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Techno-Economic Analysis of Hybrid Renewable Energy Systems Designed for Electric Vehicle Charging: A Case Study from the United Arab Emirates

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Abstract: The United Arab Emirates is moving towards the use of renewable energy for many reasons, including the country's high energy consumption, unstable oil prices, and increasing carbon dioxide emissions. The usage of electric vehicles can improve public health and reduce emissions that contribute to climate change. Thus, the usage of renewable energy resources to meet the demands of electric vehicles is the major challenge influencing the development of an optimal smart system that can satisfy energy requirements, enhance sustainability and reduce negative environmental impacts. The objective of this study was to examine different configurations of hybrid renewable energy systems for electric vehicle charging in Abu Dhabi city, UAE. A comprehensive study was conducted to investigate previous electric vehicle charging approaches and formulate the problem accordingly. Subsequently, methods for acquiring data with respect to the energy input and load profiles were determined, and a techno-economic analysis was performed using Hybrid Optimization of Multiple Energy Resources (HOMER) software. The results demonstrated that the optimal electric vehicle charging model comprising solar photovoltaics, wind turbines, batteries and a distribution grid was superior to the other studied configurations from the technical, economic and environmental perspectives. An optimal model could produce excess electricity of 22,006 kWh/year with an energy cost of 0.06743 USD/kWh. Furthermore, the proposed battery–grid–solar photovoltaics–wind turbine system had the highest renewable penetration and thus reduced carbon dioxide emissions by 384 tons/year. The results also indicated that the carbon credits associated with this system could result in savings of 8786.8 USD/year. This study provides new guidelines and identifies the best indicators for electric vehicle charging systems that will positively influence the trend in carbon dioxide emissions and achieve sustainable electricity generation. This study also provides a valid financial assessment for investors looking to encourage the use of renewable energy.

Keywords: electric vehicles; renewable energy; hybrid systems; carbon credits

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Citation: AlHammadi, A.; Al-Saif, N.; Al-Sumaiti, A.S.; Marzband, M.; Alsumaiti, T.; Heydarian-Forushani, E. Techno-Economic Analysis of Hybrid Renewable Energy Systems Designed for Electric Vehicle Charging: A Case Study from the United Arab Emirates. *Energies* **2022**, *15*, 6621. https://doi.org/10.3390/en15186621

Academic Editor: Tek Tjing Lie

Received: 26 July 2022
Accepted: 6 September 2022
Published: 10 September 2022

1. Introduction

The United Arab Emirates (UAE) is one of the most rapidly developing countries in the gulf region. Its capital city of Abu Dhabi accounts for 90% of the country's oil and natural gas consumption [1,2]. Since the end of the 20th century, the increase in carbon dioxide (CO_2) emissions, oil-price instability, and oil embargos have led the government to seek cleaner and more sustainable resources and technologies to meet the economic-growth demands of the country. According to the Abu Dhabi Statistics Centre, the electricity demand of Abu Dhabi increased from 58,735,825 MWH in 2015 to 62,681,608 MWH in 2019 [3]. Furthermore, the total emissions of air pollutants by the water and electricity sectors exceeded 10,000 tons over the past five years [4].

Therefore, the UAE formulated a visionary plan to meet 7% of energy requirements using renewable energy sources (RESs) by 2020. This target was the driving factor for promising projects, such as the Masdar initiative, Noor 1 and Shams 1, all of which employed RESs such as solar photovoltaics (PVs), wind and solar power [5]. The Masdar initiative was considered a remarkable economic development program that aimed to improve Abu Dhabi in terms of its financial resources and energy diversification by developing innovative solutions for obtaining cleaner energy, apart from oil and gas, and decreasing CO_2 emissions. The city of Abu Dhabi depends on PVs to generate electricity up to a capacity of 10 MW [6]. In addition, Abu Dhabi's annual production of renewable energy reached 2,163,799 MWH in 2019 [3]. In line with the implementation of serious steps to reduce pollution and increase sustainability, the usage of electric vehicles (EVs) has considerably evolved in the UAE. Researchers are playing an integral part in this evolution by utilizing clean technology for EV charging. The Dubai Autonomous Transportation Strategy 2030 is an excellent example of how the UAE is planning to be more ecofriendly as it aims to transfer 25% of the total transport in Dubai to autonomous means by 2030. This strategy will save 1.5 billion AED by reducing environmental pollution by 12% [7].

In this paper we present a techno-economic assessment of a hybrid renewable energy system designed for charging EVs in the United Arab Emirates. The paper is structured as follows. Section 2 provides a literature review relevant to the investigated topic. Section 3 highlights the contributions of this work. Section 4 describes the methodology applied to the case study. Section 5 presents the simulation results, focusing on the technical analysis, economic analysis, emission analysis and sensitivity analysis. Section 6 concludes the paper and provides policy implications.

2. Literature Review

Various approaches and studies, conducted throughout the world to employ renewable energy systems for EV charging, are introduced in this section. Then, the problem statement and objectives of this study are presented. Several countries have investigated the installation of renewable energy systems to supply energy to EV charging stations [8–26]. A summary of such studies is presented below.

The authors of a previous study [8] conducted in Egypt proposed an energy management system (EMS) to control the power flow from RESs to EVs. The study achieved good results with respect to the electrical performance. Another study [9] evaluated the use of an EV charging system, optimizing the sizing and power flow control of the grid-connected multisource power converter system by conducting a cost–benefit analysis. The performance of the charging system was enhanced, and an optimal output was obtained. Furthermore, the capital requirements decreased considerably. Another study, conducted in China [10], discussed charging EVs and streetlights through a group of smart hybrid poles using renewable energy. Thus, high efficiency and power output could be obtained. Muhammed et al. [11] investigated the optimal sizing of hybrid power for EV charging in Indonesia, specifically in rural areas such as Labuan Bajo. The obtained results provided the optimal configuration of different hybrid systems for charging stations. In addition, an economic analysis was presented, including only the operating cost, net present cost (NPC) and initial capital cost. Some researchers in Japan [12] explored priority charging to control the EV charging stations in park-and-ride areas when using renewable energy and energy storage systems. They implemented their approach via the mixed-integer linear programming (MILP) approach, and the results showed a large reduction in equipment costs. In addition, policymakers play integral roles in increasing the capacity of RESs for EV charging. Furthermore, some guidelines for charging service providers in terms of appropriate charging prices and electricity management had been proposed [13]. The optimal pricing and electricity procurement policies were determined using the stochastic dynamic programming (SDP) algorithm and a greedy algorithm (benchmark algorithm). The obtained results indicated that the SDP algorithm could achieve a profit gain of up to 7%. In another study [14], a pricing methodology was proposed for charging stations located in wealthy areas. This study indicated reduced traffic jams, improved renewable energy consumption and load-balanced traffic flow. In another study [15], the authors attempted to reduce the impact of EV charging in university campuses by considering two configurations with respect to the orientation of the panels and the usage of storage systems based on the effects on the levelized cost of energy (COE). Their results indicated that a system with directional PVs was economically superior to a storage system. Tongpong et al. [16] used the MERIT simulation program to optimize the performance of the renewable energy system supplying energy to the EV charging stations. The outcomes indicated considerable potential in meeting the load demand and the authors provided a brief analysis with respect to the capital cost and surplus energy. One study [17] utilized an integer linear programming (ILP)-based centralized system intended to minimize the charging price per EV. The objective of this study was achieved because faster charging could be achieved at the lowest possible price. The study in [18] on the charging of EVs at office buildings and workplaces used two algorithms to estimate the EV charging demands and annual cost reductions. The results showed that the algorithms were computationally efficient and suitable for real-time operation. In addition, they reduced the cost by 7.2% and 6.9% on average. Lili et al., in [19], presented an EV charging strategy for improving power consumption and reducing charging costs. Based on the optimal results, the charging costs could be reduced by 7.6% and 10.3% in winter and summer, respectively. Xinyi et al. [20] proposed the optimal scheduling of a DC microgrid integrated with RESs for EV charging using NSGA-II software that resulted in reduced electricity purchasing costs and enhanced energy circulation. Another research group, as per [21], proposed a design for home-based EV charging stations relying on PV and wind energy generation. The obtained results demonstrated that the energy requirements of the charging station were satisfied in different operation modes. Murat et al., in [22], presented an EMS for the charging of EVs in industrial areas in Turkey to provide the EV load with optimal cost based on Monte Carlo simulations. Their results indicated that the charging demands of EVs could be met in different time periods. Yaqin et al. [23] presented an optimization model for the charging of EVs that was able to meet changing requirements and minimize electricity costs. Novotny et al. [24] proposed a concept called ALISE, which aimed to encourage the further uptake of EVs and reduce construction costs. Fei et al. conducted a technical review on some approaches for managing the charging demands of EVs [25]. This review indicated the potential of the proposed approaches in minimizing the system's cost and enhancing the power quality. The effect of the integration of renewable energy with the charging systems of EVs through the Balmorel model was explored previously [26]. Based on that study, the load demands could be met, CO_2 emissions could be reduced, and system costs could be minimized. Another study [27] investigated a different aspect by focusing on the use of tariffs for coordinating EV aggregators. In [28], energy management was the focus of the work to optimally coordinate the demand response and EV aggregators. In [29], driving conditions were considered to attain a strategy for managing the energy for EVs. The authors in [30] provided a review for integration the transport and smart grid sectors through looking at the management of EVs. In [31] the authors focused on a power system reschedule approach taking into consideration EVs and renewable energy. On the other hand, [32] considered energy storage in addition to renewable energy and EVs and targeted home energy management rather than the commercial sector. In [33], a techno-economic study was presented for the case of Pakistan. That study focused on the use of HOMER Pro software for the design of a rural energy system including renewable resources without the involvement of EVs. Table 1 provides a summary of the literature and their corresponding results and gaps.

Table 1. Summary of previous approaches dedicated to EV charging research.

Ref.	Year	Place	Objective	Algorithm/Software	Results	Gaps
[20]	2014	China	Optimal scheduling of a DC microgrid integrated with RESs for EVC stations	NSGA-II	(1) Reducing the cost of electricity purchase; (2) enhancing energy circulation	No environmental analysis
[9]	2015	-	(1) EV charging system optimal sizing charging system via power flow control, (2) cost–benefit analysis	Numerical method-MATLAB/Simulink	(1) Enhanced charging system performance; (2) capital costs reduction	(1) No detailed economic analalysis; (2) no environmental analysis
[15]	2016	Italy	Reducing the impact of EVC in universities	Examining 2 configurations based on panel orientations and the usage of storage systems	System with directional PV is better from an economic perspective	No environmental analysis
[16]	2016	Thailand	Optimizing system performance of renewable energy system supplying energy to EVC stations	MERIT simulation program	Potential in meeting load demand and informing on capital cost and surplus energy	No environmental analysis
[18]	2017	-	Employs office buildings and workplaces for EVC	Two algorithms to meet EVC demand and obtain annual cost reductions.	(1) Computationally efficient; (2) suitable for real-time operation; (3) average cost reductions of 7.2% and 6.9%	No environmental analysis
[10]	2018	China	Charging EV and streetlights via a group of smart hybrid poles	Efficiency model	High efficiency and power output	(1) No financial assessment; (2) no environmental analysis
[11]	2018	Indonesia	Optimal sizing of hybrid power for EV charging	HOMER software	(1) Optimal configuration for different systems; (2) cost reductions	(1) No environmental analysis; (2) no detailed economic analysis (only operating, net present and initial capital costs)
[13]	2018	China	Guidelines for charging service providers for proper charging prices and electricity management	2 algorithms: (1) stochastic dynamic programming; (2) greedy algorithm (benchmark)	SDP can achieve up to 7% profit gain	No environmental analysis
[23]	2019	-	Optimization model for EV charging	MATLAB	Meets EVC requirements and minimizes electricity cost	No environmental analysis

Table 1. *Cont.*

Ref.	Year	Place	Objective	Algorithm/Software	Results	Gaps
[8]	2019	Egypt	EMS to control power flow from RESs to EVs	MATLAB/Simulink	Good results in terms of electrical performance and meeting load demand	(1) No financial assessment; (2) no environmental analysis
[26]	2019	Denmark	Effect of integrating RES with EVC system	Balmorel model	(1) Meeting load demand; (2) reducing CO_2 emissions; (3) cutting system costs	No detailed environmental analysis (CO_2 only).
[14]	2020	China	Pricing method considering charging facility service ratio, traffic flow and RES generation in wealthy areas	Pricing methodology	(1) Reducing traffic jams; (2) facilitating renewable consumption; (3) balancing traffic flow	(1) No financial assessment; (2) no environmental analysis
[12]	2020	Japan	Priority charging to control EV charging (EVC) station in park and ride areas	Mixed-integer linear programming	High reduction in equipment costs	(1) No financial assessment; (2) no environmental analysis
[17]	2020	-	Minimizing charging price per EV	Integer linear programming-based centralized system	Faster charging at lowest possible price	No environmental analysis
[19]	2020	China	EVC strategy to improve power consumption and reduce charging cost	Optimization	Charging cost of EVs can be reduced	No environmental analysis
[21]	2020	India	Design for EVC stations in homes	Control algorithm	Operation of charging station is achieved in all modes	(1) No financial assessment; (2) no environmental analysis
[22]	2020	Turkey	EMS for EVC installed in industrial areas	Monte Carlo simulation	Demands of EVCs can be met in different time periods	(1) No financial assessment; (2) no environmental analysis
[32]	2022	France	Home energy management	Matlab	Advantages for the integration of EVs, covering aspects of optimal sizing, energy autonomy and limiting grid power supply	No coverage of commercial sector
Current Study	-	UAE	Optimal sizing of EVC via RESs	HOMER software	(1) Meeting load demand; (2) increasing RES capacity; (3) cost-effective system; (4) reducing ecological damage and GHG emissions; (5) carbon credits contributing to system revenue	

3. Contribution

After reviewing and comparing all similar case studies and evaluating their drawbacks, especially the lack of environmental analyses and considerations of carbon reductions, the main contribution of this study is that it connects supplementary systems, such as batteries and utility grids, with renewable energy sources, such as PVs and wind turbines (WTs), for the charging of EVs. The main contributions of this paper are described as follows.

First, technical details of the hybrid systems installed in a commercial area are examined. Second, this study presents an environmental analysis and a carbon reduction analysis. Third, a detailed economic analysis is presented, and the effect of the carbon reduction on overall savings is investigated. Furthermore, although it is difficult to determine exactly which factor (cost, amount of electricity generation or renewable fraction) is of most importance with respect to the system performance, an attempt has been made in this paper to answer this question via sensitivity analysis.

4. Methodology Applied to the Case Study

The technical, economic and environmental analyses were conducted using HOMER software (Homer Pro Version 3.1.4.5, Boulder, CO, USA). Generally, this software is used to model and design power systems, including those with both on-grid and off-grid connections to primary and renewable energy resources. HOMER is also used to perform optimization modeling, simulations and sensitivity assessments [34]. In this section, a case study is presented along with its input data and the equations considered with respect to the HOMER software.

4.1. Case Study and Renewable Energy Resources

In this case study we considered Yas Island (Abu Dhabi, UAE) (See Figure 1) as the point of interest. This location was selected because it is a main hub in the area and has multiple points of interest, such as shopping malls, sports facilities, transportation services and hotels. This island is located at 24°29.8′ N and 54°36.2′ E, with an area of 25 km^2. The current population of Abu Dhabi is estimated to be more than 1.48 million [35].

Figure 1. Map of Yas Island.

Furthermore, PV represents a high-potential RES for this case study because of the sunny climate of Abu Dhabi. As shown in Figure 2, the highest daily solar radiation occurred in June (7.23 kWh/m^2/day), whereas the lowest daily radiation occurred in December (3.78 kWh/m^2/day). The wind speed data were also considered in this study.

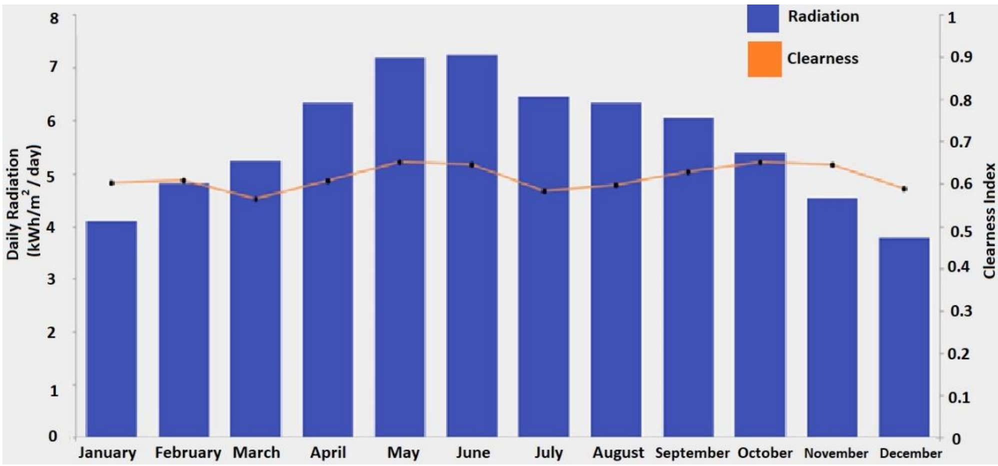

Figure 2. Daily radiation amount at Yas Island.

As shown in Figure 3, the highest wind speed was recorded in February (5.34 m/s), whereas the lowest wind speed was recorded in October (3.77 m/s). The data for solar radiation and wind speed were collected from NASA Surface Meteorology and Solar Energy using HOMER to determine the output of PVs and wind turbines.

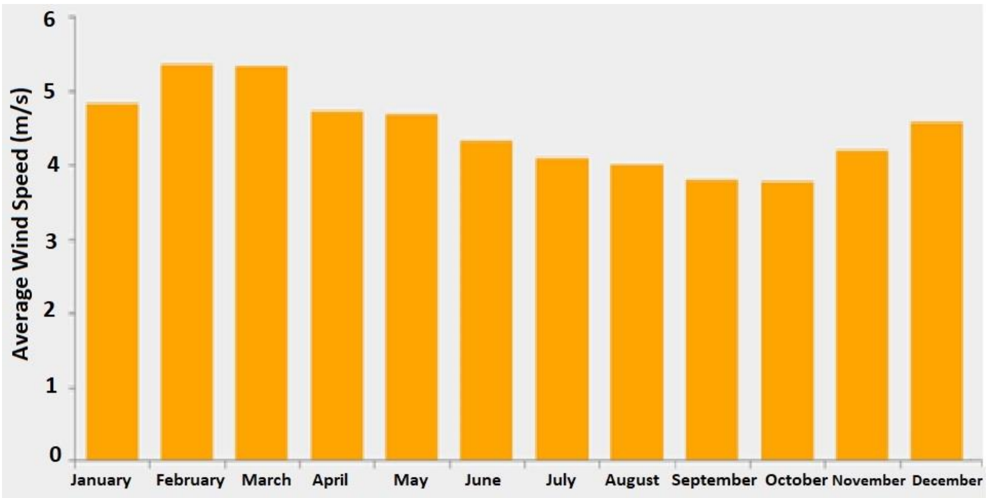

Figure 3. Average wind speed at Yas Island.

4.2. Load Profile for Yas Island

Figure 4 shows the daily, seasonal and annual load profiles of Yas Island. The project is installed in a commercial area where EV charging is considered in the load. The hypothetical data used were obtained using HOMER and they exhibited a daily random variability based on uncertainty. The maximum electricity consumption for EV charging was 3175 kWh/day, and its peak was at 297 kW. This peak can be attributed to the rush hour and increased human activity between 3:00 p.m. and 5:00 p.m. Table 2 summarizes the technical information related to the load profile.

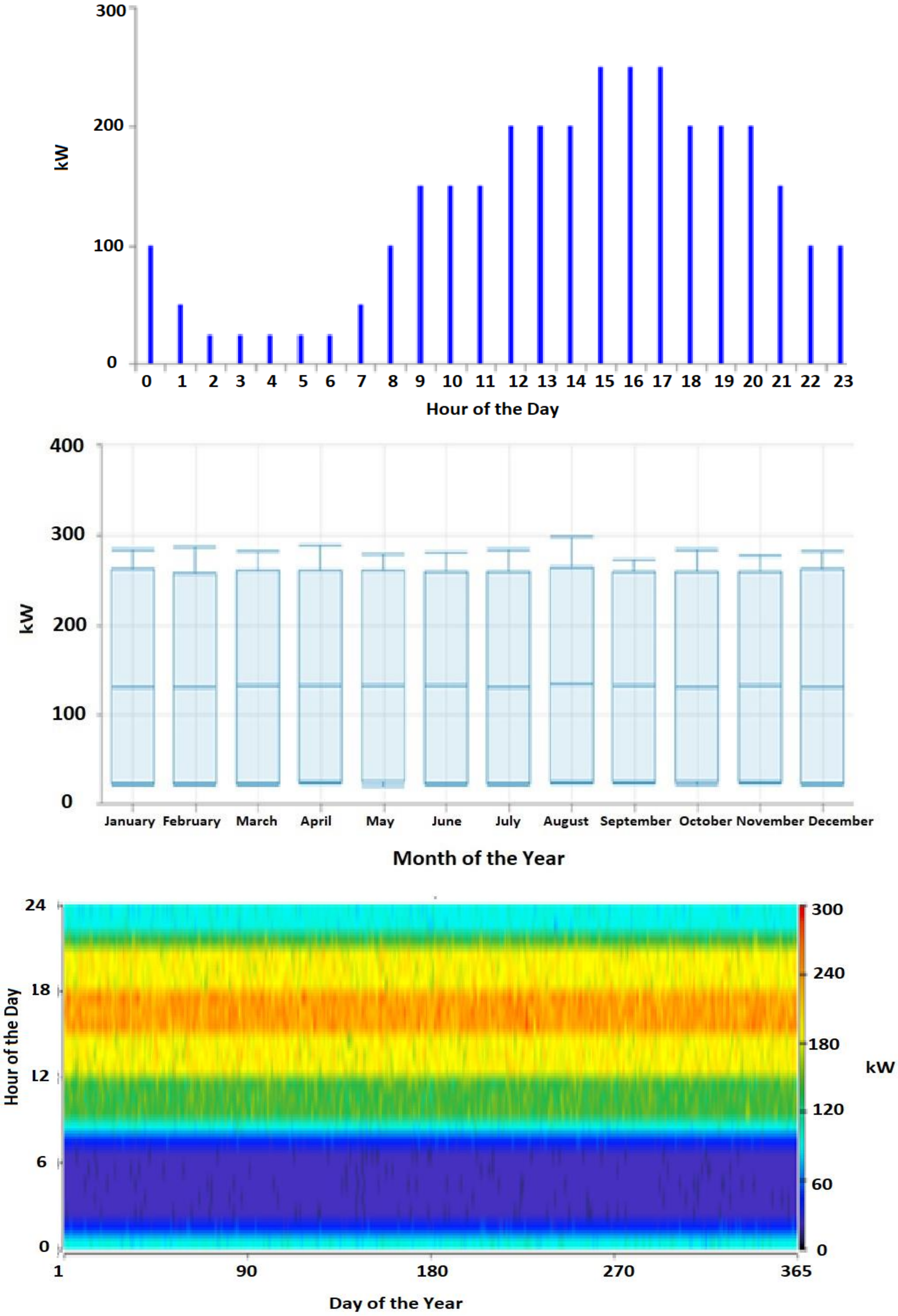

Figure 4. Daily (**top**), seasonal (**middle**) and annual (**bottom**) load profiles for Yas Island.

Table 2. Technical information regarding the load profile.

Average (kWh/Day)	Average (kW)	Peak (kW)	Load Factor	Average Energy per Month (kWh)
3175	132.29	297.93	0.44	46,646

4.3. Studied System

The UAE is investing considerably in ecofriendly cars. Hybrid power systems can satisfy energy requirements with low costs for any type of load, including commercial, industrial and residential loads. Therefore, in this study we aimed to develop a cost-effective, reliable, sustainable and ecofriendly hybrid system based on renewable energy resources for EV charging in a commercial area. Overall, our aim was to help achieve the Dubai Autonomous Transportation Strategy 2030 of the UAE. In this study, solar radiation, wind speed and load demand were the critical input data of the system, on the basis of which an optimal output could be obtained. Figure 5 presents a schematic of the proposed system.

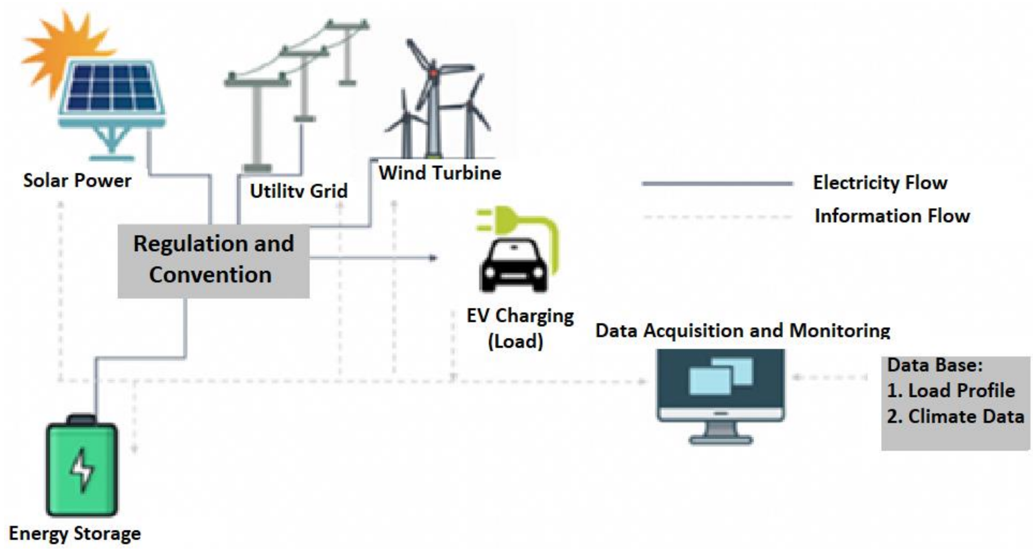

Figure 5. Schematic of the proposed system.

4.4. Modeling of the Hybrid Energy System

HOMER software was used to provide a better understanding regarding the amount of energy produced by the proposed hybrid system and the manner in which the proposed system affected the environment in terms of decreasing emissions, while also considering the economic implications. Furthermore, the concept of optimization was applied in the proposed system to select and verify the best proposed hybrid system based on the selected area and available resources. Figure 6 shows the proposed system configuration, involving a PV, a national grid, a wind turbine, a bi-directional converter, a battery and an electric load. In the HOMER software, we utilized PV and wind power as the primary energy sources and the national grid as the secondary energy source. The electricity tariff (grid) was obtained from electricity providers in the UAE, such as the Dubai Electricity and Water Authority (DEWA) and the Abu Dhabi Water and Electricity Authority (ADWEA), with a grid power price of 0.130 USD/kWh. A battery was used as the backup when insufficient power was procured from these two sources. Table 3 shows the characteristics of the components used in this study. The battery will be replaced after every 15 years. The battery charges when there is no excess electricity that is not used by the load. In addition, EV charging is conducted using the battery if the latter is fully charged. However, the power required for the load is obtained via PV power generation or from the grid, depending on the electricity tariff.

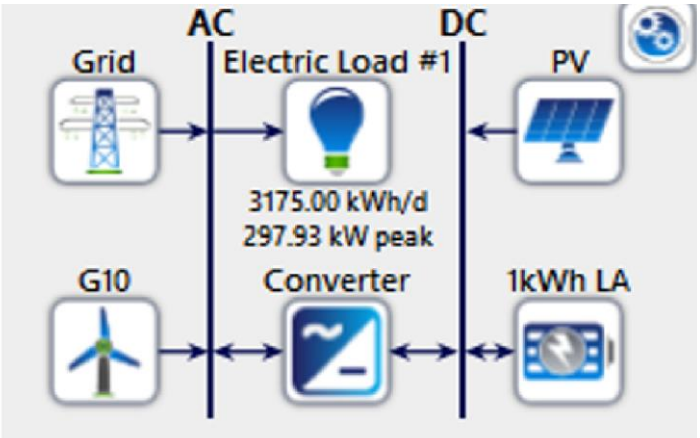

Figure 6. Structure of the proposed hybrid system.

Table 3. Characteristics of the components used in the study.

Component	Model	Capital Cost (USD)	Maintenance Cost (USD/Year)	Rated Capacity	Lifetime (Years)
PV	Generic	1500	10	20,000 kW	25
Battery	Lead Acid	300	10	1 kWh	15
Wind Turbine	Generic	50,000	500	10 kW	25
Converter	Generic	300	10	1 kW	15

Focusing on the energy deficits in Abu Dhabi, relevant data were collected from the NASA Surface Meteorology and Solar Energy databases and employed in the HOMER software. Furthermore, the output of the hybrid system was economically analyzed using two important parameters: ***NPC*** and the levelized ***COE*** [36,37].

$$NPC = \frac{C_{tot,annual}}{CRF} \quad (1)$$

$$CRF(i, N) = \frac{i(1+i)^N}{(1+i)^{N-1}} \quad (2)$$

where $C_{tot,annual}$ is the total annual cost, CRF is the capital recovery factor, i denotes the real interest rate calculated based on the nominal discount rate and N is the number of years. Furthermore,

$$COE = \frac{C_{tot,annual}}{E_{served}} \quad (3)$$

where E_{served} is the energy provided (KWh/year), which can be calculated as follows:

$$E_{served} = E_{is} + E_{grid} \quad (4)$$

where E_{is} and E_{grid} denote the electrical energy generated from the microgrid system and the amount of electricity exported to the main grid, respectively. The salvage value and return on investment (ROI) are other important economic factors. The salvage value is the remaining value of power generated by the hybrid system after the project lifetime and can be given as follows [36]:

$$Salvage = C_{ref} \frac{R_{comp} - [n - R_{comp} * INT\left(\frac{n}{R_{comp}}\right)}{R_{comp}} \quad (5)$$

where C_{ref} denotes the replacement cost of a component and R_{comp} denotes the component lifetime. ROI is defined as the annual cost savings relative to the initial investment. This value can be obtained using HOMER software as follows [38]:

$$ROI = \frac{\sum_{i=0}^{n} C_{i,ref} - C_i}{n(C_{cap} - C_{cap,ref})} \tag{6}$$

where $C_{i,ref}$ is the system's reference nominal cash flow, C_i is the system's annual current nominal cash flow, C_{cap} is the current system's capital cost and $C_{cap,ref}$ is the capital cost of a reference system. Furthermore, carbon credits are measures of how the use of renewable energy can reduce carbon dioxide emissions annually. This study can be beneficial in both environmental and economic terms. From the environmental perspective, it calculates the reduction in CO_2 emissions and hence its effect on the environment. Similarly, carbon credits can be sold because of their high potential for revenue generation. Carbon credits can be can be estimated using Equations (7)–(10) [39–41]. The annual electricity output of the project can be given as follows:

$$E = CuF \times hours \times rating \tag{7}$$

where CuF indicates the capacity utilization factor of the renewable energy project, which varies depending on the type of renewable energy source used. The term $hours$ indicates the number of hours in a year (8760) and $rating$ represents the rating of the renewable energy project. Then, the annual carbon dioxide emissions can be given as

$$M = E \times Ef \tag{8}$$

where Ef represents the emission factor, which is zero in the case of renewable energy. The annual electricity output and carbon dioxide emissions in the case of the studied project can be easily determined using the HOMER software. The annual baseline emissions can be estimated as follows:

$$Base = E \times EF_{elec} \tag{9}$$

where EF_{elec} represents the emission factor of a country in the case of electricity production; it is 0.0694 tCO_2/MWh for the UAE [41]. Finally, the annual emission reduction can be given as follows:

$$Red = Base - M \tag{10}$$

Each carbon credit corresponds to a one-ton reduction in carbon dioxide emissions [39].

5. Results and Discussion

Five different hybrid systems for Yas Island were examined based on the available technologies to obtain the optimal output with respect to reliability and affordability. As discussed above, the system components included batteries and a utility grid, combined with PVs and wind turbines as renewable energy sources to provide electricity for the charging of EVs. In this section, the simulation results for different hybrid system configurations are presented and the data are analyzed technically, economically and environmentally.

5.1. Technical Analysis

As EVs are becoming more visible on the UAE's roads and gaining more recognition in the country, awareness regarding this technology is growing. This is good because EVs have great potential in the transportation sector. Because traditional power systems rely on fossil fuels for power generation, they have harmful effects on the environment. However, the usage of renewable energy in electrical systems for charging EVs can considerably reduce emissions.

In this section, a technical analysis of each system and its monthly power production is presented. Table 4 shows the power generation for each system configuration. Most of the configurations feature PVs because of the sunny climate of Abu Dhabi. The load demand for the charging of EVs in commercial areas was fully satisfied in all scenarios; however, managing the surplus electricity is a major challenge.

Table 4. Electricity generation with the selected hybrid system configurations for EV charging in a commercial area.

Supplementary System	Renewable System	Grid (kW/Year)	Battery (kWh/Year)	PV (kWh/Year)	WT (kWh/Year)	Excess Power (kWh/Year)
Grid	PV	559,125	-	1,239,158	-	19,974
Battery–Grid	PV	562,116	1	1,211,268	-	22,122
Grid	PV–WT	554,093	-	1,229,755	11,041	20,376
Battery–Grid	PV–WT	551,260	1	1,257,185	11,041	22,006
Battery–Grid	WT	1,147,834	9	-	11,041	0

According to Table 4, when using only the utility grid as the supplementary system, PV power generation was high and the excess electricity, which represents the electrical energy not used by the load, was low. This can be attributed to the load demand. The system should have a higher capacity for renewable energy to supply the load demand, especially during peak times. When coupling the battery storage with the grid, PV power generation decreased, and the excess power increased. This can be clearly observed as the involvement of several primary energy sources provides system flexibility for reacting to the load demands. In addition, the use of wind turbines increased the capacity of renewable energy sources by 11,041 kWh/year. The highest electricity excess could be obtained when all four components (battery–grid–PV–WT system) were combined, providing an output that was equivalent to 22,006 kWh/year. The battery–grid–PV–WT system increased the solar panel capacity and renewable energy fraction because of its ability to store PV power. Figure 7 presents the power generation profiles of hybrid systems with different combinations of power sources (grid power, solar PV, wind turbines (10 kW)) and batteries.

5.2. Economic Analysis

In this section, a discussion of the economic analysis of the combinations of hybrid systems selected using HOMER software is presented. NPC and COE are the critical economic factors that are optimized using HOMER software based on the equations presented in Section 2. When performing a vital analysis with respect to the lifetime of the components, other costs such as the initial capital cost, replacement cost and operation and maintenance (O&M) costs, were considered, along with important economic factors including the salvage value and ROI.

Table 5 indicates the economic assessment of each scenario. The first scenario (grid–PV) had the lowest COE value (0.06581 USD/kWh), whereas the proposed battery–grid–PV–WT system had the highest COE value (0.06743 USD/kWh). Although there was a tradeoff between cost and other system factors, an investor may decide on what is more preferable among the economic parameters, i.e., system efficiency (lower losses) or the renewable fraction (lower emissions). The proposed power system was characterized by a high initial investment cost (equivalent to 1.29 million USD) but low operating and O&M costs.

Figure 7. Monthly electric production of the various system configurations.

Table 5. Economic assessments of the considered scenarios.

Hybrid System	Battery (kWh)	PV (kW)	Converter (kW)	WT (Unit)	Initial Investment (USD)	Operating Cost (USD)	COE (USD/kWh)	NPC (USD)	RF (%)
Grid–PV	-	709	515	-	1.22 M	18,810.22	0.06581	1,461,138	67.4
Battery–Grid–PV	1	693	497	-	1.19 M	21,187.81	0.06689	1,463,046	66.8
Grid–PV–WT	-	704	509	1	1.26 M	19,451.80	0.06814	1,509,812	67.7
Battery–Grid–PV–WT	3	719	518	1	1.29 M	17,609.36	0.06743	1,513,066	68.2
Battery–Grid–WT	9	-	1.10	1	53,031	150,525.90	0.1334	1,998,957	0.953

Based on all the data, using the proposed system with a 719-kW solar panel and a 10-kW wind turbine with three battery units and a utility grid was the most cost-effective alternative. Furthermore, this system had the highest renewable fraction among all the scenarios (68.2%), indicating its good environmental performance and producing the highest electricity surplus (22,006 kWh/year).

Finally, the best ROI was provided by the battery–grid–PV system (6.9%), whereas the lowest ROI was observed in the case of the battery–grid–WT (−3.7%). Figure 8 summarizes the costs for all the hybrid systems. This analysis is beneficial because it economically specifies how the prices of the technologies can be reduced to make them more affordable and install them in hybrid systems.

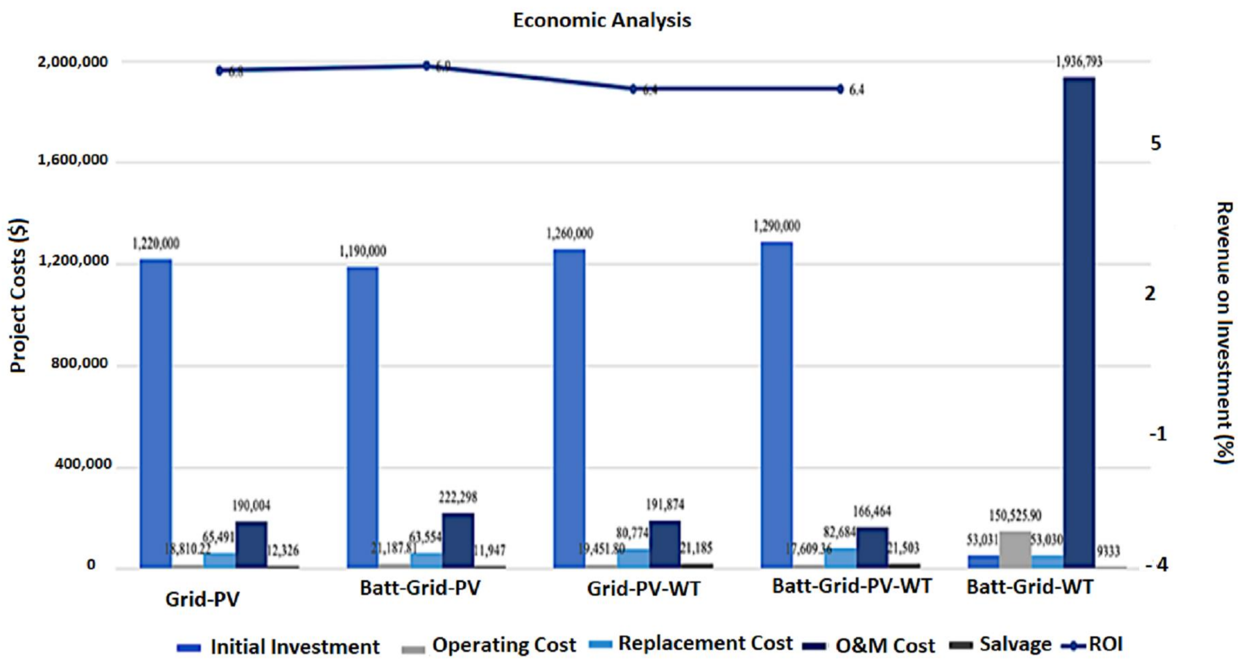

Figure 8. Projected costs for each scenario.

5.3. Emission Analysis

A greenhouse gas (GHG) absorbs and emits radiation in a specific thermal infrared range. Hence, it plays a major role in ensuring a clean and safe environment. In this section, an environmental analysis was performed by considering the GHG emissions of different hybrid power systems.

Table 6 indicates the emissions produced by different hybrid systems. The system in which only the utility grid was employed exhibited the highest emissions of all GHGs. However, the emissions were reduced significantly when considering renewable sources such as PVs and wind turbines. This can be attributed to the installation of a high capacity of renewable energy systems. Furthermore, the battery–grid–PV–WT scenario exhibited the lowest emissions of carbon dioxide, sulfur dioxide and nitrogen oxides. This system produced approximately 1.4% less pollutants than the grid–PV system. From an environmental perspective, the proposed system was ecofriendly and exhibited the best performance. In addition, it was the most efficient system in terms of delivering the required power to the load, along with increasing the system flexibility and enhancing the environmental performance. The amount of emitted pollutants, including carbon monoxide, unburned hydrocarbons and particulate matter, was zero for each system because of the absence of any fossil-fuel-based generator or fuel combustion.

Table 6. Comparison of the GHG emissions produced by each hybrid system.

Hybrid System	Carbon Dioxide (Kg/Year)	Carbon Monoxide (Kg/Year)	Unburned Hydrocarbons (Kg/Year)	Particulate Matter (Kg/Year)	Sulfur Dioxide (Kg/Year)	Nitrogen Oxides (Kg/Year)
Grid	732,409	0	0	0	3175	1553
Grid–PV	353,367	0	0	0	1532	749
Battery–Grid–PV	355,257	0	0	0	1540	753
Grid–PV–WT	350,187	0	0	0	1518	742
Battery–Grid–PV–WT	348,396	0	0	0	1510	739
Battery–Grid–WT	725,431	0	0	0	3145	1538

Finally, the carbon reductions associated with each system were determined. After estimating the annual electricity output and carbon dioxide emissions using HOMER software, the carbon credits were calculated and examined accordingly. Table 7 shows the carbon credit values for each scenario.

Table 7. Carbon credit analysis.

Hybrid System	Annual Electricity Output (MWh/Year)	Carbon Dioxide Emissions (Tons/Year)	Annual Base Line Emissions (Tons)	Carbon Credits per Year (Tons)	Carbon Credits per Year (USD)
Grid–PV	1798.28	389.52	1248.006	858.48	8584.8
Battery–Grid–PV	1773.38	391.603	1230.72	839.12	8391.2
Grid–PV–WT	1794.89	386.015	1245.65	859.63	8596.3
Battery–Grid–PV–WT	1819.49	384.041	1262.72	878.68	8786.8
Battery–Grid–WT	1158.87	799.651	804.25	4.60	46.04

One carbon credit corresponds to a one-ton reduction in carbon dioxide emission. According to Table 7, the proposed system exhibited an excellent performance with respect to carbon dioxide reductions because it provided a reduction of approximately 878.68 tons per year and up to 21,950 tons over the lifetime of the project (25 years). Furthermore, this can result in savings that are worth up to 8786.8 USD per year. Figure 9 shows that the management of carbon credits is necessary to increase profits and decrease CO_2 emissions. Therefore, governments can develop new policies and impose penalties for companies with high CO_2 emissions. Furthermore, companies can buy carbon credits to offset their remaining emissions.

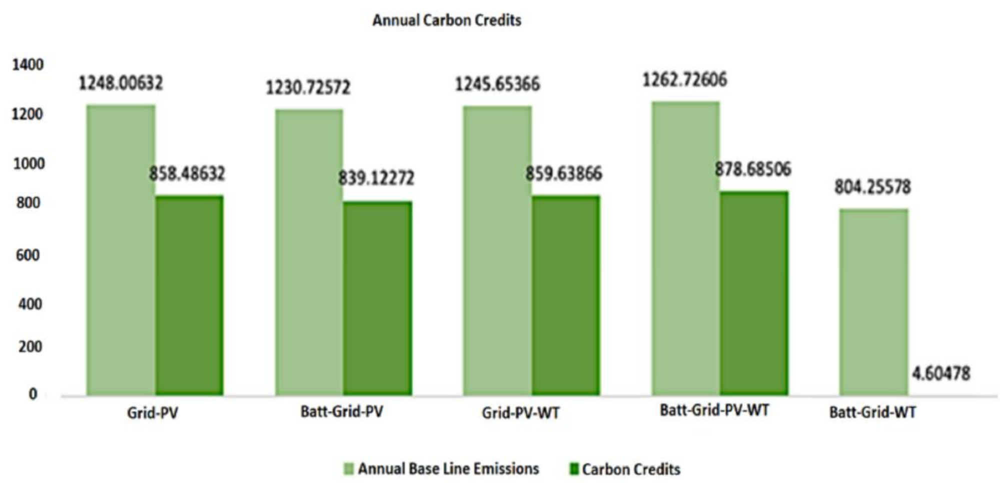

Figure 9. Reduction in carbon dioxide emissions per year.

5.4. Sensitivity Analysis

In this section, several optimizations determined using HOMER software for a low-price system are examined, making it easier to understand under which conditions the optimal model can be obtained and the manner in which the results are affected. First, the renewable fraction and NPC were assessed with respect to the average solar radiation. As shown in Figure 10, an increase in solar radiation resulted in an increased renewable fraction and decreased NPC. However, beyond 7.6 kWh/m^2/day, the NPC and renewable fraction did not change the overall performance of the system.

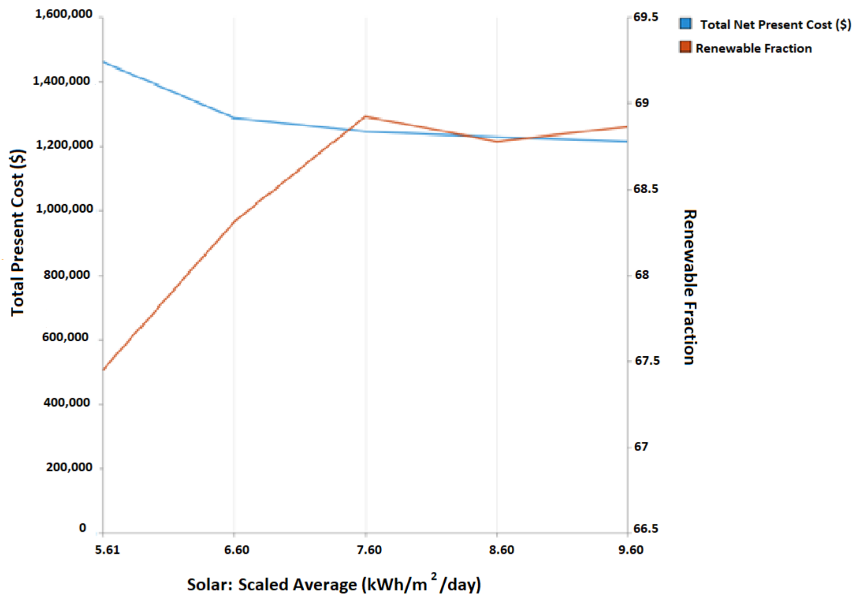

Figure 10. Sensitivity analysis of the renewable fraction and NPC based on average solar radiation.

In addition, the renewable fraction and CO_2 emissions were examined. As can be observed in Figure 11, increased solar radiation resulted in an increased renewable fraction, which played a major role in decreasing the CO_2 emissions. Furthermore, surplus electricity was considered because an increased solar radiation would result in increased excess electricity owing to the high PV output power under high solar radiation. Figure 12 shows that CO_2 emissions and excess electricity did not change significantly above 7.6 kWh/m^2/day solar energy.

The objective of the proposed project was to introduce renewable energy into a commercial area. Based on all previous cases, changing the project location to an area with a considerably higher solar radiation would result in similar performance. Furthermore, the cost of the project is the most important factor from the viewpoint of the investor. In this case, wind turbines can be ignored because wind is not prominent in the area under study, in addition to the role of infrastructure and buildings, especially those in built-up commercial areas, in preventing wind power generation.

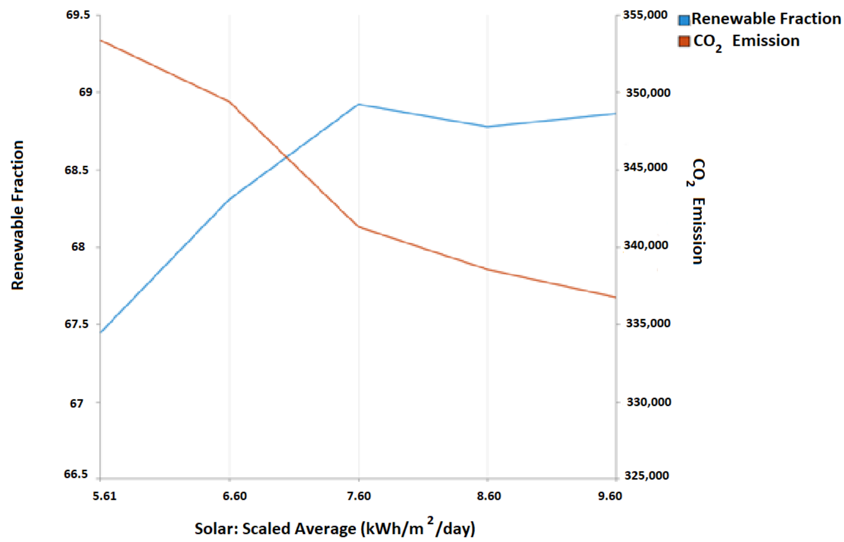

Figure 11. Sensitivity analysis of renewable fraction and CO_2 emissions based on average solar radiation.

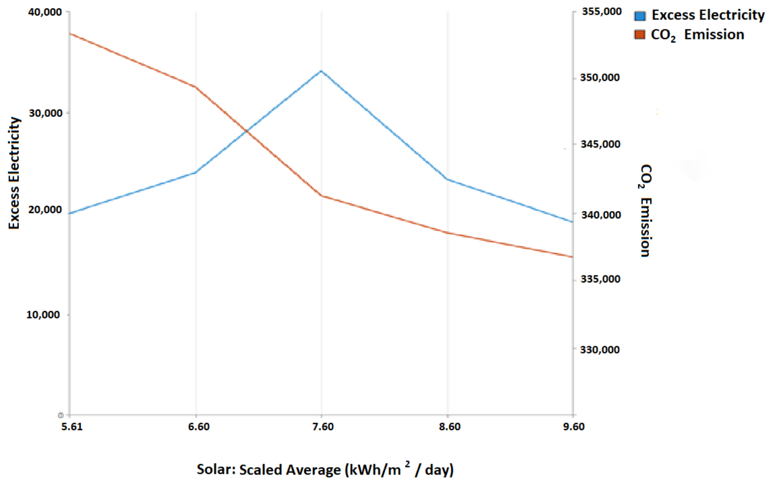

Figure 12. Sensitivity analysis for excess electricity and CO_2 emissions based on average solar radiation.

6. Conclusions

Since energy crises and environmental problems have raised major concerns for scientists and policymakers around the globe, EVs have high application potential in the automotive sector because they provide green transportation and reduce the sector's carbon dioxide footprint. Thus, the establishment and deployment of renewable energy resources for the charging of EVs will promote sustainable electricity, enhance system reliability, ensure resource diversity and improve ecological performance. The aim of this study was to conduct a techno-economic analysis of different hybrid systems using HOMER software. Technically, the proposed system including PVs, wind turbines, utility grids and batteries could offer benefits in terms of supplying the load demand, minimizing energy losses and providing surplus electricity (22,006 kWh/year). Economically, the PV–grid system configuration had the lowest energy cost of 0.06581 USD/kWh. The addition of a wind turbine and battery storage system increased the energy cost to 0.06743 USD/kWh. The proposed system had the lowest O&M costs. Carbon credits were also considered because they contributed to the overall profit by approximately 8786.8 USD per year. Environmentally, the proposed system exhibited the highest renewable fraction, providing an annual reduction in all emissions and especially in the case of CO_2 emissions by more than 878 tons/year, indicating the positive environmental impact of the system. Sensitivity analysis results showed that an increase in solar radiation would increase electricity generation and the renewable fraction and decrease CO_2 emissions. On the other hand, and considering a combined qualitative and quantitative assessment of the study, it can be concluded that the battery–grid–PV system configuration has potential, and the use of wind turbines can be neglected because of the low wind speed and urban buildup in the UAE, preventing wind power generation. From the economic point of view, the study indicated that the best return on investment would be provided by the battery–grid–PV system configuration, with an estimated value of 6.9%, indicating an appropriate business opportunity in the field of energy and transport sectors. Such a configuration also produced 1.4% less pollutants in comparison to the grid–PV system, indicating a more ecofriendly performance configuration. In terms of carbon credits, such a configuration can attain almost 839.12 carbon credits per year, which is a worth value of 8391.2 USD per year. Furthermore, we conducted a sensitivity analysis and observed that a solar radiation level of 7.6 kWh/m^2/day would be a threshold beyond which the net present cost and renewable fraction would not change the overall system performance. This conclusion also applies to carbon dioxide emissions, with no significant variation above this value. It can be concluded that the nature of the area under study and the infrastructure of commercial buildings limit the potential of wind energy compared to solar energy and battery deployment.

The study had some limitations due to the lack of real data on EVs' load profiles in this area or in similar areas, thus requiring the utilization of hypothetical data. In future studies, a dynamic load model that accounts for different types of EVs must be considered, along with different types of EV chargers to realize fast charging. Eventually, variations between residential, educational and industrial sites must be accounted for in future studies.

Some policy implications exist as some cities in the United Arab Emirates have suggested that a specific percentage of parking lots should be allocated for green vehicles. However, there is a mandate for the study presented in this paper as it has been recommended that such cities investigate the optimal configuration for the source of power when charging the EVs. Furthermore, many UAE initiatives have been conducted in order to encourage the use of electric cars, such as DEWA charging stations of electric cards. Therefore, this study can help in installing hybrid systems in all public charging stations, as well as petrol stations, to expedite and enhance the process of charging electric vehicles and help to make the UAE a global model of a green economy.

Author Contributions: Conceptualization, A.S.A.-S. and M.M.; methodology, A.S.A.-S. and M.M.; software, A.A. and N.A.-S.; validation, A.A. and N.A.-S., formal analysis, A.S.A.-S., A.A., N.A.-S., M.M., T.A. and E.H.-F., investigation, A.S.A.-S., M.M., A.A. and N.A.-S.; resources, A.A. and N.A.-S.; data curation, A.A. and N.A.-S.; writing—original draft preparation, A.S.A.-S., A.A. and N.A.-S.; writing—review and editing, A.S.A.-S., M.M., T.A. and E.H.-F.; visualization, A.S.A.-S., A.A. and N.A.-S.; supervision, A.S.A.-S., M.M. and T.A., project administration, A.S.A.-S.; funding acquisition, A.S.A.-S. All authors have read and agreed to the published version of the manuscript.

Funding: This work is supported by Khalifa University under Award No. kkjrc-2019-trans 2 and Research Excellence Award # 8474000427.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The HOMER software has built in databases which allowed to select and simulate all the required components a long with NASA Surface Meteorology and Solar Energy Database which is employed in the software. In addition, the data for electrical tariffs were added using the UAE Statistical Year book data for 2019.

Conflicts of Interest: The authors declare no conflict of interest.

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