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Techno-Economic Assessment of a Hybrid Renewable Energy Powered Electric Vehicle Charging Station For Shopping Mall in Edirne, Turkey

Edirne'deki Alışveriş Merkezi İçin Hibrit Yenilenebilir Enerji ile Çalışan Elektrikli Araç Şarj İstasyonunun Tekno-Ekonomik Değerlendirmesi

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Abstract

24% of global greenhouse gas emissions originate from the transport vehicles, with the use of fossil fuels in vehicles. If electric vehicles are charged with renewable energy, there is an 80-95% reduction in carbon dioxide emissions compared to electricity produced by conventional methods. In this study, the technical and economic evaluation of a photovoltaic (PV)-wind hybrid energy system for two electric vehicle charging stations for a shopping mall in Edirne was investigated. Optimization of the hybrid renewable energy powered charging station was made using HOMER software. The optimal system types, cash flows, impact analyse, and energy production analyse were discussed. The results show that the most suitable wind-PV hybrid system for the EVS station includes vertical axis wind turbines with 50 kW rated power, 50 kW PV system and 52.1 kW power converters. The wind-PV hybrid system has a total net present cost of $145,961, the net present cost of $145,961, an annual operating cost of $1,881/year and the levelized cost of energy of $0.0193/kWh. The renewable energy powered hybrid electric vehicle charging station for shopping mall is engineering solutions that can be applied universally.

Keywords: Charging station, electric vehicle, greenhouse gas reduction, renewable energy.

Öz

Küresel sera gazı emisyonlarının %24'ü ulaşım araçlarından, araçlarda fosil yakıtların kullanılmasından kaynaklanmaktadır. Elektrikli araçların yenilenebilir enerji ile şarj edilmesi durumunda, geleneksel yöntemlerle üretilen elektriğe kıyasla karbondioksit emisyonlarında %80-95 oranında azalma olmaktadır. Bu çalışmada, Edirne'deki bir alışveriş merkezi için iki elektrikli araç şarj istasyonu için fotovoltaik (PV)-rüzgar hibrit enerji sisteminin teknik ve ekonomik değerlendirmesi incelenmiştir. Hibrit yenilenebilir enerji ile çalışan şarj istasyonunun optimizasyonu HOMER yazılımı kullanılarak yapılmıştır. Optimum sistem tipleri, nakit akışları, etki analizleri ve enerji üretim analizleri tartışılmıştır. Sonuçlar, EVS istasyonu için en uygun rüzgar-PV hibrit sisteminin 50 kW nominal güce sahip dikey eksenli rüzgar türbinleri, 50 kW PV sistemi ve 52.1 kW güç dönüştürücüleri içerdiğini göstermektedir. Rüzgar-FV hibrit sisteminin toplam net bugünkü maliyeti 145.961 $, yıllık işletme maliyeti 1.881 $/yıl ve seviyelendirilmiş enerji maliyeti 0,0193 $/kWh'dir. Alışveriş merkezi için yenilenebilir enerji ile çalışan hibrit elektrikli araç şarj istasyonu, evrensel olarak uygulanabilecek mühendislik çözümleridir.

Anahtar Kelimeler: Şarj istasyonu, elektrikli araç, sera gazı azaltımı, yenilenebilir enerji.

1. Introduction

Transportation networks, which are part of the modern world, use vehicles that are heavily dependent on fossil fuels. Transport emissions from fossil fuels alone cause 24% of energy sector emissions. 74.5% of transport emissions come from road vehicles. The disruption of transportation in the COVID-19 crisis reduced global fossil oil demand by 57% in 2020 and a decrease in transportation emissions was observed. Global CO_2 emissions from the transport sector rose 8% to around 7.7 Gt CO_2 in 2021, as pandemic restrictions were lifted, and passenger and transportation increased after the decline in 2020. Transport emissions

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increased by an average of 1.7% annually from 1990 to 2021; this was faster than any other sectors (www.iea.org/reports).

Annual emissions caused by the transport vehicles in Turkey decreased by 1.8 million tons of CO_2 equivalent (2.18%) in 2020 compared to the previous year and decreased to 80.68 million tons of CO_2 equivalent. Figure 1 shows the annual greenhouse gas emissions caused by transportation in Turkey from 2011 to 2020 (www.eurostat.ec.europa.eu).

There are about 16 million electric cars on the roads around the world, and around 30 TWh of electricity is consumed annually. Figure 2. Shows the global EV sales by scenario from 2020 to 2030. Electric cars have helped reduce fossil fuel consumption and CO_2 emissions in 2021 (www.iea.org/commentaries).

Hybrid electric car sales in Türkiye continued to rise steadily. Figure 3 shows the electric car sales in Turkey from 2015 to 2022 The number of electric cars sold in the first 6 months of 2022 reached 2413 with a 3-fold increase compared to the same period of 2021. According to the data, hybrid car sales figures declined for the first time in the first 6 months of 2022. Despite the addition of new models this year to the hybrid car market, which breaks records every year, the total figure amounted to 9,731 units. In the first 6 months of 2021, 11 thousand 851 hybrid cars were sold (www.tehad.org/2022). With the increasing interest in electric vehicles in Turkey, there has been a great increase in charging stations. Currently, there are a total of 2981 (2714 AC, 267 DC) charging stations throughout Turkey (www.tehad.org/2021). There are 9 charging stations in Edirne. 2 of the 9

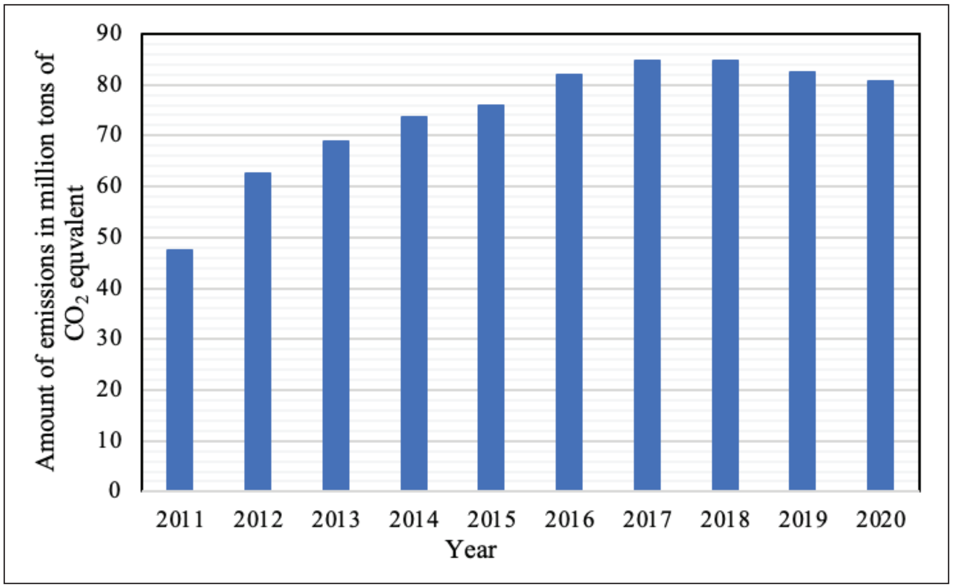


Figure 1. Greenhouse gas emissions in the transport vehicles in Turkey.

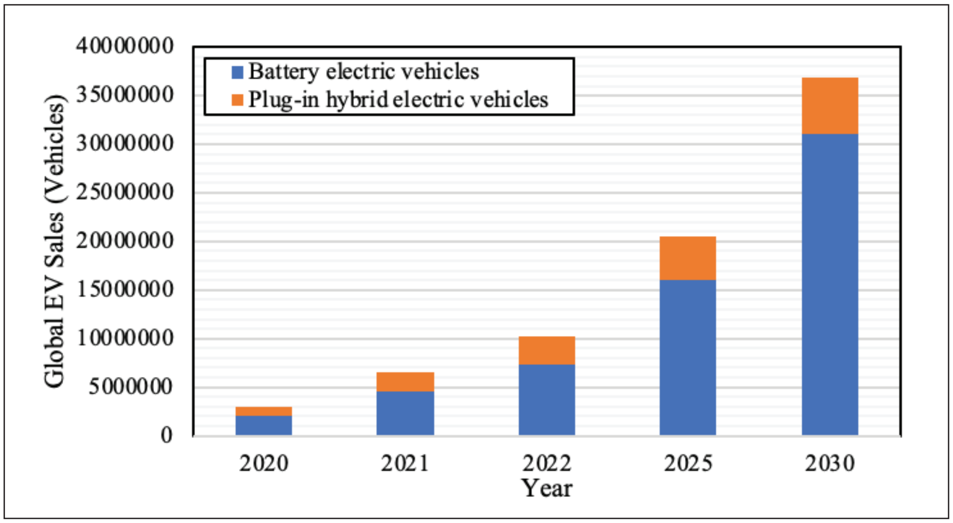


Figure 2. Global EV sales by scenario from 2020 to 2030 (www.iea.org/data).

charging stations are in the shopping mall (www.elektrikli.com.tr). Figure 4 shows the main EV charging stations in Turkey.

Electric vehicles drawing high amounts of energy from the grid will lead to an increase in energy demand, albeit indirectly, through tourism. Especially in the tourism season, with the increase in the visitors' number, there is an increase in the number of charged electric vehicles in shopping malls. Depending on the charging habits of the users, simultaneous charging of many vehicles will cause problems in seasonal demand variability in the load and energy supply security in the grid (Moslehi and Kumar 2010). Existing power system components are not designed to handle the extra loads for long periods. This can cause overloading of components or damage existing transformers. In addition, phase and voltage imbalance in the energy grid is one of the important problems encountered. If many electric vehicles are charged using the same phase, a phase imbalance may occur in the grid. Unplanned charging of electric vehicles causes serious problems in distribution networks (Geth et al. 2012). Simultaneous charging of many EVs may cause voltage drops and deviations at the connection points of the chargers (Singh et al. 2010, Ma et al. 2017, Ucer et al. 2018). During charging, electric vehicles cause active power consumption with high power demand from the grid, which leads to power loss in the distribution system. Positioning the charging stations at the most suitable points and choosing the right power capacity can minimize the power loss in the network (Nurmuhammed and Karadağ 2021). Excessive harmonics that will occur during the charging of electric vehicles pose a potential problem in power systems (Staats et al. 1997). Charging systems with excessive harmonic

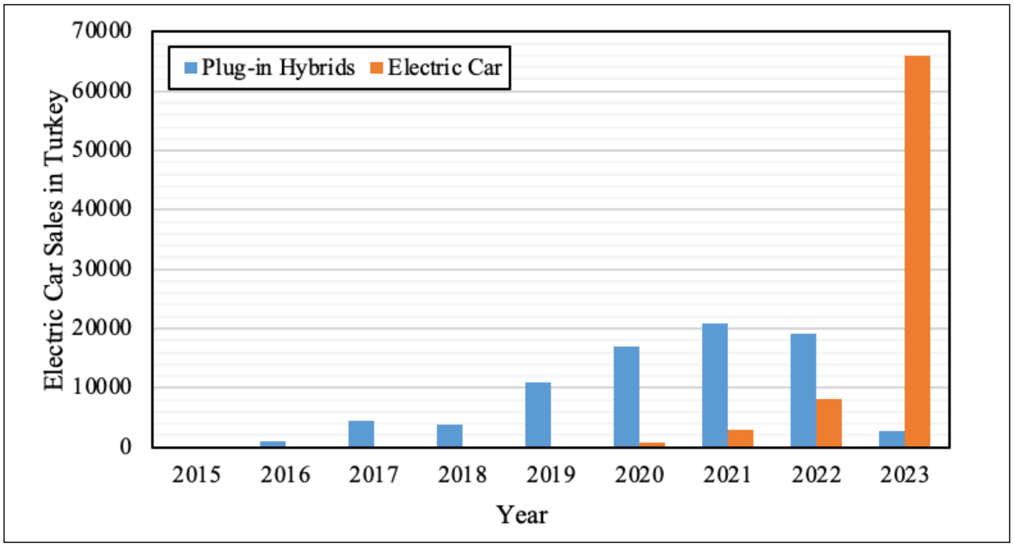


Figure 3. Electric car sales in Turkey from 2015 to 2023 (www.statista.com/chart).

Figure 4. Main EV charging stations in Turkey (www.google.com/maps).

current distortion may cause secondary distribution line and transformer value reductions or quality of service problems (Bass et al. 2001).

The simultaneous or unpredictable charging of many electric vehicles causes large differences in electricity supply and demand drawn from the grid. In addition, vehicles charging at high speeds can cause the power losses and the voltage imbalance in the grid, thus negatively affecting the electricity grid. It is importance that the charging stations are in the right place and that the electrical energy is supported by renewable energy systems or that they are fed with RES independently from the grid. In addition to planning, operation and control in the grid, renewable energy provides solutions to the problems of providing environmentally energy production.

Since electric vehicles do not emit carbon, they provide 100% nature-friendly transportation. Greenhouse gas emissions in transportation are prevented with electric vehicles that are charged at charging stations that work with grid electricity. However, if the grid electricity is not produced with environmentally friendly energy production systems, greenhouse gas emissions are released for the operation of the electric vehicle in general. At this stage, it would be appropriate for the charging stations to be independent from the grid or connected to the grid, to be fed with a minimum level of grid electricity and to be operated with mostly or completely renewable energy sources. In addition, if electric vehicles are charged with renewable energy, 80-95% more reduction is achieved in carbon dioxide emissions compared to electricity produced by conventional methods (www.eea.europa.eu/highlights).

In the literature, many studies have been carried out on the hybrid electric vehicle charging station. Li et al. conducted a technical and economic feasibility study of a hybrid wind turbine/ PV/battery power system in Urumqi, China using HOMER (Li et al. 2013). Hiendro et al. analysed the potential use of wind turbine and PV for a hybrid system at a remote location using HOMER software (Hiendro et al. 2013). Mouli et al. In the Netherlands, they studied the possibility of charging battery electric vehicles by using solar energy at work. A 10kW PV array was considered and modelled in MATLAB with data from the Netherlands Meteorological Institute. Considering the air temperature, they concluded that the angle at which the maximum efficiency is achieved is 28°C (Mouli et al. 2016). Das et al. realized the hybrid charge station in Bangladesh, a combination of an off-grid biogas generator, PV modules, diesel generators and wind turbines by using Homer (Das et al. 2017). Çiçek and Erdinç designed a PV battery hybrid system with the aim of reducing the total energy cost of the electric vehicle parking lot. They have created a charge management model to reduce the total cost by charging the batteries both with increased energy from PV and during tariff periods when electricity is cheap, and by using them during periods when electricity is expensive (Çiçek and Erdinç 2019). Bansal et al. investigated the technical and economic analysis of the charging station for electric vehicles and fuel cell electric vehicles (Bansal et al. 2020). Li investigated the technical and economic evaluation of a off-grid wind fuel cell (FC)-battery hybrid power system for a residence in Xining-China by using HOMER (Li 2021). Early et al. designed and optimized a wind solar hybrid charging station via HOMER software (Early et al. 2021). Sun reviewed the optimal design for fast EV charging stations with wind turbine, PV, and energy storage system. An EV charge load simulation model has been created that dynamically changes the charge expectation according to the electricity price for the duration of use and considers the demand response (Sun 2021). Agustin and Lopez described the design and control strategies for diesel hybrid systems containing wind and/or PV and/or batteries or fuel cells as energy storage components (Agustin and Lopez 2009). Calise et al. proposed a new approach to the problems due to the high density of vehicular traffic in the shopping malls by incorporating PV panels into the energy system by considering a shopping mall in Italy (Calise et al. 2021). Jain and Bhullar studied the operating modes of an electric vehicle charging station powered by a grid-connected solar PV system (Jain and Bhullar 2024). Nandini et al used hybrid optimization approach to study power quality and grid dependency in electric vehicle charging station with photovoltaic system (Nandini et al. 2023. Ulah et al. worked on the optimal scheduling and techno-economic analysis of a grid-connected charging station powered by a PV system (Ullah et al. 2023). Topuz et al. investigated the design parameters of the photovoltaic system and modelled it in computer environment (Topuz et al. 2017).

There are several studies in the literature outlining methods that attempt the control, optimization, and analysis of a PV power system with an EV charging station. Muhammed et al. presented an optimization algorithm for an EV charging station with a PV power system (Mohamed et al. 2020). Islam et al. proposed a new correlated probabilistic model for EV charge loads in coordination with a PV system (Islam et al. 2021). Fadaee and Radzi investigated optimization methods for a off-grid hybrid renewable energy system with evolutionary methods (Fadee and Radzi 2012). Engin examined the suitability of a wind turbine and PV hybrid system. The system was designed in the HOMER. As a result of the analyses made by introducing the wind speed, solar radiation values and temperature values of the selected region to the program, it was stated that the PV-wind system is unsuitable for energy production (Engin 2010). Veliz et al. developed a new model for optimal programming of PV assisted charging stations (Veliz et al. 2022). Engelhardt et al. proposed an energy management system for interfacing power converters (Engelhardt 2022). Chang et al. Evaluated the performance of rooftop PV and EVs for different building types in Seoul, Korea (Chang et al. 2022). Wali et al. investigated the techno-economic evaluation of an off-grid hybrid system in a rural community in Bangladesh (Wali et al. 2023). Shad Abid et al. undertook a techno-economic and environmental assessment of electric vehicle charging stations powered by renewable energy sources (Shadman Abid et al. 2024). Lee et al. conducted a techno-economic assessment of hybrid PV/wind-powered EV charging stations with integrated hydrogen production in Kentucky (Lee et al. 2024). Karthikeyan and Thomas studied optimisation strategies for EV charging and routing (Karthikeyan and Thomas 2024).

This research aims to perform an analysis of a hybrid electric vehicle charging station for shopping mall in Edirne, Turkey. The contribution of this paper is to present a comprehensive hybrid electric vehicle charging station model for shopping malls that will reduce the possible interference between the electric grid and EVs and CO_2 emissions. A solar and wind energy hybrid system has been investigated to provide electricity to electric vehicle charging stations in a shopping centre independent from the main electricity grid in Turkey. The renewable energy powered hybrid electric vehicle charging station for shopping mall is engineering solutions that can be applied universally.

In this study, a techno-economic analysis has been made on the support of the EV charging station in a shopping mall located in Edirne, Turkey with renewable energy sources. The designed hybrid charging station consists of PV – Wind Turbine components. In the hybrid system where wind energy is used, a horizontal axis air guided wind turbine is selected. The selected horizontal axis wind turbine is suitable for high building roof applications. Since shopping malls are in residential areas, the use of horizontal axis turbines with the same power will have disadvantages and application difficulties. With the increase in the number of visitors in shopping mall, especially in the tourism season, the number of charged vehicles increases. In this case, the fact that the charging station is supported by renewable energy prevents possible overloading of components, phase and voltage imbalance in the energy grid, and greenhouse gas emissions. In the analyses made, the status of the hybrid charging station being connected to the grid and being independent from the grid was also examined. The hybrid charging station has been conducted by employing HOMER software. The optimal system types, power generation, cash flows, sensitivity analysis and operating conditions have been discussed. This article aims to optimize an electric vehicle charging station powered by renewable energy sources for a shopping mall and provide a general guideline for future studies. The main purpose of the article is to provide useful information for electric vehicle charging station power supply design.

2. Material and Methods

2.1. Simulation Tool Description

Homer Pro is used for power generation systems analysis and optimization. HOMER allows the modeler to provide a method for finding and comparing several different design options, considering the technical and economic characteristics of the system components. It performs the lowest cost system analysis based on energy source data and a specific load size (www.file:/// chapter3_ HOMERMODELING).

2.2. Site Description

The case study under review represents a typical example of Turkey's shopping mall buildings. The land area is 20.500 m^2 and the total construction area is 96.000 m^2. It has been accepted that the shopping mall operates 12 hours a day, the working hours range is 10.00-22.00 and the average number of people is 5500. In the design, a rather wide gallery is left in the middle of the main mass, which is placed in a linear manner. The gallery space is shaped to provide maximum visual connection between the floors by continuing across 4 floors. Above the gallery, a roof structure made of steel and glass was designed on the roof. There is an area of 5.000 m^2 on the roof for system installation. The shopping mall building's height is 20 m, and the building roof is suitable for vertical axis wind turbine installation. Figure 5 shows the shopping mall building. Table 1 summarises the shopping mall building's location and heating characteristics in Edirne.

Figure 5. Shopping mall building.

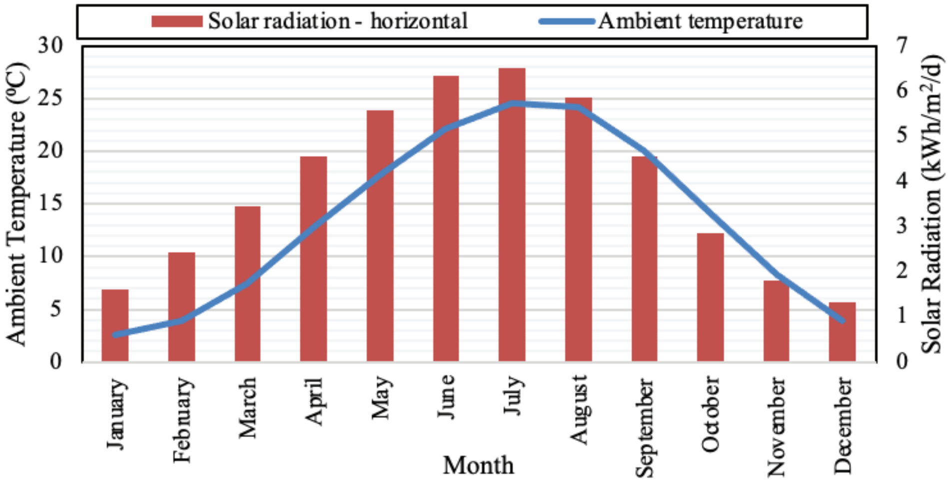


Figure 6. Monthly average ambient temperature and solar radiation in Edirne, Turkey (www.RETScreen-NRCan).

Table 1. Shopping mall location's climate data (www.RETScreen-NRCan).

Parameter	Unit	Edirne
Latitude	ºN	41.7
Longitude	ºE	26.6
Elevation	m	51
Earth temperature amplitude	ºC	21.8
Average annual air temperature	ºC	13.5
Annual relative humidity	%	69.5
Annual average of horizontal solar radiation	kWh/m²/d	3.91
Annual atmospheric pressure	kPa	99.3
Annual average of wind speed	m/s	1.9

- Solar energy potential

A detailed analysis of the solar source, meteorological, geographic data and PV power potential helps to identify the most suitable locations for a full understanding of the climate of a region and the installation of solar power plants (www.solargis.com/products /regional-solar-study). The monthly average ambient temperature and solar radiation of the shopping mall location in Edirne are seen Figure 6.

- Wind energy potential

The monthly average wind speed in Edirne is seen Figure 7.

The wind speed ($V_{(Hr)}$) measured at a height of 10 meters is taken as reference (www.RETScreen-NRCan). The hub height of the wind turbines discussed in this study is 20 m.

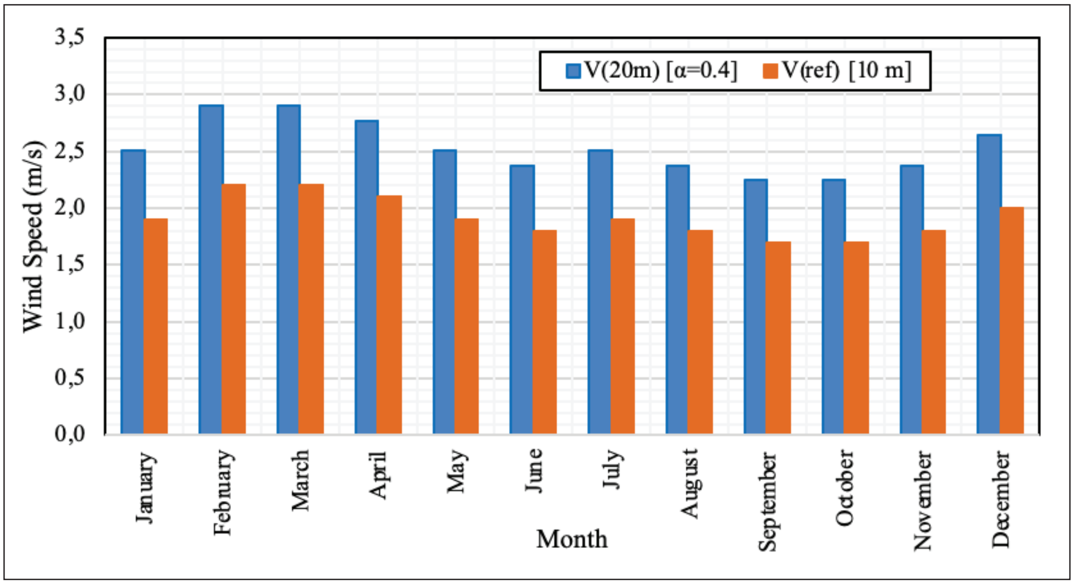


Figure 7. Monthly average wind speed in for 10 m and 20 m in Edirne.

The wind power profile law is used to find the value at the desired height by using the wind data measured at a certain height (Patel 2006). The following equation is calculated using the wind speed power law for different heights.

$$\frac{V_{(H)}}{V_{(Hr)}} = \left(\frac{H}{H_r}\right)^{\alpha} \tag{1}$$

In the Equation 1, $V_{(Hr)}$ is the measured wind speed, $V_{(H)}$ is the wind speed to be determined, the height at which $V_{(Hr)}$ is measured is H(r), the height at which $V_{(H)}$ is to be determined is H, α is the Helman coefficient and the wind speed is the measurement location. depends on its features. Figure 10 shows the monthly average wind speed for 10 m and 20 m in Edirne. When calculating the wind speed at 20 m, the Hellmann coefficient was taken as 0.4, considering the characteristics of the region where the installation was made.

The turbine power curve of this function was found by using the wind energy potential analysis, Weibull probability density function for Edirne. With the help of wind speed averages, the wind energy potential of the site can be found (Manwell et al. 2009). Weibull distribution function can be represented as:

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left(-\left(\frac{v}{c}\right)^{k}\right) \tag{2}$$

where P(v) is the probability density function, k is the shape factor, c is the scale parameter, v is the wind speed. The shape parameter is calculated with the following equation.

$$k = \left[\frac{\sum_{i=1}^{n} v_i^k \ln(v_i)}{\sum_{i=1}^{n} v_i^k} - \frac{\sum_{i=1}^{n} \ln(v_i)}{n}\right]^{-1} \tag{3}$$

$$k = \left(\frac{\sigma}{V_{ort}}\right)^{-1.086} \tag{4}$$

where σ is the standard deviation. Weibull scale parameter can be expressed as follows:

$$C = \frac{V_{ort}}{\Gamma\left(1 + \frac{1}{k}\right)} \tag{5}$$

where Γ represents a gamma function, which can be represented as:

$$\Gamma(X) = \int_0^{\infty} e^{-t} t^{x-1} dt \tag{6}$$

The above equation can be expanded as:

$$\Gamma(x) = (\sqrt{2\pi x})(x^{x-1})(e^{-x})\left(1 + \frac{1}{12x} + \frac{1}{288x^2} - \frac{139}{51840x^3} + \cdots\right) \tag{7}$$

In energy potential analysis with Weibull distribution, Weibull probability density function was calculated with the help of average wind speeds. In Figure 8, the probability density function based on annual average wind speeds for Edirne is plotted. The shape parameter (k) for Edirne is taken as 1.5.

Based on the Weibull distribution, the wind speed with the greatest frequency is calculated with the following equation.

$$v_{\text{mod}} = c\left(1 - \frac{1}{k}\right)^{1/k} \tag{8}$$

Deaves and Lines also determined the maximum wind speed with Equation 9 (Deaves and Lines 1997).

$$v_{\max} = c\left(\frac{k+2}{k}\right)^{1/k} \tag{9}$$

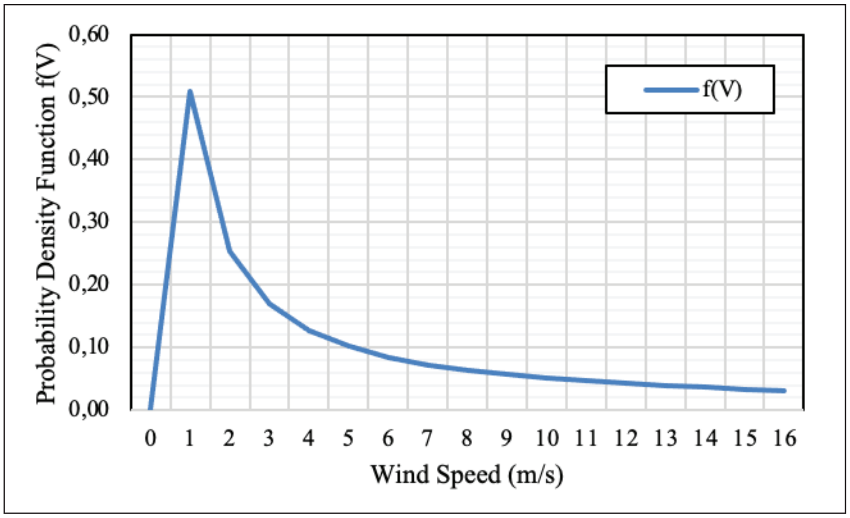


Figure 8. Probability density function f(V) based on annual average wind speeds for Edirne.

Table 2. Weibull parameters, speed, and power estimates for all months for Edirne.

	$V_{(20m)}$ (m/s)	k	c (m/s)	f(V)	V(mod) (m/s)	Vmax (m/s)	P_w (W/m^2)
January	2.5071	1.5	3.342753	0.202971	1.607028	5.880607	45.44
February	2.9029	1.5	3.870557	0.175294	1.86077	6.809124	70.54
March	2.9029	1.5	3.870557	0.175294	1.86077	6.809124	70.54
April	2.7710	1.5	3.694622	0.183641	1.776189	6.499619	61.35
May	2.5071	1.5	3.342753	0.202971	1.607028	5.880607	45.44
June	2.3751	1.5	3.166819	0.214248	1.522448	5.571102	38.64
July	2.5071	1.5	3.342753	0.202971	1.607028	5.880607	45.44
August	2.3751	1.5	3.166819	0.214248	1.522448	5.571102	38.64
September	2.2432	1.5	2.990885	0.22685	1.437867	5.261596	32.55
October	2.2432	1.5	2.990885	0.22685	1.437867	5.261596	32.55
November	2.3751	1.5	3.166819	0.214248	1.522448	5.571102	38.64
December	2.6390	1.5	3.518688	0.192823	1.691609	6.190113	53.00

Considering that the wind turbine power shaft is a rotating machine with the exchange of momentum of the air mass particles flowing through the blade swept area, the wind power in the swept area is proportional to the size of this area, the density of the air and the cube of its speed. Accordingly, the power that can be obtained from the wind can be written as (Simmons 1975):

$$P = \frac{1}{2}\rho A v^3 \tag{10}$$

Where, P is the power output of the wind turbine as a function of wind speed. However, it should be noted that with the Equation 10, power is estimated for wind speeds lower than 15 m/s (Deaves and Lines 1997).

Considering the density of air at sea level at 15.6 ^{0}C and 1 atmosphere pressure as ρ_0=1.225 kg/m^3 and height above sea level (H_m) as 71 m, the corrected air density (1.2165226 kg/m^3) for other location information is found as follows (Patel 1999):

$$\rho = \rho_0 - 0.0001194\ H_m \tag{11}$$

where, A (m^2) is the swept area, ρ (kg/m^3) is the air density calculated depending on the location, pressure, and temperature of the region. Average power density (P_w) for the Weibull distribution can be expressed as:

$$P_w = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right) \tag{12}$$

Table 2 shows the Weibull parameters, speed, and power estimates of the wind turbines for all months. The Weibull power density is shown in Figure 9.

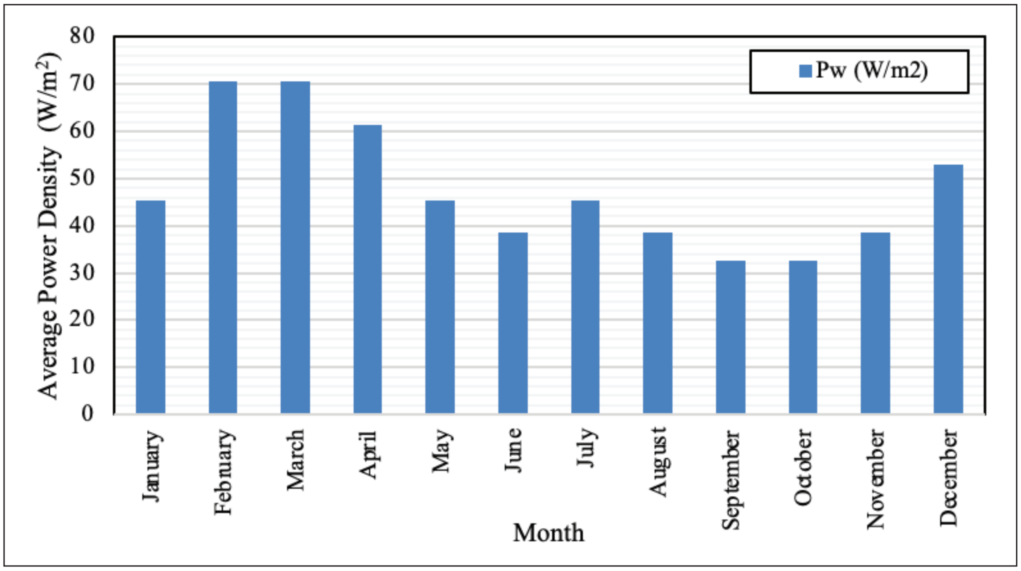


Figure 9. Average monthly Weibull power density for Edirne.

Table 3. EV Charging stations technical specifications.

Technical Specifications	
Type	EVC04-AC22 (Type 2)
Power	22 kW max AC
Voltage	400 V AC, 50/60 Hz, 3-Phase
Current	3x32 A
Power level control	10-13-16-20-25-30-32 A
Socket type	IEC 62196 Type 2 EU
Protection	DC 6mA RCD function
Material	PC plastic, 5VA Flame retardant
Dimensions	460x315x135
IP rating	IP 54
IK rating	IK08

There are 2 electric vehicle charging stations in the shopping mall. Table 3 shows the technical specifications of the electric vehicle charging station. Two charging stations consume an average of 3500 kWh and 4000 kWh of energy per month. On weekends, when tourism increases, there is a daily energy consumption of 190-210 kWh (shopping mall technical office manager's report).

2.3. The Developed Interface

- Electrical load

The number of vehicles charged at the charging stations in shopping malls is proportional to the number of visitors, especially during the tourism season. While making the technical and economic evaluation of a hybrid charging station for shopping mall by using HOMER software, the average monthly energy consumption of the charging station in the shopping mall and the tourism statistics data (data.tuik.gov.tr) for the province of Edirne are ., and total electrical load of the charging station is predicted as shown in Figure 10. Two charging stations consume an average of 3500 kWh and 4000 kWh of energy per month.

- PV module

PV panels are monocrystalline type. PV panels' lifetime is 25 years. The capital cost is 900 \$/kW, the replacement cost is 900 \$/kW and the maintenance cost is 1.55 \$/kW/year (yenitrakyaenerji.com). The technical properties of monocrystalline PV module are shown at Table 4.

-Wind turbine

Table 5 shows the technical properties of two wind turbines selected for system analysis. The lifetime for wind turbines was 15 years. The wind turbines' capital cost is \$1,600 per kW, the replacement cost is \$1,600 per kW and the operational and maintenance cost is \$30 per kW (hi-techsolution.eu).

The wind turbines system can be combined with solar PV modules and function as a hybrid system. Vertical axis wind turbine has 11 moving blades and 11 wind booster driving blades. The wind booster driving blades increase the wind speed reaching the moving blades approximately 2.5 times (Moreno et al. 2021).

The wind turbine capacity factor CF is calculated as follows (Li and Priddy 1985):

$$CF = \left(\frac{E_C}{WTC\ h_y}\right)100 \tag{13}$$

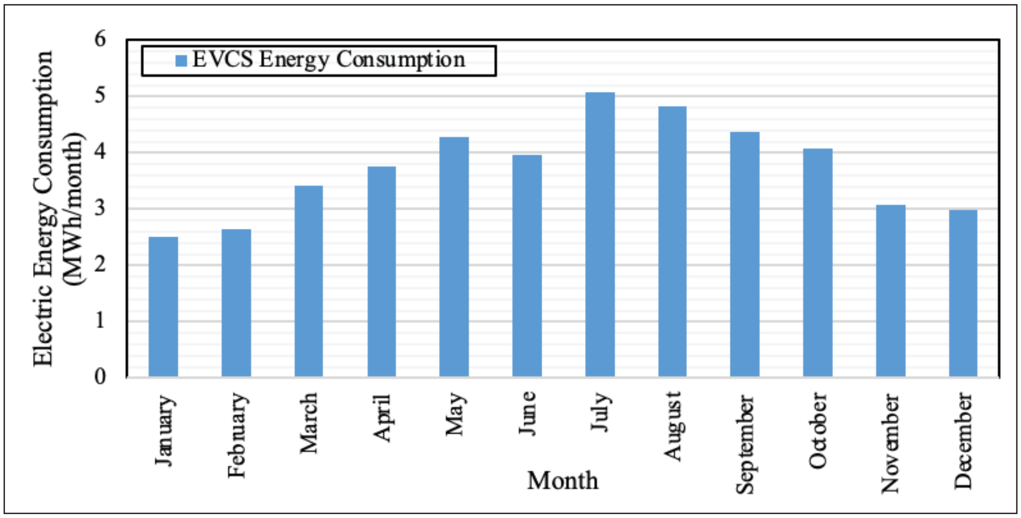


Figure 10. Total EVCS electrical load used in Homer software's analysis.

Table 4. Technical properties of PV module (www.anerngroup.com).

Properties	
Power	400W
Voltage (Maximum Power)	41.70 V
Current (Maximum Power)	9.60 A
Voltage (Open Circuit)	49.80 V
Current (Short Circuit)	10.36 A
PV module efficiency	20.14 %
Number of cells	72
Cell type	Monocrystalline
Power rating	0 W / 5 W
Working range	-40^{0}C ~ +85^{0}C
Dimensions	1989 x 1005 x 40 mm
Area	2 m^2
Warranty	25 Years
Weight	20,0 kg
Front surface	Low iron tempered glass
Certificate	IP67

Table 5. Technical properties of wind turbine (https://hi-techsolution.eu/products).

Properties	
Power	10.5 kW
Nominal Power	12 kW
Voltage	AC, 110/220 V, Three phase
Blades	22 (11 driving blades + 11 moving blades)
Startup wind speed	2,5 m/s
Dimensions	D:350cm, H:450 cm
Swept area	15.75 m^2
Noise levels	<40 dB
Wind turbine type	Vertical axis
Generator type	Tree-Phase Permanent Magnet
Lifetime	15 Years
Weight	435 kg
Certificate	IP54

where E_C is the renewable energy collected, expressed in kWh, WTC is the wind türbine capacity, expressed in kW, and h_y is the number of hours in a year. Figure 11 shows the wind turbine power curve and energy curve.

-Storage battery

The capacity of the Li-ion battery chosen for electricity storage is 100 kWh, its nominal capacity is 167 Ampere-hour (Ah), and its efficiency is 90%. The battery's capital cost per quantity was $15,000, the replacement cost was $15,000, and the operating and maintenance cost was $1,000 per battery per year.

-Converter

The selected converter has a capacity of 150 kW, a life of 25 years and an efficiency of 95%. The capital cost of the converter is $300 per kW, the replacement cost is $300 per kW, and the operating and maintenance cost is $5 per kW.

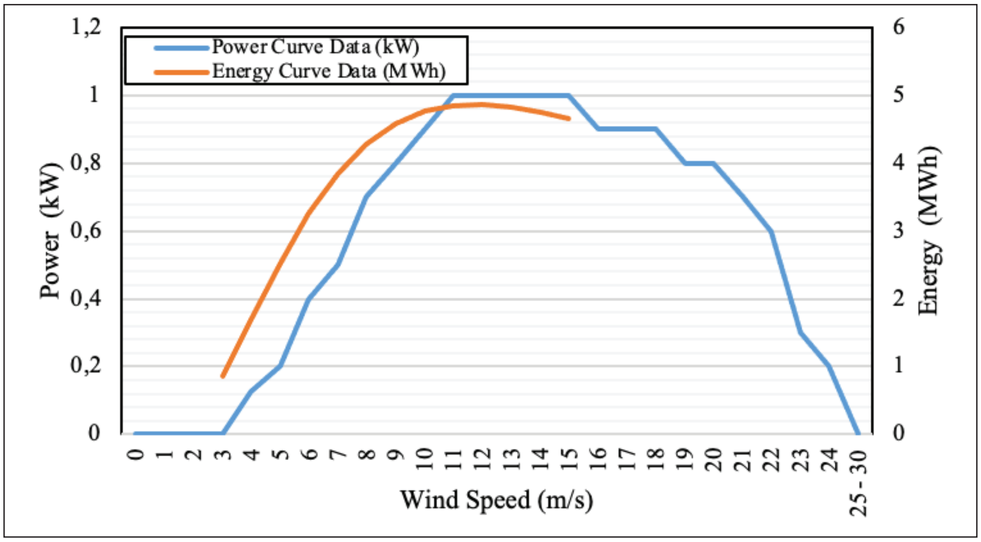


Figure 11. Wind turbine power curve and energy curve.

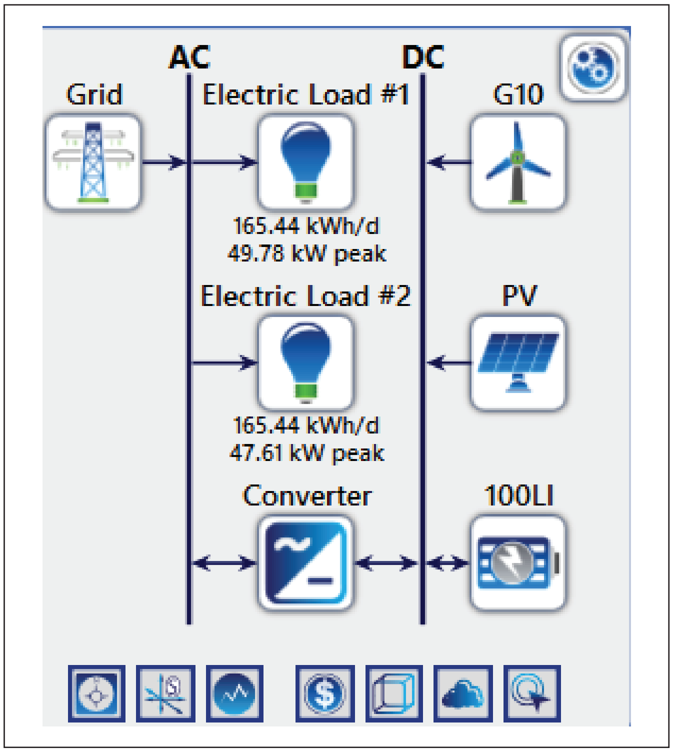


Figure 12. Hybrid system configuration for EV charge station in Homer.

-Grid

Grid power price is $0.089 per kWh, grid sellback price is $0.05 per kWh. Carbon Dioxide emission is 632 g/kWh, Sulphur Dioxide emission is 2.74 g/kWh and Nitrogen Oxides emission is 1.34 g/kWh.

3. Results and Discussion

The Electricity production, economic gain, and emission analysis calculations of the hybrid system with Homer software are included.

Homer hybrid system analysis

After entering the data of the hybrid system elements into the HOMER software, the system diagram was created. Figure 12 shows the hybrid system configuration for EVS station in Homer. Table 6 shows the hybrid system optimization inputs in HOMER analysis. There are two electrical vehicle charging stations with a power of 22 kW in the shopping mall. Two charging stations consume an average of 3500 kWh and 4000 kWh of energy per month. Figure 13 shows the hybrid system's electric load (one EVS station's load) specifications in HOMER simulation.

Table 6. Hybrid system optimization inputs in HOMER analysis.

Components	Optimization inputs
PV size (kW)	0 – 10 – 20 - 30 – 40 - 50
WT size (kW)	0 – 10 – 20 - 30 – 40 - 50
Converter capacity (kW)	0 – 7.2 – 14.4 – 21.6 – 28.8 – 36.0 – 43.2 – 50.4 – 57.6 – 64.8 – 72.0
Battery strings	0 – 3 – 6 – 9 – 12 – 15 – 18 – 21 – 24 – 27 - 30
Grid (kW)	999,999

3.1. Energy Production

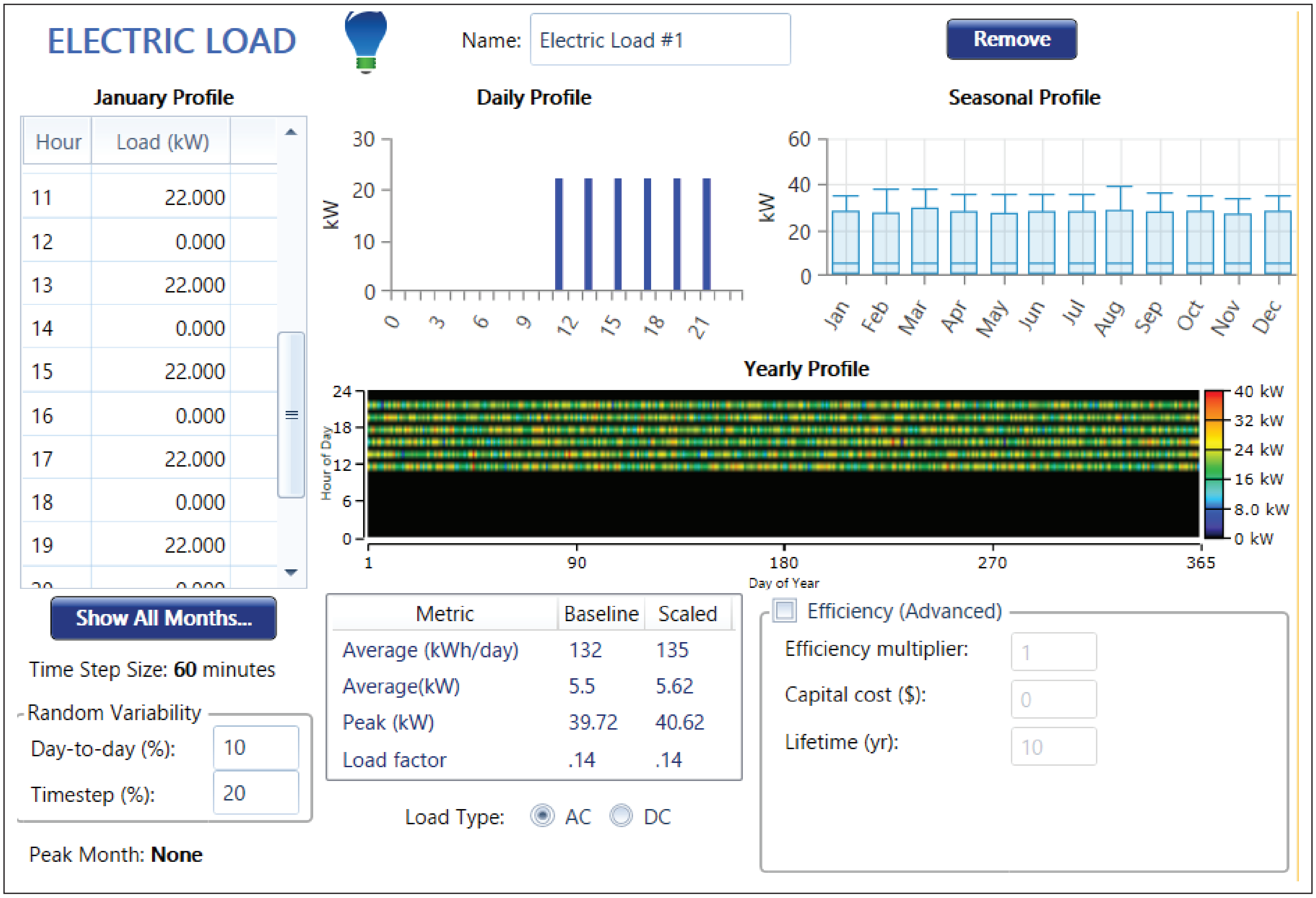
Figure 14 shows the daily electricity produced by the PV system and Figure 15 shows the daily electricity produced by the wind turbines in Homer simulation.

3.2. Economic Analysis Results

Table 7 shows the cost of EV charging station components. Table 8 shows the renewable energy powered hybrid system cost summary of HOMER analysis. Figure 16 shows the hybrid system cumulative nominal cash flow. Discount rate is 10%, inflation rate is 14% and project life is 25 years in the HOMER analysis.

3.3. Optimization Results

In this study, 6,334 solutions were simulated: 6,334 were feasible. 4001 optimization results were obtained with Homer analysis, only 8 of them were presented. Table 9 shows the Homer optimization's hybrid system's architecture results.



Name: Electric Load #1

Hour	Load (kW)
11	22.000
12	0.000
13	22.000
14	0.000
15	22.000
16	0.000
17	22.000
18	0.000
19	22.000

Time Step Size: **60** minutes

Random Variability

Day-to-day (%): 10

Timestep (%): 20

Peak Month: **None**

Metric	Baseline	Scaled
Average (kWh/day)	132	135
Average(kW)	5.5	5.62
Peak (kW)	39.72	40.62
Load factor	.14	.14

Load Type: ● AC ○ DC

☐ Efficiency (Advanced)

Efficiency multiplier: 1

Capital cost ($): 0

Lifetime (yr): 10

Figure 13. Hybrid system's electric load (one EVS station's load) specifications in HOMER simulation.

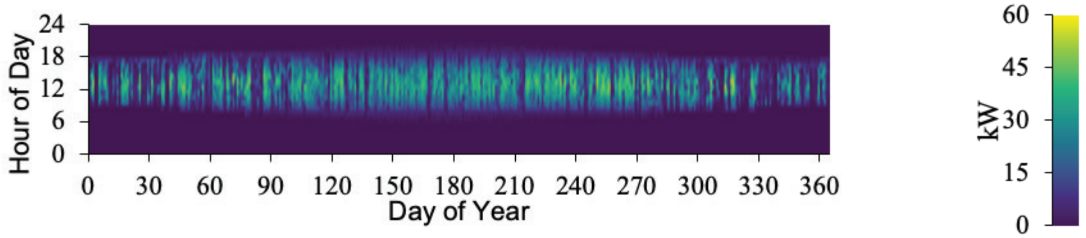


Figure 14. Daily electricity produced by the PV system in Homer simulation.

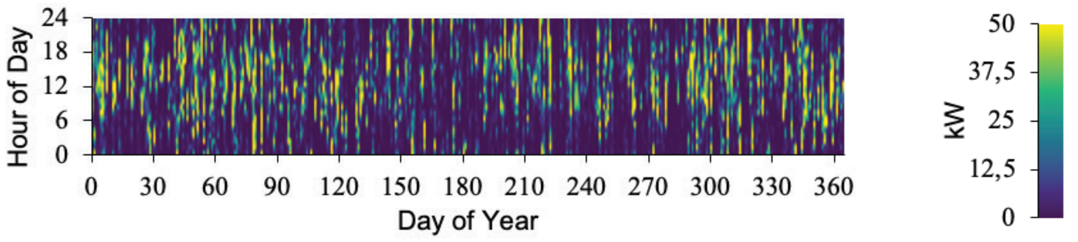


Figure 15. Daily electricity produced by the wind turbines in Homer simulation.

Table 7. The components' cost.

	Capital Cost ($)	Replacement Cost ($)	O & M Cost ($)
Converter (per kW)	300	300	10
Battery (per quantity)	15,000	15,000	1000
Wind Turbine ($/kW)	1,600	1,600	30
PV Module ($/kW)	900	900	5

Table 8. Renewable energy powered hybrid system cost summary of HOMER analysis.

Economic Metrics		
IRR	11%	
ROI	7.4%	
Simple Payback	8.4 yr	
Cost Summary		
	Base Case	Lowest Cost System
NPC	$401,191	$145,961
Initial Capital	$0	$68,638
O&M	$9,760/yr	$1,881/yr
LCOE	$0.0890/kWh	$0.0193/kWh

PV capacity factor is 14.6%, PV total production is 64,131 kWh/yr, PV hours of operation is 4,386 hrs/yr. Wind turbines' capacity factor is 19.3%, wind turbines total production is 84,391 kWh/yr, wind turbines' hours of operation is 6,122 hrs/yr. Converter capacity factor is 29.5%, converter operation hours are 7,141 hrs/yr and converter energy out is 142,748 kWh/yr. The electricity storage system's nominal capacity is 100 kWh. The annual throughput is 24,657 kWh/yr.

Table 10 shows the Homer optimization's electrical results. The annual energy purchased from the grid and the annual energy sold to the grid for eight cases are seen Table 14.

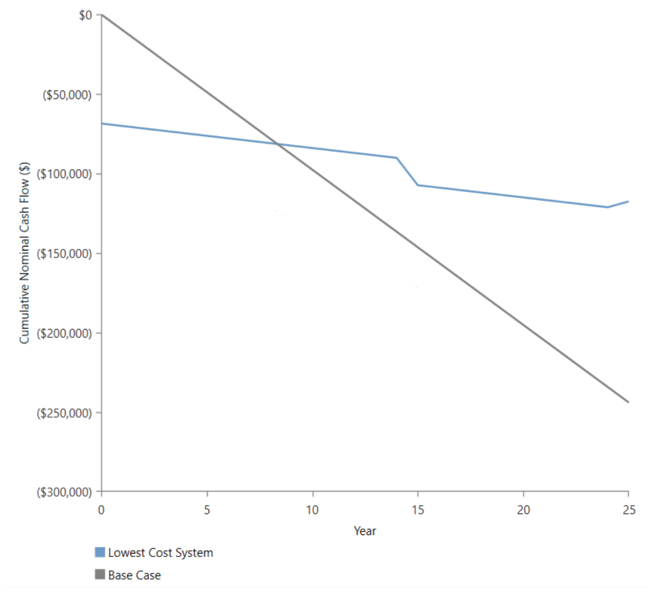


Figure 16. Hybrid system cumulative nominal cash flow.

Figure 17 shows the monthly energy purchased and energy sold for the case 1, 2, 3, 4, 5, 6, 7 and 8.

Table 11 shows the Homer optimization's cost, renewable energy fraction and grid results. Table 12 shows the Homer optimization's economics results.

Figure 18 shows the annual savings of optimization's cases. Figure 19 shows the cumulative cash flow over project lifetime for case 1, 2, 3, 4, 5, 6, 7 and 8.

3.4. Impact Analysis Results

The effects of the proposed application on the environment or other equipment and systems, and the CO_2 emission reduction due to the savings to be made are given in Table 13. Net annual GHG emission reduction 29.7 tCO_2 is equivalent to 5.4 cars and light trucks not used.

Table 9. Homer optimization results: Hybrid system's architecture.

Case	Architecture										
	PV	WT	B	G	C	PV (kW)	WT (kW)	Battery	Grid (kW)	Converter (kW)	Dispatch
1	✓	✓	-	✓	✓	50	50	-	999,999	52.5	CC
2	✓	✓	✓	✓	✓	50	50	1	999,999	51.0	LF
3	-	✓	-	✓	✓	-	50	-	999,999	43.9	CC
4	-	✓	✓	✓	✓	-	50	1	999,999	40.5	LF
5	✓	-	-	✓	✓	50	-	-	999,999	32.1	CC
6	✓	-	✓	✓	✓	50	-	1	999,999	27.0	LF
7	-	-	-	✓	-	-	-	-	999,999	-	CC
8	-	-	✓	✓	✓	-	-	1	999,999	1.50	LF

Table 10. Homer optimization results: Electrical.

Case	Production (kWh/yr)				Consumption (kWh/yr)		
	PV	WT	Grid purchases	Total	AC load	Grid sales	Total
1	64,131	83,978	48,539	196,648	109,661	74,010	183,671
2	64,131	83,978	26,317	174,426	109,661	49,132	158,793
3	-	83,978	75,599	159,578	109,661	44,684	154,345
4	-	83,978	58,181	142,159	109,661	24,509	134,170
5	64,131	-	69,685	133,816	109,661	18913	128,574
6	64,131	-	54,115	118,246	109,661	1,421	111,082
7	-	-	109,661	109,661	109,661	-	109,661
8	-	-	109,589	109,589	109,661	-	109,661

Table 11. Homer optimization results: Cost, renewable energy fraction and grid.

Case	Cost				Renewable Fraction	Grid	
	NPC ($)	LCOE ($/kWh)	Operating Cost ($/yr)	CAPEX Capital İnvestment ($)		Energy Purchased (kWh)	Energy Sold (kWh)
1	145,961	0.0193	1,881	68,638	73.6	48,539	74,010
2	195,107	0.0299	2,720	83,300	83.4	26,317	49,132
3	241,877	0.0381	5,369	21,163	51.0	75,599	44,684
4	285,840	0.0518	6,099	35,150	56.6	58,181	24,509
5	302,786	0.0573	6,037	54,631	56.9	69,685	18,913
6	346,307	0.0758	6,768	68,100	45.8	54,115	1,421
7	401,191	0.0890	9,760	0.00	0	109,661	0
8	471,923	0.1050	11,105	15,450	0.0657	109,589	0

Table 12. Homer optimization results: Compare economics.

Case	Net Present Value ($)	Annual worth ($/yr)	Return of investment (%)	Internal rate of return (%)	Simple payback (yr)	Discounted payback (yr)
1	255,230	6,209	7.4	10.5	8.35	7.19
2	226,085	5,013	4.3	6.8	10.46	8.75
3	159,314	3,876	16,4	21.2	4.52	4.12
4	115,352	2,806	6.0	9.1	8.27	7.13
5	98,405	2,394	2.7	8.9	8.39	7.22
6	54,884	1,335	0.2	0.4	24.65	20.50
7	-	-	-	-	-	-
8	70,732	1,721	-13.2	-	-	-

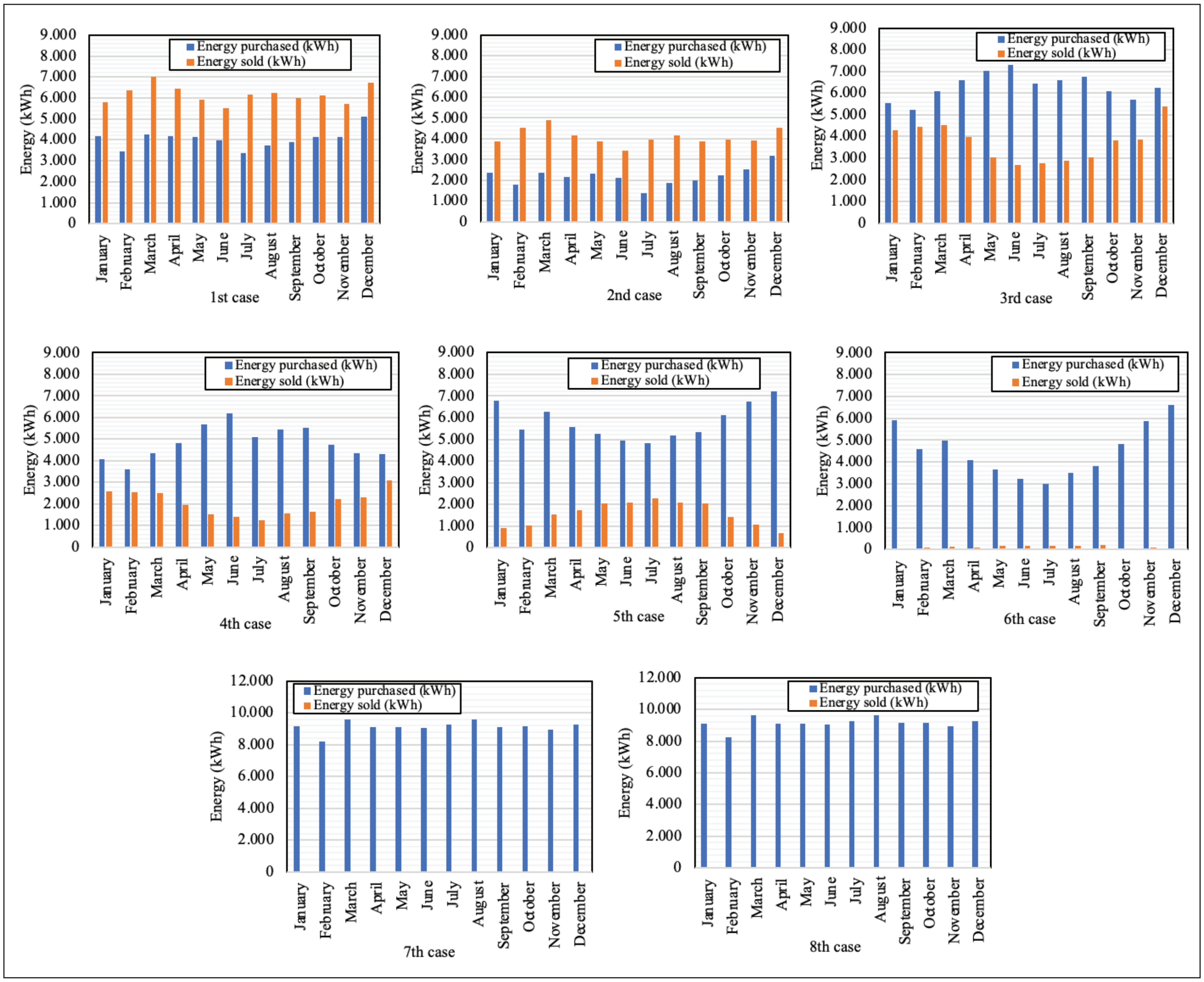


Figure 17. Monthly energy purchased, and energy sold for the case 1, 2, 3, 4, 5, 6, 7 and 8.

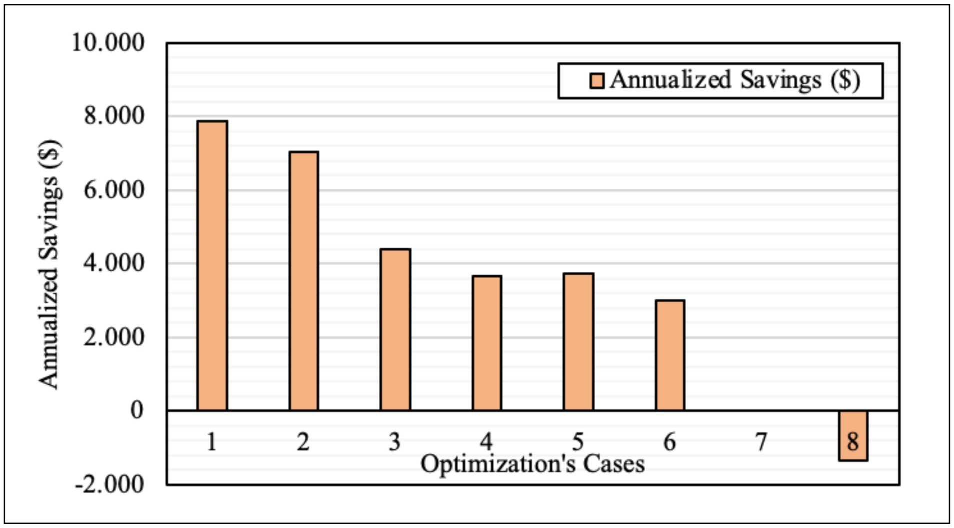


Figure 18. Annual savings of optimization's cases.

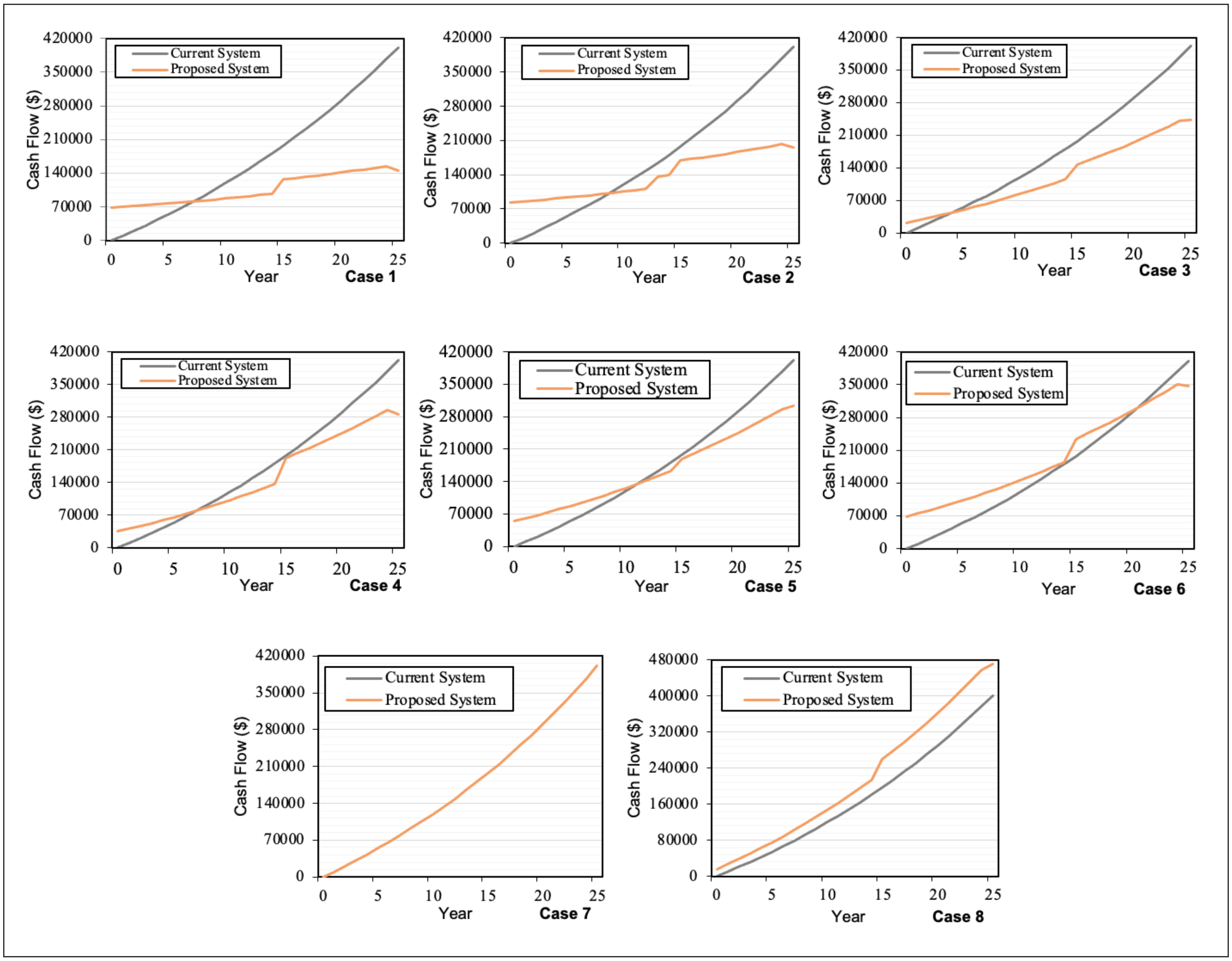


Figure 19. Cumulative cash flow over project lifetime for case 1, 2, 3, 4, 5, 6, 7 and 8.

Table 13. Impact analysis of the PV system.

Emission Analysis		
Country - region	-	Turkey
GHG emission factor	tCO_2/MWh	0.460
Produced electricity	MWh	64,513
Net annual GHG emission reduction	tCO_2	29.7

The effects of the proposed application on the environment or other equipment and systems, and the CO_2 emission reduction due to the savings to be made are given in Table 14. Net annual GHG emission reduction 38.2 tCO_2 is equivalent to 7 cars and light trucks not used.

Table 14. Impact analysis of the wind turbines.

Emission Analysis		
Country - region	-	Turkey
GHG emission factor	tCO_2/MWh	0.4596
Produced Electricity	MWh	83,145
Net annual GHG emission reduction	tCO_2	38.2

The effects of the proposed application on the environment and the Homer optimization's emissions results for cases are shown in Table 15.

Table 15. Homer optimization results: Emissions.

Case	Carbon Dioxide (kg/yr)	Sulphur Dioxide (kg/yr)	Nitrogen Oxides (kg/yr)
1	30,677	133	65
2	16,632	72.1	35.3
3	47,779	207	101
4	36,770	159	78.0
5	44,041	191	93.4
6	34,201	148	72,5
7	69,306	300	147
8	69,260	300	147

4. Conclusion and Suggestions

As a result of generating electricity with renewable energy in the shopping mall, greenhouse gas emissions will decrease, and the effects of global warming caused by carbon emissions will decrease. At this point, it becomes important that the charging stations in shopping malls work with renewable energy support. However, the fact that many electric vehicles are charged at the same time or in unpredictable time periods causes huge differences in electricity supply and demand. This situation causes voltage imbalance and power losses in the network with the effect of charging stations fed to the grid and may adversely affect the energy grid. At this stage, the importance of a battery hybrid EV charging stations working with renewable energy sources is increasing day by day.

This research investigates the techno-economic feasibility of a renewable energy powered hybrid electric vehicle charging station for shopping mall by using HOMER software. The contribution of this paper is to present a comprehensive hybrid electric vehicle charging station model for shopping malls that will reduce the possible interference between the electric grid and EVs and CO_2 emissions. The results indicate that the optimal wind-PV hybrid system for the EVS station contains the wind turbines with rated power of 50 kW, PV system of 50 kW, and 52.1 kW power converters. This wind-PV hybris system is found to have the net present cost NPC of $145,961, an annual operating cost OC of $1,881/year, a total net present cost NPC of $145,961 and the levelized cost of energy LCOE of $0.0193/kWh.

The following is the study's main conclusion:

- By installing a renewable energy system with a capacity of 100 kW on the roof of the shopping mall in Edirne, Turkey. 148.52 MWh/yr electrical energy can be produced annually.
- PV capacity factor is 14.6%, PV total production is 64,131 kWh/yr, PV hours of operation is 4,386 hrs/yr.
- Wind turbines' capacity factor is 19.3%, wind turbines total production is 84,391 kWh/yr, wind turbines' hours of operation is 6,122 hrs/yr.
- Converter capacity factor is 29.5%, converter operation hours are 7,141 hrs/yr and converter energy out is 142,748 kWh/yr.
- The electricity storage system's nominal capacity is 100 kWh. The annual throughput is 24,657 kWh/yr.
- Thus, the electricity needs of the electric vehicle charging station will be produced using renewable energy sources and the emission of 67.9 tCO_2 to the atmosphere will be prevented. Net annual GHG emission reduction 67.9 tCO_2 is equivalent to 12.4 cars and light trucks not used.

- The payback period of the renewable energy powered hybrid electric vehicle charging station for shopping mall is 8.35 years.
- The annualized saving of the hybrid system is $7,879/yr and the capital investment is $68,638.

The hybrid system is engineering solutions that can be applied universally. This study provides methodology to improve energy efficiency not only for electric vehicle charging station in Turkey but also for the other electric vehicle charging station in shopping mall worldwide. Although the hybrid system has been studied for a case study in Edirne, the analysis can be applied anywhere in the world by modifying solar and wind energy data.

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No conflict of interest is declared by the authors. There are no individuals or organizations supporting the research.

Author contribution:

Hacer Akhan: Planned, designed, gathered and analyzed data about the study, wrote the article by analyzing the study.

Ethics committee approval: There is no need for ethics committee approval.

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