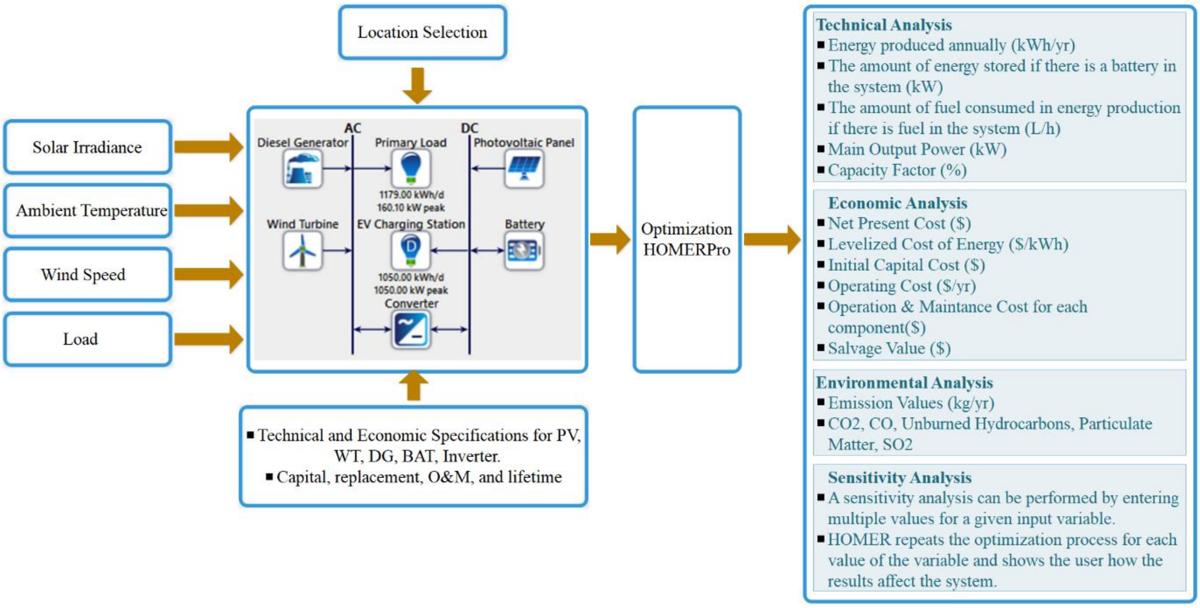


Figure 1. HOMERPro optimization flowchart

2.3. Load Profile

For the optimization process, a pre-defined load profile of a sample gas station was input into the HOMER program. Figure 2 presents the annual load profile, whereas Figure 3 illustrates the daily load profile. In the daily load profile, the peak value is designated as 88.4 kW at 18:00, and the minimum value is noted as 26.46 kW at 03:00.

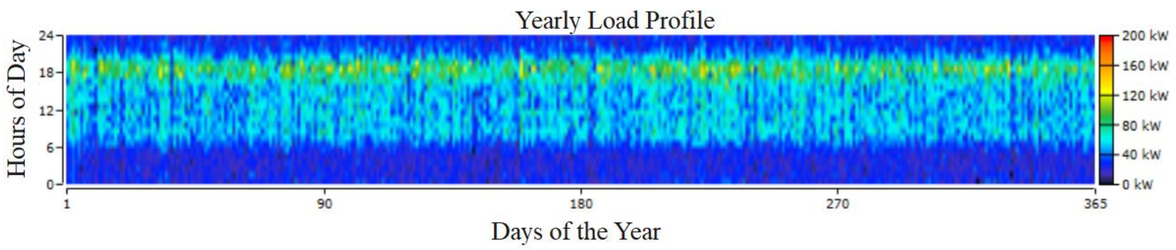


Figure 2. Annual load profile of the study area

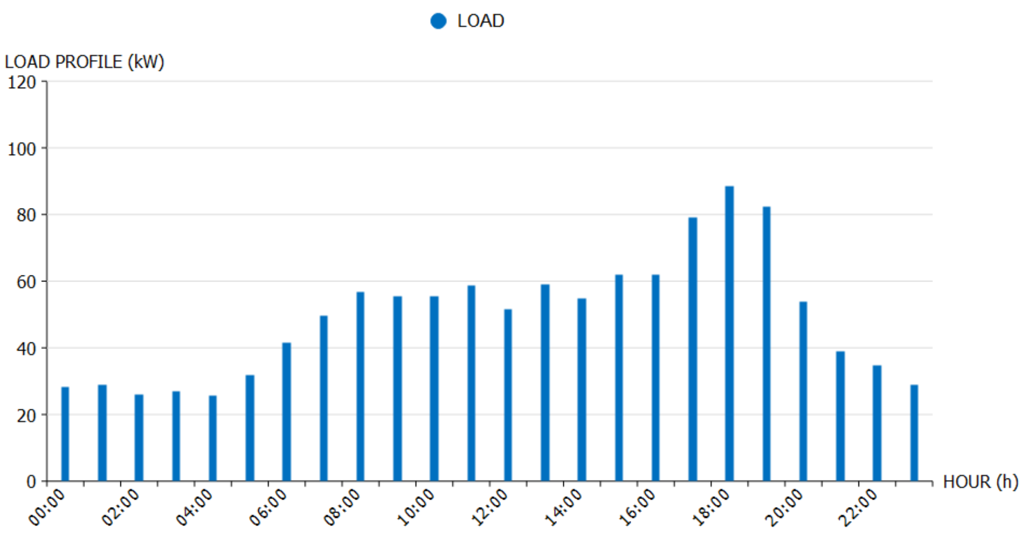


Figure 3. Daily load profile of the study area

2.4. Location Meteorological Data

The graphs in Figure 4, 5, 6 present the annual average values of solar radiation, wind speed, and temperature obtained from NASA (National Aeronautics and Space Administration), which are used as input data in the HOMER program for the selected locations. These data are crucial for the analysis process as they contribute to energy production and optimization. The solar radiation data is depicted in Figure 4, the wind speed data is illustrated in Figure 5, and the temperature data is shown in Figure 6. These graphs play a significant role in evaluating the renewable energy potential and optimizing energy production for each location.

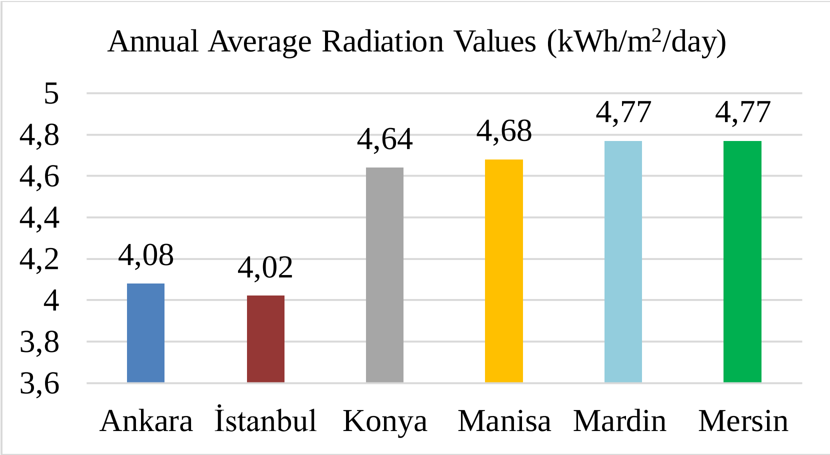


Figure 4. Graph of annual average solar radiation for selected locations

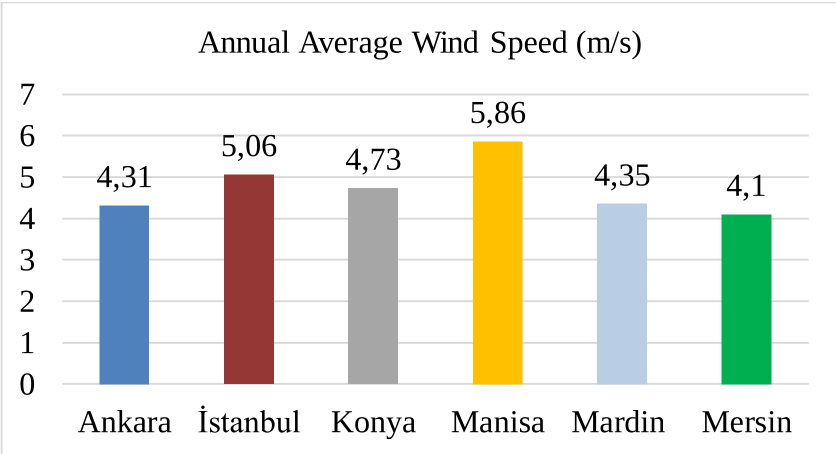


Figure 5. Graph of annual average wind speeds for selected locations

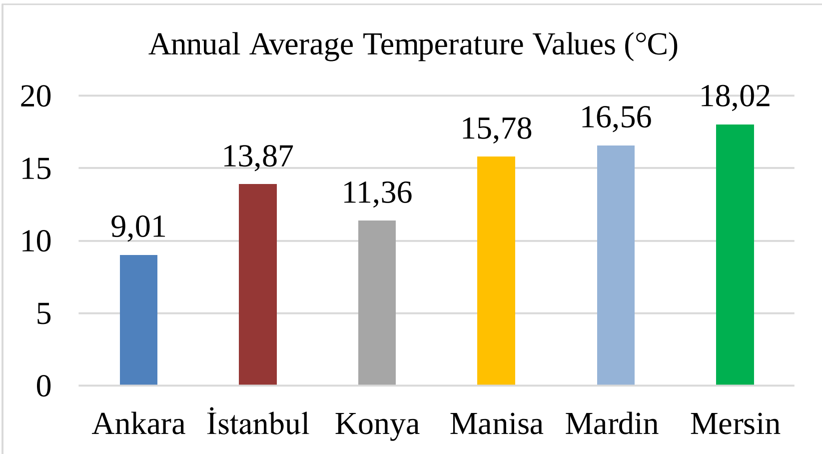


Figure 6. Graph of annual average temperature values for selected locations

2.5. System components

The hybrid charging station in this study, simulated using HOMER Pro, consists of several key components, namely photovoltaic panels (PV), wind turbines (WT), diesel generator (DG), inverter (INV), and battery (BAT). These components work together to optimize the operation of the hybrid electric vehicle charging station (HEVCS) and provide a total output power of 1050 kW, with each component unit having a power capacity of 350 kW. The system utilizes renewable energy sources (RES), including PV and WT, to generate electricity for charging EVs. Additionally, the study aims to provide energy to the surrounding area where the HEVCS is located. The schematic representation of the system on HOMER is shown in Figure 7.

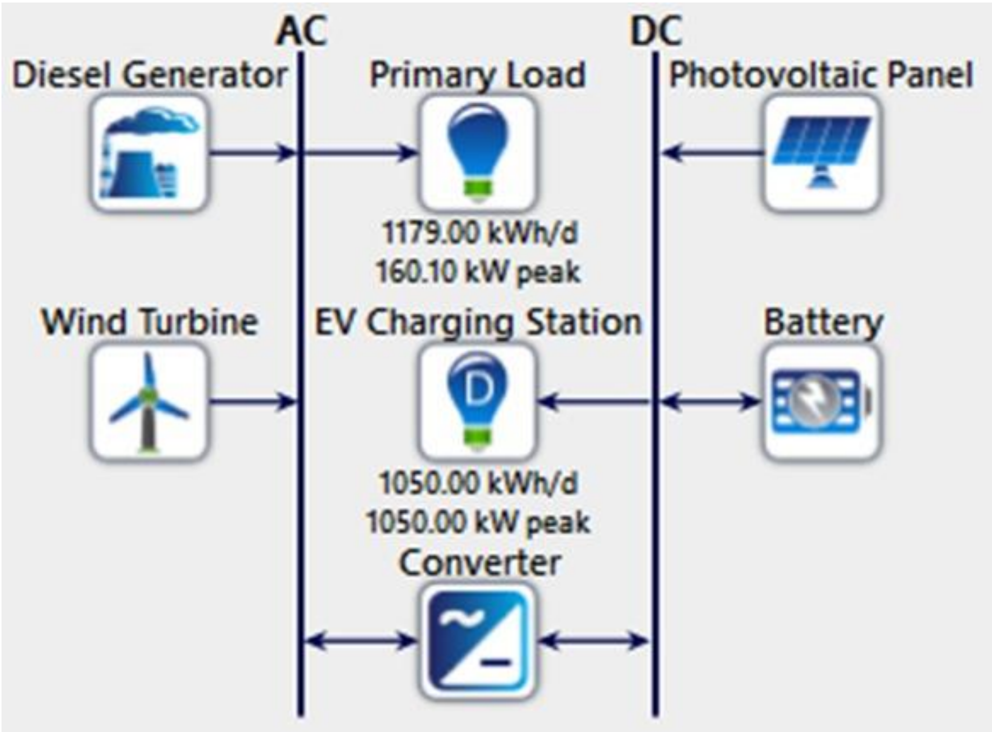


Figure 7. System components diagram

2.5.1. Modeling of solar phototovoltaic system

PV systems are mechanisms that produce clean energy when exposed to sunlight. In this system, designed through HOMER Pro, a flat plate panel of Peimar SG360M brand with a power of 1kW has been chosen. The cost of the panel is assumed to be $650 for initial capital cost (ICC), $650 for replacement cost (RC), and $50 for annual operation and maintenance cost (OM), and a simulation has been conducted based on these assumptions. Moreover, equation (1) can be used to calculate the power output of PVs [14].

$$P_{PV} = Y_{PV}\, f_{PV} \left(\frac{G_T}{G_{T.STC}}\right) \left[1 + \propto_f \left(T_C - T_{C.STC}\right)\right] \tag{1}$$

In this equation; P_{PV} (kW) represents the output power of the PV in the current time interval, Y_{PV} (kW) represents the nominal output power of the PV under Standard Test Conditions (STC), and f_{PV} (%) is defined as the PV degradation factor. G_T (kW/m^2) represents the solar irradiance passing over the PV over time, whereas $G_{T.STC}$ (1 kW/m2) represents the solar irradiance passing over the PV under STC (at 25°C). $\propto_f$ (%/°C) defines the temperature coefficient per degree Celsius for the PV, T_C (°C) indicates the temperature of the PV at the current time interval, and $T_{C.STC}$ (°C) describes the temperature of the PV under STC (at 25°C).

If the effect of temperature on the PV [$\propto_f$ (%/°C)] is not taken into account in the HOMER software program, the calculation for the PV is conducted via equation (2).

$$P_{PV} = Y_{PV}\, f_{PV} \left(\frac{\bar{G}_T}{\bar{G}_{T,STC}}\right) \tag{2}$$

2.5.2. Modeling of wind turbine system

Introducing wind turbines, these are systems that convert the mechanical energy generated when wind strikes the blades into electrical energy. Among various turbines for system design, it has been decided that the Generic 1 kW would be the most appropriate choice in terms of efficiency and usage. The chosen WT has an ICC of $7000, RC of $7000, and annual OM of $70. The height of the turbine is 17 meters, and it has an economic lifespan of 20 years.

The HOMER Pro software program calculates the power output of the WT in three stages. Firstly, the wind speed that rotates the turbine is calculated through Equation (3). Subsequently, based on the calculated wind speed under STC, the power curve of the wind turbine depicted in Figure 7 is used to estimate the expected power output from the WT. Finally, to align with actual conditions, HOMER Pro multiplies the power value estimated under standard conditions by the air density ratio according to Equation (4), thereby calculating the real power output facilitated by the WT.

$$U_{hub} = U_{anem} \frac{\ln(Z_{hub}/Z_o)}{\ln(Z_{anem}/Z_o)} \tag{3}$$

In this equation, U_{hub} (m/s) represents the wind speed at the hub height of the WT, U_{anem} (m/s) denotes the wind speed at the anemometer height of the WT, Z_{hub} (m) signifies the hub height of the WT, Z_{anem} (m) indicates the anemometer height of the WT, and Z_o (m) points to the surface roughness length.

$$P_{WTG} = \left(\frac{\rho}{\rho_0}\right) P_{WTG,STC} \tag{4}$$

In this equation, P_{WTG} (kW) represents the output power of the WT under actual conditions, $P_{\mathrm{WTG,STC}}$ (kW) represents the output power of the WT under Standard Test Conditions (STC) determined through the power curve, ρ (kg/m3) denotes the actual air density, and ρ_0 (1.225 kg/m3) stands for the air density under STC [15]. Figure 7 provides the power curve.

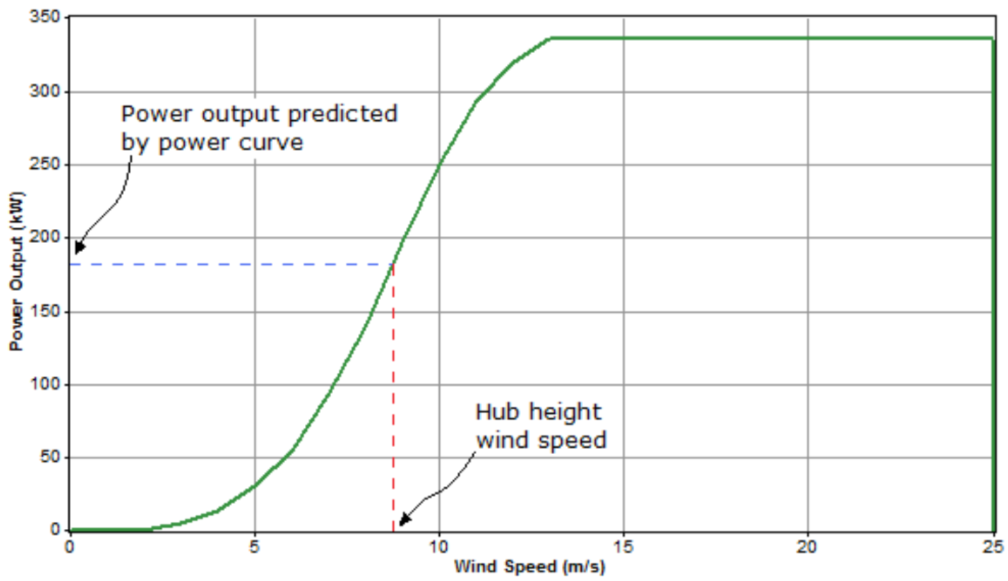


Figure 8. Power curve of the wind turbine [16]

2.5.3. Modeling of diesel generator

When the electricity produced from the PV array and the energy stored in the battery bank fail to meet the load demand, a diesel-based generator is employed to cover this shortfall. The amount of fuel consumed by the DG is dependent on the volume of electricity generated [17]. The simulation was conducted assuming the price of DG fuel to be $1 per liter. The costs for the DG were determined as follows: an ICC of $250, a RC of $250, and an annual OM of $30. The output power supplied by the DG in the system is directly proportional to the fuel that the DG requires.

Therefore, an increase in diesel fuel costs is expected as the power output increases. The fuel consumption rate was calculated in relation to the power output using Equation (5).

$$F(t) = F_0\, Y_{gen} + F_1\, P_{gen} \tag{5}$$

In this equation, $F(t)$ denotes the fuel consumption rate of the DG, F_0 (L/h/kW) is the fuel curve intercept coefficient, F_1 (L/h/kW) signifies the slope of the fuel curve, Y_{gen} (kW) represents the nominal power of the DG under STC, and P_{gen} (kW) indicates the output power of the DG in the current time interval [17].

$$\eta_{DG} = \left(\frac{3{,}6xP_{gen}}{\dot{m}_f x \mathrm{LHV}_f}\right) \tag{6}$$

HOMER software has plotted the fuel curve for the DG, as shown in Figure 9, with a slope of 0.236 L/h/kW and an intercept coefficient of 17.7 L/h. HOMER uses the method of least squares to fit the line to the data points. Fuel consumption at idle is represented by the y-axis intercept, known as the no-load fuel consumption. The slope of this curve is referred to as the marginal fuel consumption. $\dot{m}_f$ (kg/h) denotes mass flow rate of fuel, LHV_f (MJ/kg) refers to the lower heating value of the fuel, and efficiency (η_{DG}) is calculated using Equation (6). The efficiency curve is plotted as shown in Figure 10.

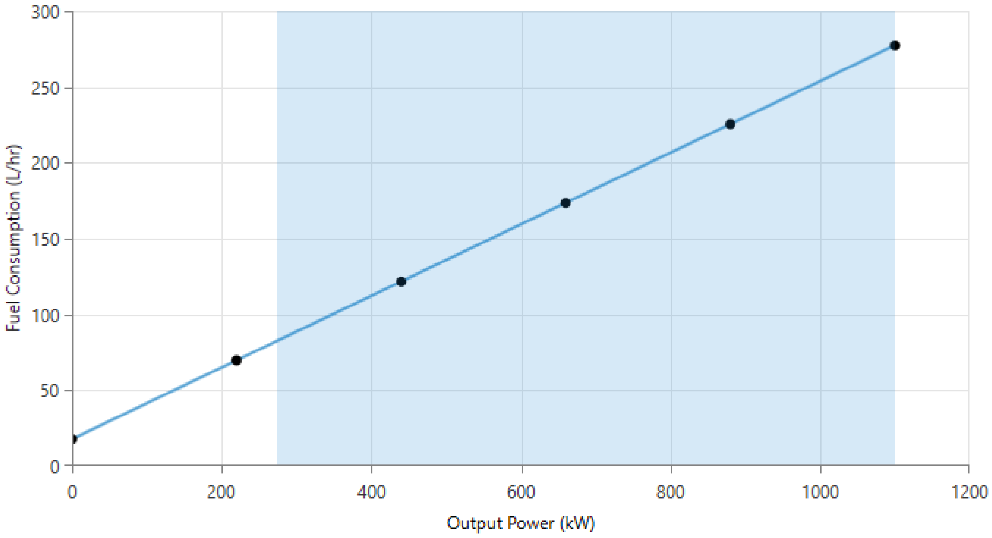


Figure 9. DG fuel curve

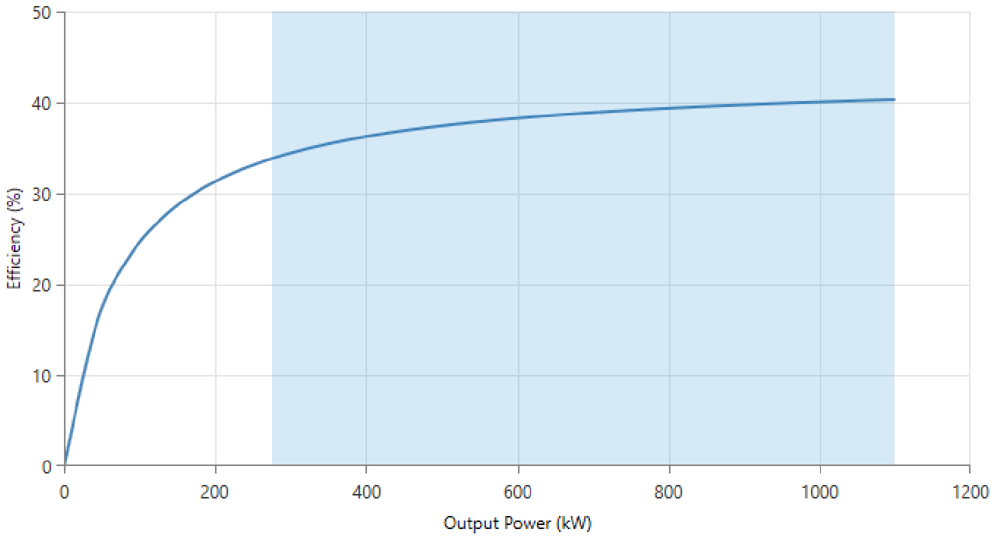


Figure 10. DG efficiency curve

2.5.4. Modeling of converter

A converter (CONV) is defined as a system component that enables the necessary conversion between alternating current and direct current. To sustain energy flow between direct current and alternating current components, a CONV is needed for the hybrid energy system composed of PV, WT, and BAT [18]. The efficiency of the converter in this system is 95%. ICC of the used converter is assumed to be $300, the RC is $300, and the annual operation and maintenance cost is $50. For this system, the capacity of the inverter within the converter is calculated using Equation (7).

$$P_{inv} = \frac{E_{L,max}}{\eta_{DC/AC}} \tag{7}$$

In this equation; P_{inv} (W) represents the capacity of a power converter, $E_{L,\max}$ (Wh) denotes the maximum energy demand required by the load, and $\eta_{DC/AC}$ represents the conversion efficiency.

2.5.4. Modeling of batteries

A battery is a component that allows electrical energy to be converted and stored as chemical energy, and when necessary, converts chemical energy back into electrical energy. For the simulation option, HOMER program's load-following (LF) and cycle-charge (CC) strategy were chosen. Since batteries, like wind turbines, significantly increase system costs, the effect of the number of batteries on the system is very important [4]. As a result of the analyses carried out over the HOMER program, the Generic 1kWh Li-Ion brand battery was preferred for the system. The ICC of the battery is accepted as $550, the RC as $550, and the OM as $10. Additionally, the battery's depth of discharge has been used in the system as 80%. The required number of BATs for the system can be calculated using Equation (8).

$$N_{bat} = \frac{E_d \text{ x } n_d}{V_{bat} \text{ x } Ah \text{ x } DD} \tag{8}$$

In this equation; E_d (kWh) represents the daily energy demand, n_d represents the autonomous days, V_{bat} (V) represents the battery voltage, Ah (Ah) represents the battery capacity, and DD (%) represents the depth of discharge.

2.6. Economic Formulation

In any study carried out using HOMER Pro software, understanding the economic formulation is critical to the optimization process. Not only does it require the appropriate selection of system components, but it also requires various economic calculations and formulations to fully assess the feasibility and efficiency of the proposed system.

2.6.1. Net present value (NPV)

Net Present Value (NPV) is a crucial economic indicator in project assessment. It represents the sum of all costs and revenues over the lifetime of the project when discounted to their present values [19]. The mathematical formula for NPV is shown in equation (9):

$$NPV = \frac{M_{total\_annual}}{CRF(i, N)} \tag{9}$$

In this equation, M_{total_annual} represents the total annual cost of the system, CRF is the capital recovery factor, i is the discount rate, and N denotes the project lifespan [20]. The NPV helps to determine if the future benefits of the energy project outweigh the initial investment costs.

2.6.2. Capital recovery factor (CRF)

Capital Recovery Factor (CRF) is another significant economic measure used to calculate the annual equivalent cost of an asset over its lifespan, including the interest costs. The CRF is calculated using equation (10):

$$CRF = \frac{i\,(1+i)^N}{(1+i)^N - 1} \tag{10}$$

$$i = \frac{i' - r}{1 + r} \tag{11}$$

In equation (11), i' stands for the interest rate, and r represents the annual inflation rate [20]. For this study, i' and r have been accepted as 19% and 17% respectively [21].

The CRF is essentially used to find out how much needs to be set aside each year to recover the original investment, considering the time value of money.

2.6.3. Levelized cost of energy (LCOE)

Levelized Cost of Energy (LCOE), also known as the unit-cost of electricity over the lifetime of a system, is one of the most important indicators for comparing the cost-effectiveness of different energy technologies. The LCOE is calculated as the ratio of the total annual cost ($M_{annual,total}$) to the annual total beneficial energy production ($E_{anual,total}$) as shown in equation (10) [22]:

$$LCOE = \frac{M_{annual,total}}{E_{anual,total}} \tag{12}$$

The LCOE provides a measure that is inclusive of all costs (capital, operation, maintenance, and fuel) and allows for direct comparison of disparate energy technologies by equalizing them to a cost per unit of energy (e.g., cost per kWh) basis. These economic formulations are fundamental to HOMERPro’s optimization algorithm and play a critical role in determining the most cost-effective and efficient configuration for a hybrid energy system [23].

3. OPTIMIZATION RESULTS

Six different optimization processes for EVCS have been performed in the HOMER Pro software program for six different regions. As a result of the simulation, the most efficient scenarios for each region, including the cost and annual amount of energy produced, the number of batteries needed, and the capacity of the generator, are presented in Table 1.

Table 1. The optimal scenario results for techno-economic analysis for six different provinces

	ANKARA	İSTANBUL	KONYA	MANİSA	MARDİN	MERSİN
NPV (M$)	9.68	8.9	8.35	7.24	8.41	8.2
LCOE($/kWh)	0,509	0.542	0.509	0.441	0.512	0.499
OM($/year)	248.021	221.850	216.089	175.795	216.832	208.600
ICC(M$)	4.67	4.42	3.99	3.69	4.03	3.99
PV(kWh/year)	2.704.721	2.705.831	3.344.589	2.677.183	2.416.183	2.605.377
WT(kWh/year)	26.480	191.926	70.016	372.754	0	45.429
BAT(Unit)	5.724	3.907	3.897	2.384	5.414	4.395
CONV(kW)	157	182	181	183	155	199

3.1. Technical Analysis

According to the six different most efficient scenarios determined as a result of the optimization, the use of DG was not deemed necessary in the EVCS system. Moreover, the optimization strategy was determined as cycle CC. While 52.9% of the energy produced in all provinces provides energy to the region where the EVCS is located, the remaining 47.1% is used by the EVCS itself. According to the optimization results carried out separately for six different provinces, all six EVCS systems derive a significant portion of their energy from solar power. In the planned EVCS in Mardin province, the system's energy is entirely provided through PV.

Table 2. Required PV energy production parameters for EVCS

Cities	Energy Produced by PV (kWh/year)	Share in Total Energy Production (%)	Average Output Power (kW)	Nominal Capacity Power (kW)	Capacity Factor (%)	Annual Operating Time (hours/year)
Ankara	2.704.721	99.03	309	1.948	15.9	4.374
İstanbul	2.705.831	93.40	309	2.024	15.3	4.378
Konya	3.344.589	97.95	382	2.131	17.9	4.353
Manisa	2.677.183	87.80	306	1.718	17.8	4.391
Mardin	2.416.183	100.00	276	1.539	17.9	4.387
Mersin	2.605.377	98.30	297	1.668	17.8	4.372

As seen in Table 2, it is stated that the province with the highest annual energy production is Konya, while the province with the lowest is Mardin. Nevertheless, the PVs planned to be installed in these two provinces have the highest capacity factor at 17.9%. Even though there is no significant difference between the annual operating times of PV components in these provinces, it has been determined that the PV with the longest operating time is located in Manisa.

According to the optimization results carried out separately for six different provinces, all six EVCS systems derive a small portion of their energy from wind speed. In the planned EVCS in Mardin province, the system's energy is entirely provided through PV (photovoltaic systems), therefore, no WT (wind turbine) component is needed.

Table 3. Required PV energy production parameters for EVCS

Cities	Energy Produced by WT (kWh/year)	Share in Total Energy Production (%)	Average Output Power (kW)	Nominal Capacity Power (kW)	Capacity Factor (%)	Annual Operating Time (hours/year)
Ankara	26.480	0.97	3.02	29.00	10.4	6.303
İstanbul	191.926	6.60	21.90	128.00	17.1	6.876
Konya	70.016	2.05	7.99	57.00	14.0	6.654
Manisa	372.754	12.02	42.60	172.00	24.8	7.300
Mardin	0	0.00	0.00	0.00	0.0	0
Mersin	45.429	1.71	5.19	60.00	8.7	6.105

As seen in Table 3, Manisa is stated to be the province with the highest annual energy production, while Mardin has the lowest. Furthermore, Manisa is also the province with the highest wind turbine capacity factor and longest annual operating time.

Based on the optimization results carried out individually for six different provinces, it's observed that the EVCS system in Ankara requires the most BAT, while the one in Manisa necessitates the least amount of BAT.

Table 4. Required BAT energy production parameters for EVCS

Cities	Number of BAT(Unit)
Ankara	5.724
İstanbul	3.902
Konya	3.897
Manisa	2.384

Mardin	5.414
Mersin	4.395

The converter in the system is specifically designed to be bidirectional, incorporating both an inverter and a rectifier. The inverter converts the load from direct current to alternating current, while the rectifier performs the opposite function. Based on the optimization results obtained for six different provinces, the statuses of the inverters and rectifiers in the six distinct EVCS systems have been individually evaluated in Tables 5 and 6. The EVCS systems in Ankara and Konya demand the highest number of inverters. On the other hand, the EVCS system in Manisa requires the fewest inverters.

Table 5. Specific parameters of the inverter included in the Converter required for EVCS

Cities	Inverter Capacity (kW)	Annual Energy Input (kWh/year)	Annual Energy Output (kWh/year)	Average Output Power (kW)	Maximum Output Power (kW)	Capacity Factor (%)	Annual Operating Time (hours/year)
Ankara	157	424.785	403.545	46.10	157	29.4	8.731
İstanbul	182	304.864	289.621	33.10	158	18.2	7.310
Konya	181	381.637	362.555	41.40	160	22.9	8.501
Manisa	183	235.200	223.440	25.50	172	13.9	5.946
Mardin	155	452.501	429.876	49.10	155	31.7	8.746
Mersin	199	406.351	386.034	44.10	159	22.2	8.616

Table 6. Specific parameters of the rectifier included in the Converter required for EVCS.

Cities	Inverter Capacity (kW)	Annual Energy Input (kWh/year)	Annual Energy Output (kWh/year)	Average Output Power (kW)	Maximum Output Power (kW)	Capacity Factor (%)	Annual Operating Time (hours/year)
Ankara	157	72.3	68.7	0,01	10.4	0.005	14
İstanbul	182	16.996	16.146	1.84	99.3	1.01	583
Konya	181	1.680	1.590	0.18	34.9	0.1	159
Manisa	183	34.825	33.084	3.78	172.0	2.07	857
Mardin	155	0	0	0	0	0	0
Mersin	199	1.105	1.050	0.12	47.5	0.0603	86

In Manisa's EVCS system, which requires the fewest inverters compared to other provinces, there is a greater need for rectifiers. This arises from Manisa being the province that most frequently employs the WT component, from which alternating current is derived. As mentioned in previous sections, among the six distinct EVCS systems examined in this study, only the system in Mardin does not necessitate a WT component. Consequently, as shown in Table 6, since there is no WT component in Mardin, there is no need for a rectifier component that converts alternating current to direct current.

3.2. Economical Analysis

In the simulation performed using the HOMER program, an interest rate of 19% and an inflation rate of 17% were considered. The system's lifespan is assumed to be 25 years. The subsequent graphs and tables provide comparisons of the NPV, LCOE, OM, and ICC for a hybrid EVCS powered by renewable energy sources and operating independently of the grid across six distinct regions. An examination of the results reveals that in all regions where the establishment of an EVCS is intended, the BAT is the component with the highest cost. The primary reason for this is that the project operates without grid connectivity, and therefore no energy exchange occurs with the grid. As a result, any surplus energy generated by the RESs that isn't immediately consumed needs to be stored, addressing the energy storage issue.

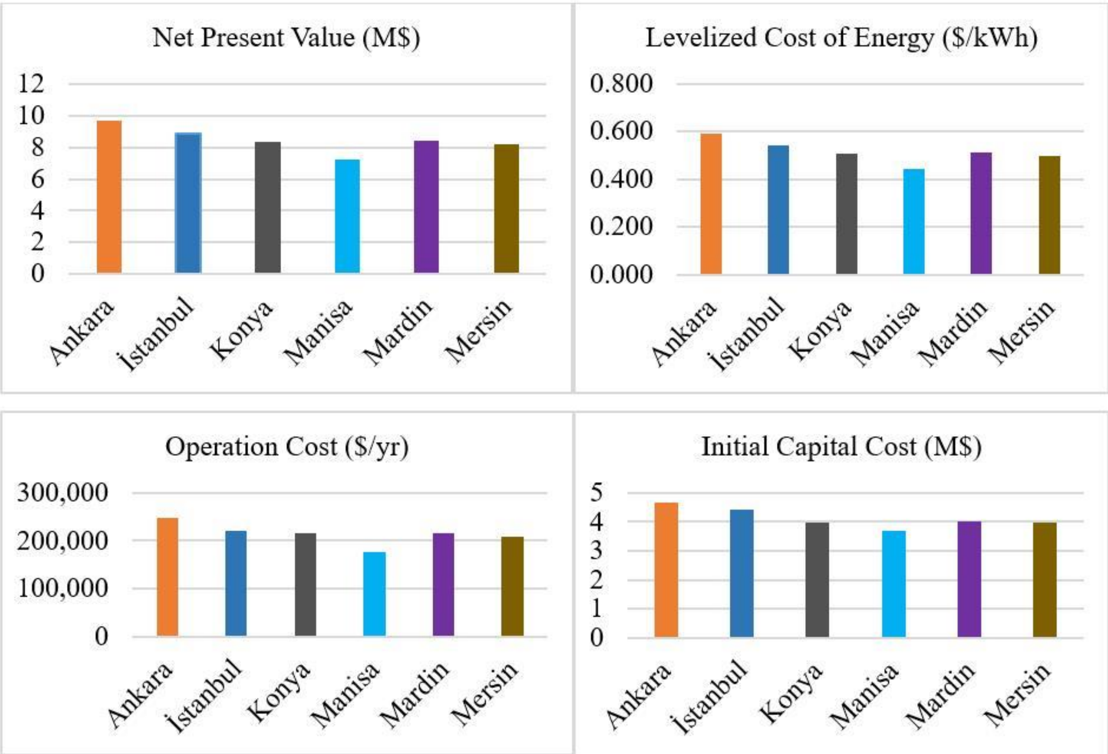


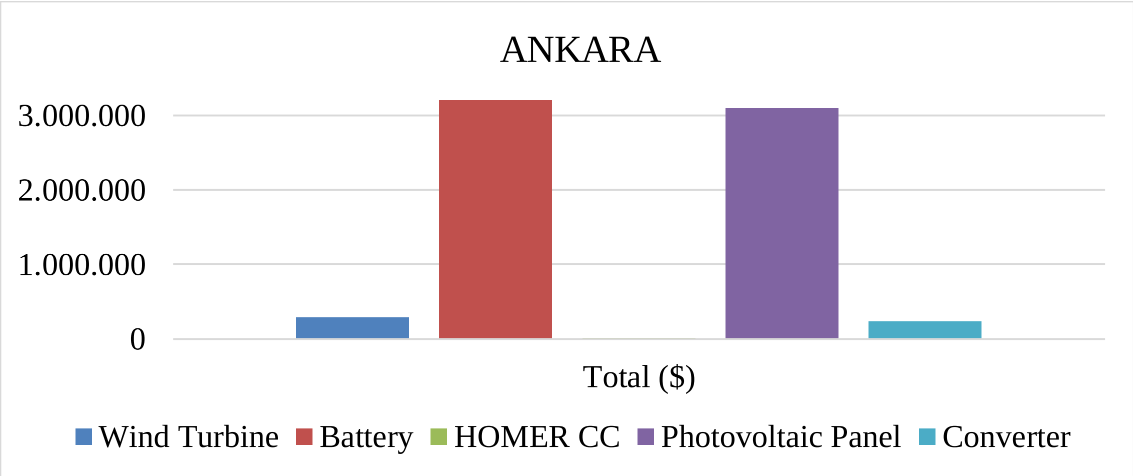
Figure 11. Energy cost graphs for the most suitable scenarios in six different provinces

Moreover, the costs of the components used in the most suitable scenarios created for each province are shown in Table 7, Figure 12, and Figure 13.

Table 7. Cost optimization results of the systems to be installed in Ankara, Istanbul, Konya, Manisa, Mardin and Mersin

ANKARA						
Components	ICC ($)	RC ($)	OM ($)	Fuel ($)	Salvage ($)	Total ($)
WT	203.000,00	144.635,21	41.018,60	0,00	99.662,05	288.991,77
BAT	3.148.200,00	2.441.438,67	1.156.603,34	0,00	686.931,72	6.059.310,30
HOMER CC	5.000,00	0,00	202,06	0,00	0,00	5.202,06
PV	1.266.082,34	0,00	1.967.901,77	0,00	138.128,47	3.095.855,63
CONV	47.003,89	36.451,66	158.295,06	0,00	10.256,17	231.494,44
System	4.669.286,23	2.622.525,55	3.324.020,83	0,00	934.978,40	9.680.854,20
İSTANBUL						
Components	ICC ($)	RC ($)	OM ($)	Fuel ($)	Salvage ($)	Total ($)
WT	896.000	638.390	181.048	0	439.888	1.275.550
BAT	2.148.850	1.666.440	789.457	0	468.875	4.135.871
HOMER CC	5.000	0	202	0	0	5.202
PV	1.315.450	0	2.044.634	0	143.514	3.216.570
CONV	54.741	42.452	184.352	0	11.944	269.600
System	4.420.041	2.347.282	3.199.692	0	1.064.222	8.902.793
KONYA						
Components	ICC ($)	RC ($)	OM ($)	Fuel ($)	Salvage ($)	Total ($)
WT	399.000	284.283	80.623	0	195.887	568.018
BAT	2.143.350	1.662.174	787.436	0	467.675	4.125.285
HOMER CC	5.000	0	202	0	0	5.202
PV	1.385.073	0	2.152.852	0	151.110	3.386.815
CONV	54.379	42.171	183.132	0	11.865	267.816
System	3.986.802	1.988.628	3.204.245	0	826.538	8.353.137
MANİSA						
Components	ICC ($)	RC ($)	OM ($)	Fuel ($)	Salvage ($)	Total ($)
WT	1.204.000	857.836	243.283	0	591.099	1.714.020
BAT	1.311.200	1.016.840	481.716	0	286.102	2.523.654
HOMER CC	5.000	0	202	0	0	5.202

PV	1.116.754	0	1.735.797	0	121.837	2.730.715
CONV	54.909	42.582	184.918	0	11.981	270.429
System	3.691.864	1.917.258	2.645.917	0	1.011.019	7.244.020
			MARDİN			
Components	ICC ($)	RC ($)	OM ($)	Fuel ($)	Salvage ($)	Total ($)
BAT	2.977.700	2.309.215	1.093.964	0	649.729	5.731.151
PV	1.000.362	0	1.554.887	0	109.139	2.446.110
HOMER CC	5.000	0	202	0	0	5.202
CONV	46.355	35.948	156.108	0	10.114	228.296
System	4.029.417	2.345.163	2.805.161	0	768.982	8.410.759
			MERSİN			
Components	ICC ($)	RC ($)	OM ($)	Fuel ($)	Salvage ($)	Total ($)
WT	420.000	299.245	84.866.07	0	206.197	597.914
BAT	2.417.250	1.874.585	888.063	0	527.440	4.652.458
HOMER CC	5.000	0	202	0	0	5.202
PV	1.084.237	0	1.685.255	0	118.289	2.651.203
CONV	59.805	46.379	201.404	0	13.049	294.538
System	3.986.291	2.220.209	2.859.790	0	864.976	8.201.314



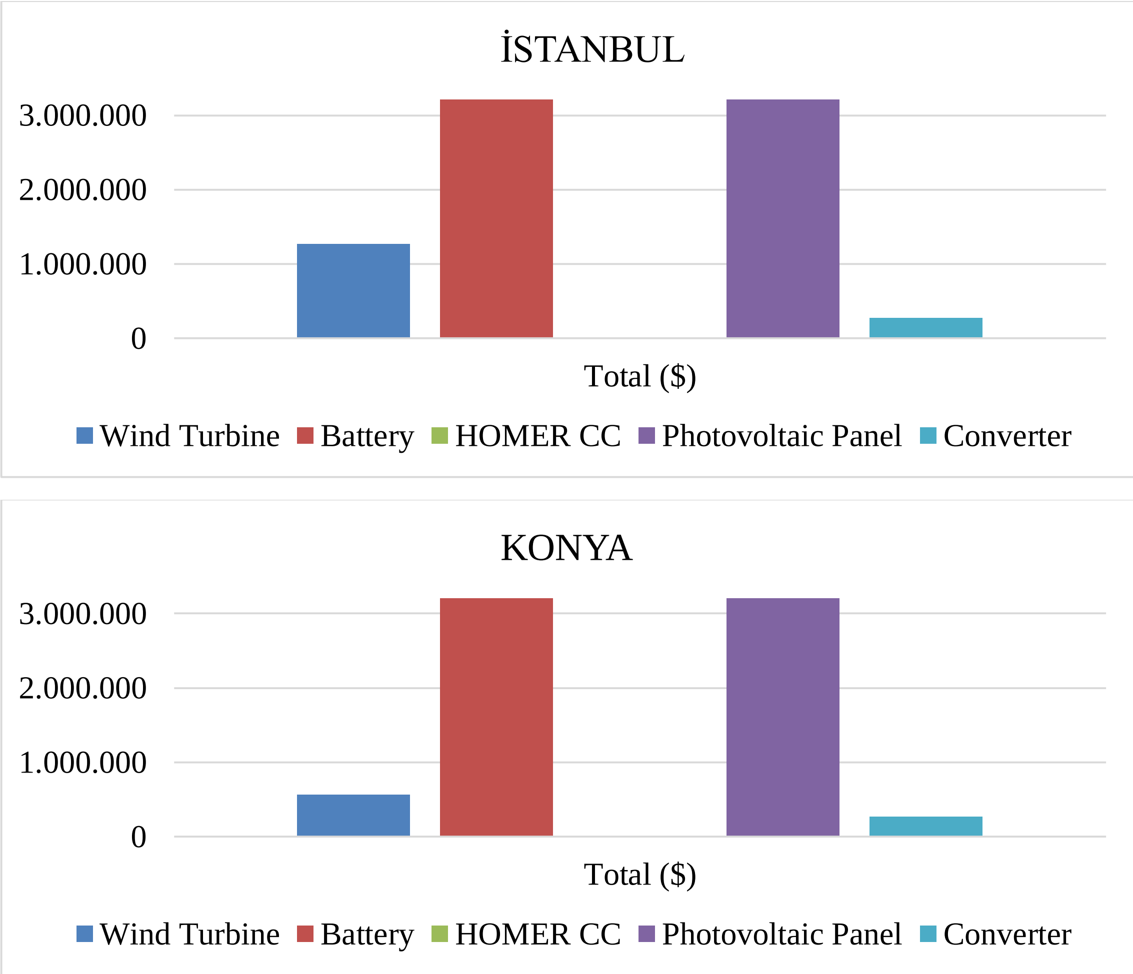
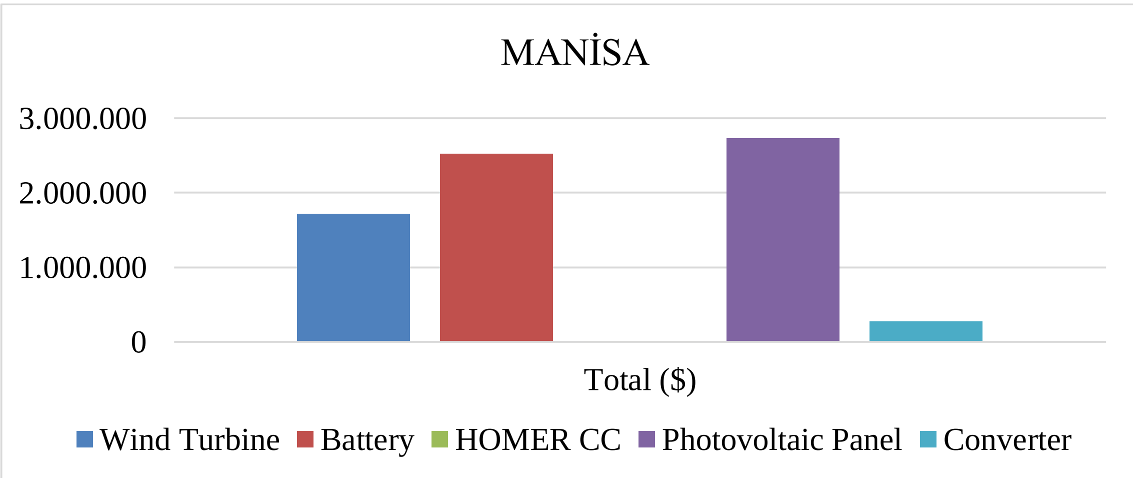
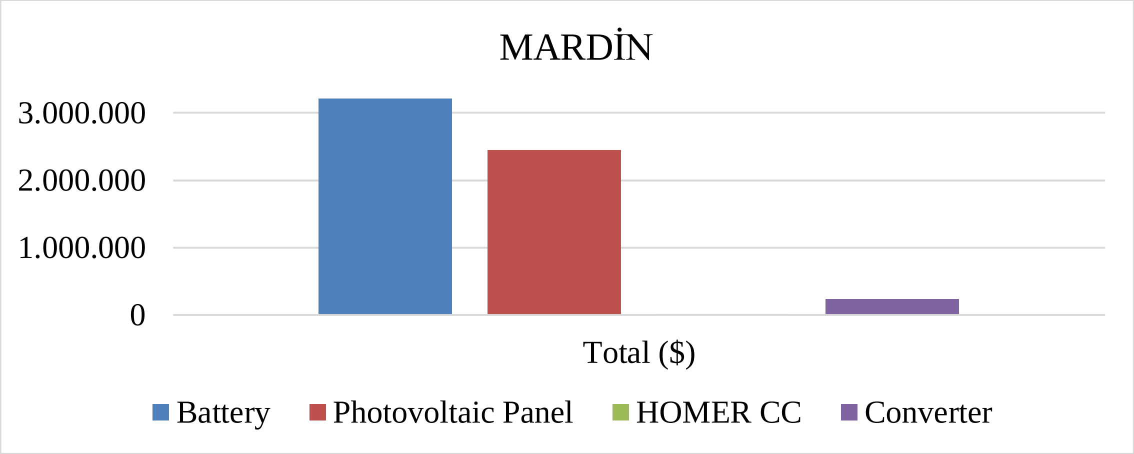


Figure 12. Costs of EVCs in Ankara, Istanbul and Konya provinces





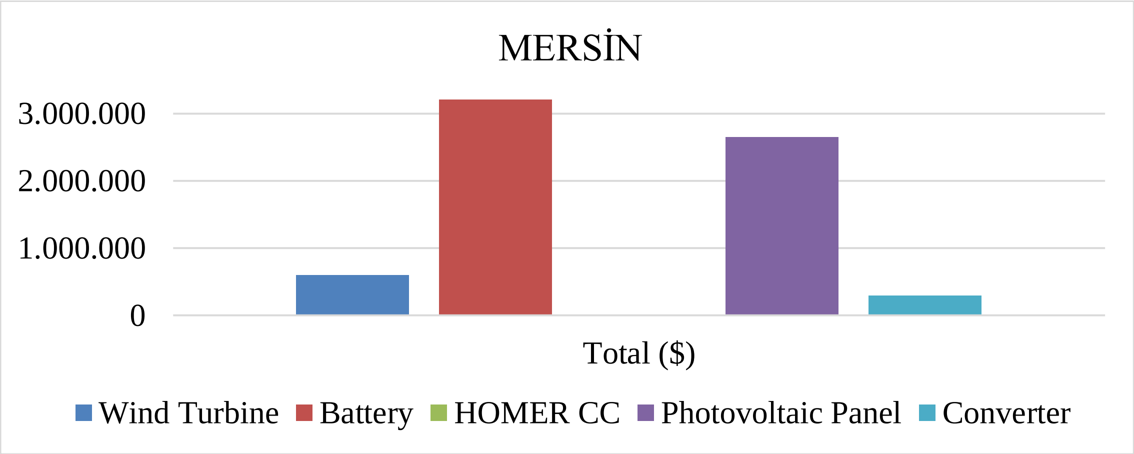


Figure 13. Costs of EVCs in Manisan, Mardin and Mersin provinces

In terms of installation costs, Mersin and Manisa offer more economical options for WT installation. However, it is also necessary to examine the turbine requirements for the envisioned system. Upon reviewing the results, it's clear that regions with higher solar potential require fewer turbines compared to other provinces. Despite Mardin's wind potential being lower than Mersin's, Table 6 indicates that there's no requirement for WT during installation. Furthermore, Manisa stands out as the region with the greatest need for WT, thus necessitating the largest investment in WT. The fundamental reason for this is that among the selected provinces, Manisa possesses the highest wind potential.

3.3. Sensivity analysis

In this study, a sensitivity analysis has been conducted in two distinct ways to assess the impacts of output power and the minimum load ratio on the system design. The minimum load ratio of the output power in the system is the least permissible load, represented as a percentage of the nominal output power. Given this context, it has been hypothesized that to evaluate its economic and technical implications, the system's minimum load ratios should be calculated based on three distinct values: 20%, 50%, and 80%. Additionally, calculations have been carried out for the EAŞİ output power over five different values (250-300-350-400-1050 kW). A sensitivity analysis was performed on the system for different minimum load ratios and average output powers for each province included in the study. Comparative charts depicting the sizing of the EVCS, along with its economic NPV and LCOE values, are presented in Figures 14, 15, 16, 17, 18, and 19.

Figure 14. Sensitivity analysis for Ankara province

In the EVCS planned to be established in Ankara, the minimum load rates and average output powers progress in direct proportion to both the cost necessary for the system and the amount of energy produced through PV and stored by BAT. In situations where the minimum load rate is 50%, there is no need for WT. However, when it is 80%, the system only requires WT if the average output power is 250 kW. Additionally, a need for DG arises only when the minimum load rate is 20% and the average output power is 250 kW for the system to work flawlessly.

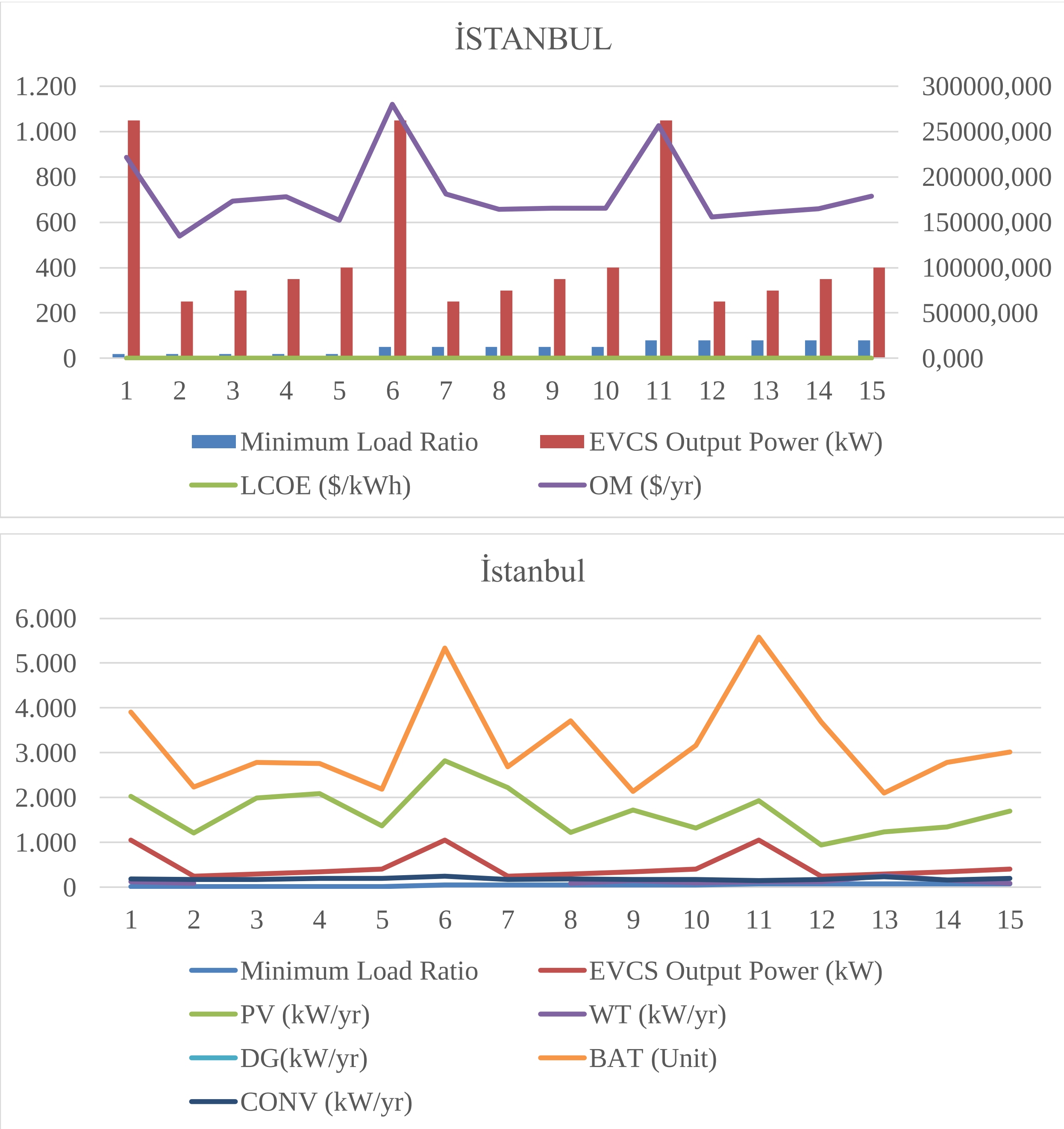


Figure 15. Sensitivity analysis for İstanbul province

In the EVCS planned to be established in Istanbul, the apparent cost and provided energy values, when the minimum load rate is 50%, are seen to be higher than the values when it is 80%. Compared with Ankara, it can be observed that there are more cases where WT is needed in the system in Istanbul. On the other hand, the need for BAT is less in Istanbul than it is in Ankara, as can be seen from Figure 15. Additionally, there is a need for DG in two different situations for the system to be conducted healthily.

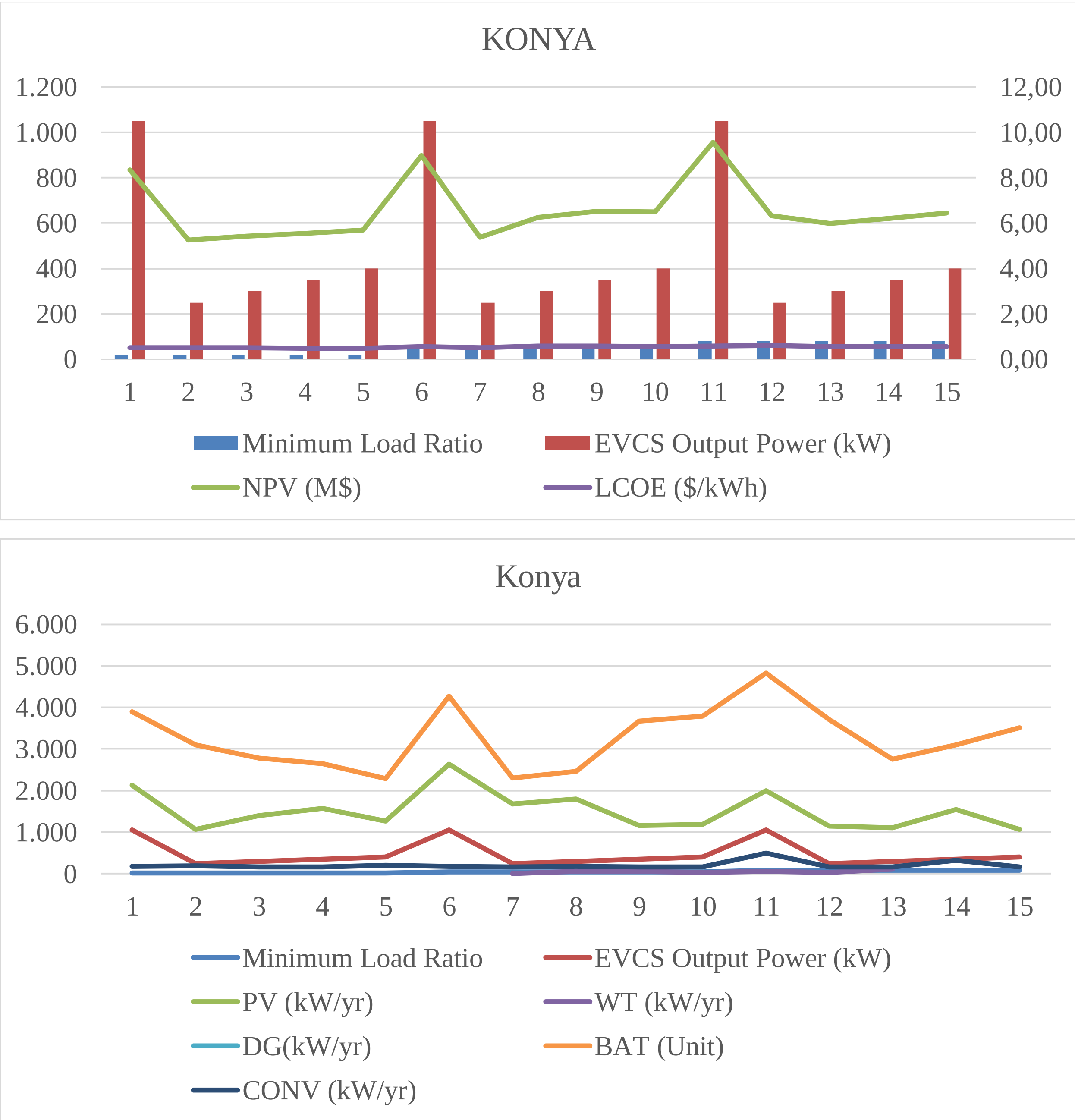


Figure 16. Sensitivity analysis for Konya province

In the EVCS planned to be established in Konya, the minimum load rates and average output powers progress in direct proportion to both the cost necessary for the system and the amount of energy produced through PV and stored by BAT, just as in Ankara. When compared with Ankara, it can be seen that there are more cases where WT is needed in the system in Konya. The need for BAT, however, is less when the minimum load rate is 20%, as can be seen from Figure 16. Additionally, there is no need for DG in the system in any way.

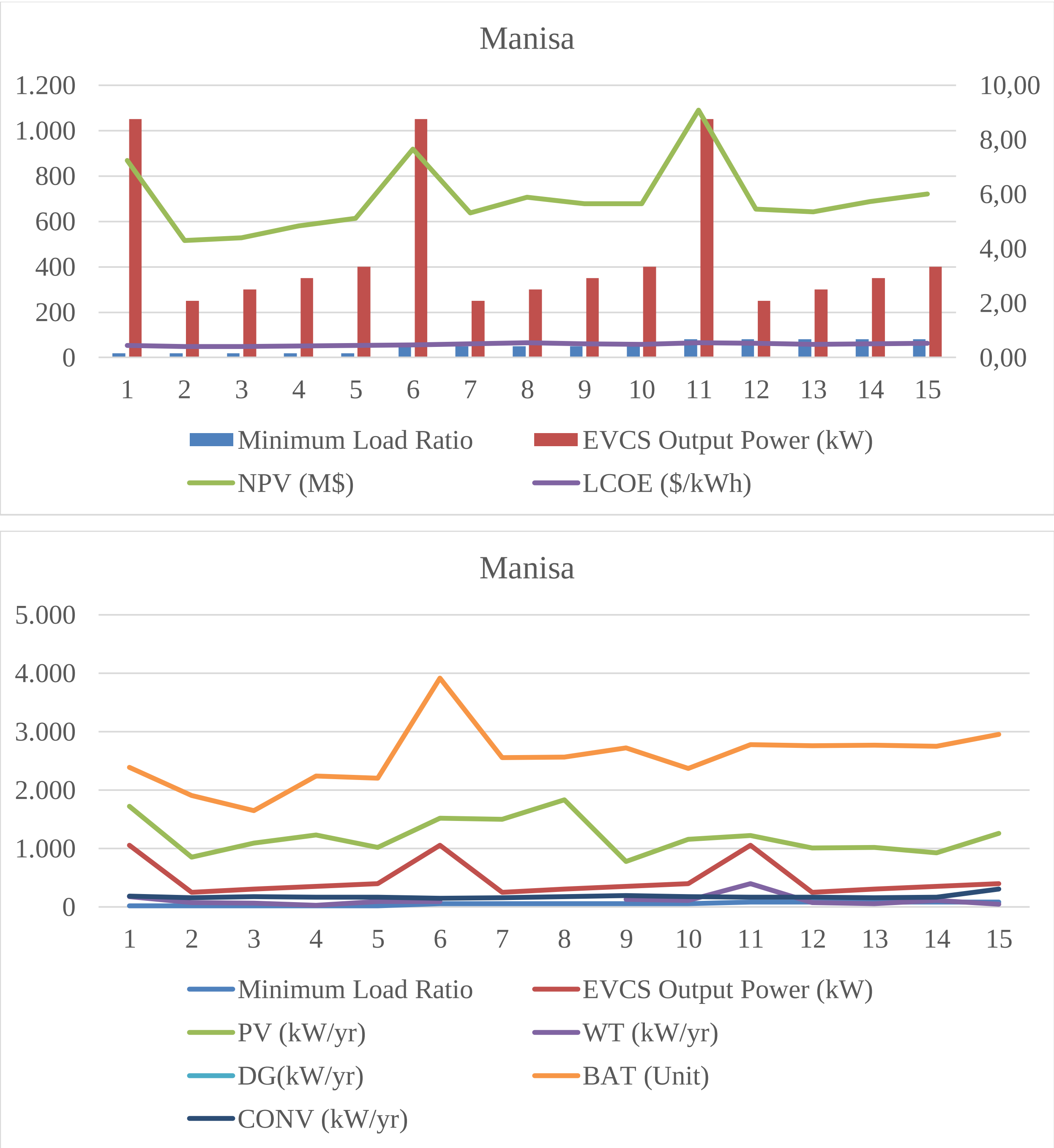
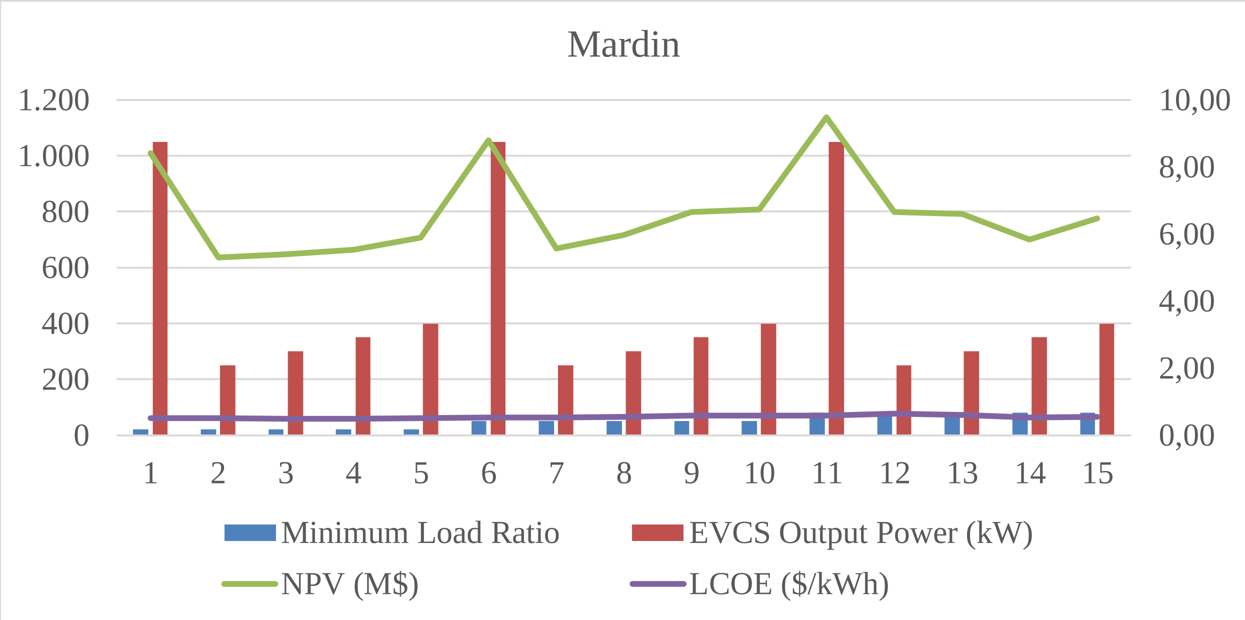


Figure 17. Sensitivity analysis for Manisa province



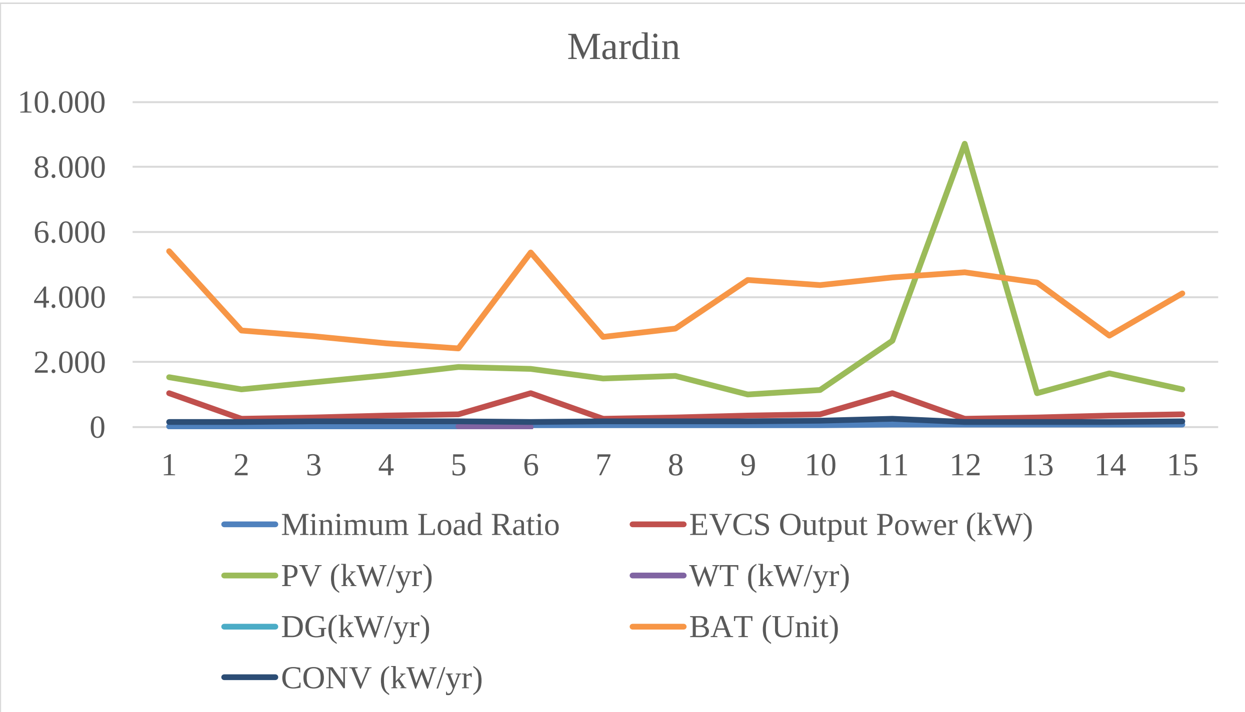


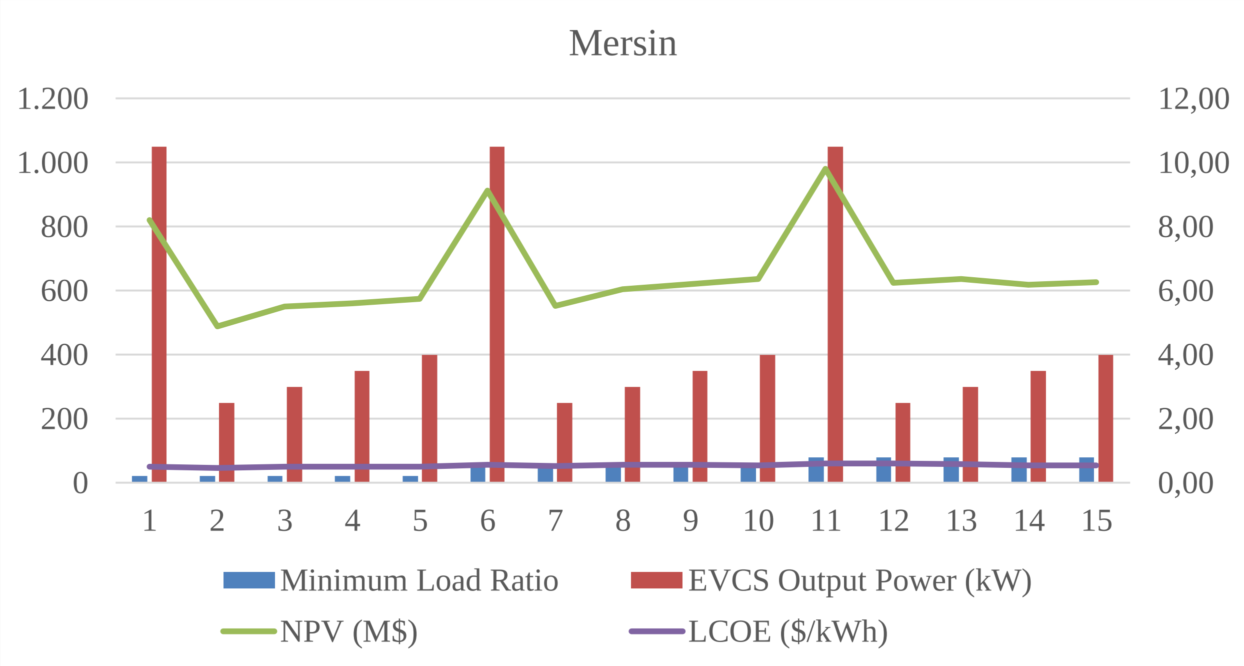
Figure 18. Sensitivity analysis for Mardin province

In the EVCS scheduled for establishment in Manisa, the minimum load rates and average output powers directly correlate with both the system's required cost and the amount of energy produced and stored by PV and BAT, similar to the situations in Ankara and Konya. However, when the minimum load rate is 80%, the cost significantly exceeds that of other scenarios. Compared to other provinces, it’s evident that the system in Manisa requires WT in more situations. Consequently, the amounts of energy produced through PV are lower than in other provinces. Nevertheless, the demand for BAT in Manisa is less in comparison to other provinces. Furthermore, akin to Konya, there is no need for DG within the system under any circumstances.

In the EVCS slated for implementation in Mardin, both the required system cost and the amount of energy produced through PV correlate directly with the minimum load rates and average output power, while inversely relating to the amount of energy stored by BAT. Compared to other provinces, there is a significantly lower occurrence of scenarios necessitating WT within the system in Mardin. However, the need for BAT is less pronounced compared to other provinces. Moreover, mirroring the situation in Konya, there is no requirement for DG within the system under any circumstances.

In the EVCS that’s planned for installation in Mersin, the minimum load rates and average output power directly correlate with both the cost required for the system and the amount of energy generated through PV. However, mirroring the observations from Istanbul, the quantities of energy stored by the BAT are higher when the minimum load rate is 50%, compared to when it’s 80%. It’s also noticeable that while not as prevalent as in most other provinces, there’s still a requirement for WT within the system in Mersin. A significant observation is that, in the sensitivity analysis conducted across six different provinces, the scenario with a minimum load rate of 80% and an average output power of 1050 kW generates more energy through PV than any other scenarios. Similar to the cases of Konya and Mardin, there’s no necessity for DG within the Mersin system under any circumstances.

The optimization study for the EVCS conducted for six different provinces, as known, has been implemented entirely off-grid, with energy sources being entirely renewable. Any hydroelectric power plant or EVCS that does not obtain its energy through the grid, will not emit any emissions into the environment or atmosphere, and is also sensitive to the environment. Therefore, the biggest advantage in the six EVCS located in six different provinces, which are idealized in this study, is that the EVCS aims to be an environmentally friendly and sustainable system.



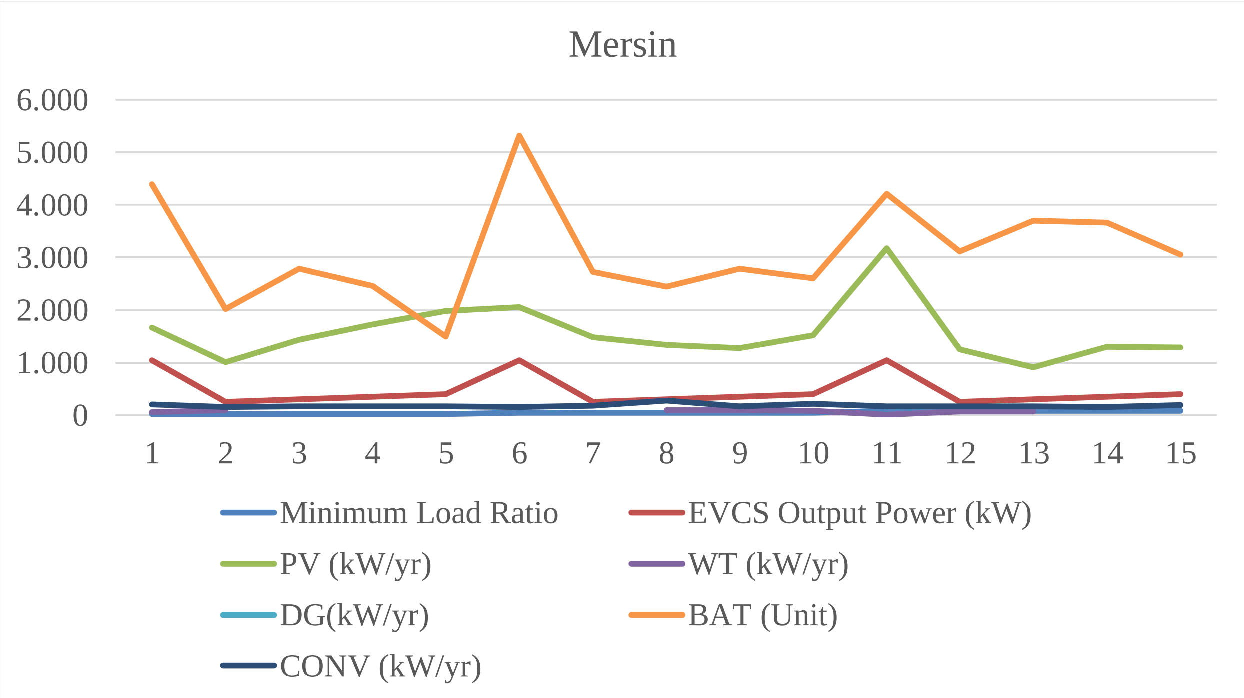


Figure 19. Sensitivity analysis for Mersin province

4. CONCLUSION

As energy demand increases, so does traffic density. This traditional approach, dominated by vehicles with internal combustion engines, significantly contributes to the levels of harmful CO_2 and greenhouse gases released into the environment. To minimize these detrimental environmental effects, renewable energy sources should replace fossil fuels. Moreover, with the growing preference for EVs both nationally and globally, it's crucial to expand the infrastructure of EVCS, which provide power to these vehicles. The environmental impact of EVCS can vary depending on the source of energy production and the location of the charging stations. However, generally, EVCS systems, much like existing EVs, pose less harm to the environment and the atmosphere.

In this study, unlike others, an optimization analysis was carried out for EVCS that rely not only on grid connections but also exclusively on renewable energy sources (solar and wind) as the power supply for EVs. This analysis was conducted on the HOMER program, comparing the results for six different cities. After analyzing the technical and economic aspects, the study concluded that the planned EVCS, with a total energy production of 3,049,337 kWh/year, NPV of 7.24 M$, LCOE of 0.441 $/kWh, OM of 175,795 $/year, and initial capital of 3.69 M$, should be established in Manisa. This proposal to replace the current grid system with Hybrid Power Systems (HPS) and EVCS offers significant potential to reduce emissions and carbon footprints in the region where the system is located significantly. Furthermore, it allows for the utilization of excess energy when needed. 52.9% of the produced energy is intended to power the region where the EVCS is located, while the remaining 47.1% is used by the EVCS itself. Studies of this nature are part of the steps toward a future generation's goal of a cleaner environment and a sustainable economy, including in educational fields, residential areas, commercial points, and industrial facilities.

NOMENCLATURE

ICC	: Initial Capital Cost
BAT	: Battery
DG	: Diesel Generator
CONV	: Converter
EV	: Electrical Vehicle
EVCS	: Electric Vehicle Charging Station
PV	: Photovoltaic Panel
HRES	: Hybrid Renewable Energy System
OM	: Operation and Maintenance Cost
NASA	: National Aeronautics and Space Administration
NPV	: Net Present Value
WT	: Wind Turbine
LCOE	: Levelized Cost of Energy

CRF : Capital Recovery Factor

STC : Standard Test Conditions

RES : Renewable Energy Sources

RC : Replacement Cost

AC : Alternative Current

DC : Direct Current

LF : Load Following

CC : Cycle Charge

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DECLARATION OF ETHICAL STANDARDS

The authors of the paper submitted declare that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Aykut Fatih Güven: Wrote the manuscript, Conceptualization, Methodology, Data curation, Writing - Original draft preparation.

Emrecan Yücel : Software, Validation, Optimization and results.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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