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Research Article

Design of a Charging Station for Electric Vehicles Based on a Photovoltaic-Biodiesel Hybrid Renewable Energy System Combined with Battery Storage

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The rapid deployment of electric vehicles (EVs) in Jordan requires massive efforts to prepare the infrastructures that serve the transportation sector. The lack of EV charging stations is the major obstacle that faces EV drivers. Utilizing renewable energy in EV charging stations contributes to the spread of these stations. Renewable energy technologies are environmentally friendly as they mitigate greenhouse gases that cause the global warming phenomenon. In this paper, an EV charging station, based on a PV-biodiesel-battery hybrid system, is investigated. The importance of this article is to discuss the hybrid system of PV and waste vegetable oil (WVO) along with storage that applies the maximum reliability supply, having an environmentally friendly supply and achieving the lowest energy cost of charging. This station is designed based on renewable and WVO utilization. In fact, WVO, coming from restaurants, is exploited to produce electricity by a diesel generator through direct burning after converting it into biodiesel. The capacity of each station is 14 cars/day with a medium-speed charger of 7 kW. The system is simulated and optimized using iHOGA software where multiobjective optimization is applied to achieve the minimum net present cost (NPC) and CO_2 emissions considering three cases, PV-diesel, PV-biodiesel, and PV-WVO, all with battery-hybrid system. These values for the EV charging station that uses the PV-biodiesel-battery hybrid system are 624408 € and 15.4 tons/year, respectively. The corresponding values are 781473 € and 15.14 tons/year and 615310 € and 18.84 tons/year for the systems that work with diesel and WVO, respectively, and energy cost is achieved in best solution to be 0.11 Euro/kWh. Simulation results show that the proposed technique led to enhanced operational efficiency in terms of both NPC and annual CO_2 emissions.

1. Introduction

Renewable energy investigation has become a global trend due to the incremental rapid demand for renewable energy resources and the necessity of sustainable development. Many countries changed their energy policies to encourage the exploitation of renewables, and as a result, many projects were performed. Furthermore, the hybrid energy system concept became an important motif through generating energy from two or more renewable energy resources, thus improving the energy supply.

Jordan is one of the countries that depend on imported energy sources, which mainly come from natural gas and oil by around 93% [1, 2]. Jordan is facing a chronic energy challenge that requires a well-prepared plan based on the available alternative energy resources to overcome this challenge safely.

Most of the energy consumption in Jordan is attributed to the transportation sector, as it contributed to around 3363 thousand tons of oil equivalent (TOE) in 2018. This represents about 49% of the total energy consumption compared to household, industry, and other sectors which represent 21.5%, 14%, and 15.5%, respectively, as shown in Figure 1 [2, 3]. The reason belongs to the huge number of diesel and kerosene vehicles in Jordan which are more than 1.5 million vehicles. The large usage of these machines replaces the reliance on modern alternatives, such as electric vehicles that reach only 8310 by the end of 2018.

In 2018, Jordan's total generation capacity of electricity was about 5236 MW. This includes 980 MW generated from renewable energy resources, representing 18.7% of the total energy production. However, the government has introduced some regulatory instructions to deal with the associated challenges, hence enhancing the share of local sources of energy such as oil shale and renewable sources (solar, wind, and biofuel). The target is to reach a contribution of oil shale and renewable resources of 15% and 20%, respectively, by 2020 [2].

Biodiesel is a liquid biofuel obtained by chemical reactions from animal fats or vegetable oils and an alcohol that can be used in standard diesel engines, alone or mixed with diesel oil [4]. Further, biodiesel is a mixture of long-chain monoalkylic esters from fatty acids obtained from renewable resources (vegetable oil (VO) or animal fats), to be used in diesel engines.

Biodiesel has several advantages that encourage its usage, in addition to considering it as a sustainable source of energy. The other merits are the lower toxicity compared to diesel fuel and the lower emissions (particulate matter, carbon monoxide, aldehydes, and polycyclic aromatic hydrocarbons). Further, it has no sulfur dioxide (SO_2) emissions. Moreover, it has lower health risks, and higher flash point (more than 100°C(. Also, it degrades rapidly more than diesel fuel, which thus minimizes the environmental consequences of biofuel leakages. In addition, biodiesel can be mixed with diesel fuel at any proportion, and it can be used in conventional engines without modification. Furthermore, fat residues from meat processing and cooking used oils may be employed as raw materials that imply a low production cost and an excellent lubricant.

Up to now, this kind of bioenergy source has not been exploited and explored in Jordan to its maximum extent. A significant project is the Rusifa landfill which is managed by Jordan Biogas Company to produce biogas from organic waste and produce electricity. The generated electric energy reached 6.5 GWh in 2017. Some private companies collect waste vegetable oil (WVO) from restaurants and hotels to recycle it as biodiesel. The annual consumption of vegetable oil in Jordan is around 120,000 tons, which is classified as shown in Table 1 [5].

As a matter of fact, this massive consumption of oil makes thousands of tons of wasted oil, which can be managed by utilizing it as biofuel. This can be done directly or by converting it to biodiesel. It is worth to mention that bioenergy in Jordan can influence a noticeable share in energy supply, with around 12 megatons per year. Different thermochemical conversion processes rather than biodiesel can be used for biomass utilization like biogas and direct combustion [6].

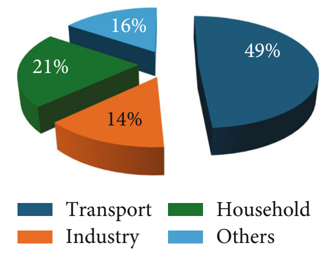

Figure 1: Energy consumption of various sectors in Jordan in 2018 [2].

Table 1: Share percentages for different types of vegetable oil in Jordan [5].

Vegetable oil type	Sharing percentage
Sunflower oil	10%
Corn oil	20%
Soy oil	30%
Palm oil	40%

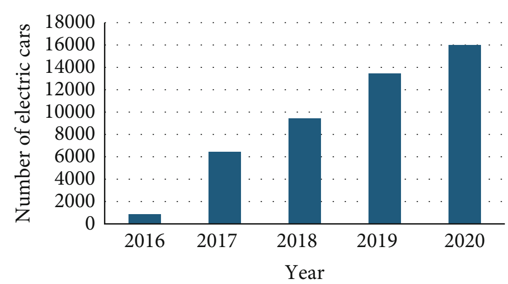

Figure 2: Number of electric cars in Jordan [7].

The demand for electric cars has been growing rapidly over the past decade worldwide. Actually, 5 million cars were sold globally in 2018 in which 45% of them were in China compared to 24% and 22% in Europe and the USA, respectively. In Jordan, the electric car deployment has increased in the past 5 years to reach around 16 thousand cars in 2020. See Figure 2.

Figure 2 shows that the number of electric cars increases linearly in Jordan. This growth refers to the continuous yearly inflation of conventional fuel prices in Jordan. Several statistics in many countries indicate that the huge obstacle facing electric car drivers is the lack of electric vehicle (EV) charging stations. In Jordan, EV charging stations are likely uncommon, where they are currently around 150 stations. This makes some difficulties for the dominance of electric cars in Jordan [8].

Table 2: Other related hybrid charging stations.

Reference	Description
Bhadra et al. [23]	PV is connected to the electrical grid to minimize the overall cost of electricity supply. No biodiesel is used. Referring to the inverter size, a 5 kW power can be delivered.
Kokchang et al. [24]	PV-battery hybrid system for camping charging stations with level 2 PV system. Calculating the payback period to be 4.1 to 5.2 years with minimum CO_2 emissions. The charging cost varies between 0.13 and 0.22 USD/kWh.
Sánchez-Sáinz et al. [25]	Renewable (mainly solar and wind) with hydrogen for fuel cells, no biodiesel. The PV sizing is 2827.6 kW that is designed for the whole system, around 2000 kW from wind, and 1500 kW from electrolyzer. No cost and CO_2 emissions are analyzed.
Shafiq et al. [26]	Technical, economic, and environmental impacts have been studied for renewable tied to the electrical grid for the minimum cost. 13% of electricity generated is used for charging and the rest is sold out to the grid. The total energy produced from PV system is 254,030 kWh/year which minimizes the losses from 0.22 USD/kWh to 0.016 USD/kWh. No CO_2 emission analyses are provided.
Vermaak et al. [27]	Study the standalone PV-wind-battery charging station in Congo. HOMER software is used to study energy production, equipment, and financial viability. The best scenario is achieved by charging the cars in series using fixed load. The estimated COE is 0.499 USD/kWh for a total project NPC of 39,705 USD. The CO_2 production from the diesel generator is 2640 kg/year.
Badea et al. [20]	Concentrate on the financial and CO_2 emissions using iHOGA by installing PV panels that are integrated with the national grid; a lower LCOE is achieved compared to the energy consumed from the electrical grid only. The total energy produced from PV panels is 5789 kWh/year, CO_2 emissions is 583 kg/year, with LCOE of 0.17 Euro/kWh.
Boonraksa et al. [28]	Study the exploitation of solar/wind hybrid EV charging station using IEEE 34 bus system using artificial bee colony (ABC). The study opens new prospects in utilizing the combination of renewable sources for rural and remote areas. The only presented information is the charging capacity of the station with 1.2 MW; no cost and CO_2 emissions are analyzed.

Table 3: EV charging station specifications.

Car name	Nissan
Car model	Leaf 2018
Battery capacity	40 kWh
Charging speed	Medium
Charging time	6 hours
Charger specification	1-phase, 32 A, 7.4 kW
Number of cars/day	14
Maximum number of cars at the same time	5

Table 4: Daily load demand distribution.

Period	Number of cars	Monthly average power (W)
0:0 AM-6:00 AM	2	14,800
6:00 AM-12:00 PM	5	37,000
12:00 PM-6 PM	4	29,600
6:00 PM-0:0 AM	3	22,200

In the published literature, many studies were performed, which are related to the design of charging stations of electric vehicles with the aid of a renewable energy system such as a hybrid PV/diesel system.

According to the Department of Energy, around 80% of electric car owners charge at homes; however, people who live in rural areas or drive long distances demand on road charging stations. The charging stations can be directly powered from the electrical grid, but in order to decrease stressing the electrical grid, renewable integration became a proper solution with storage banks [9, 10]. A proper storage idea like biodiesel generators, by storing the raw material itself, is a great solution to overcome the usage of batteries and avoiding their high prices.

Al-Rousan et al. studied the amounts of biowaste available for proper investigation in Jordan. The substantial quantities of biowaste were observed by considering dairy and poultry farms, products of wastewater treatment plants, and agricultural activities. Results showed that olive residues are with the highest potential of biodiesel production with around 39% [11].

Electric vehicles became the shining solution of reducing the greenhouse emissions that are associated with using internal combustion ones; however, the efficiency of reducing the greenhouse gases is highly dependable on the source of electricity for charging electric cars. Barman et al. discussed four cores of the infrastructure development including the usage of renewables. It has proved that the more flexible charging, the more efficient electric cars can operate; however, the variation of the original sources of solar and wind energy performs a major challenge [12]. Therefore, in this paper, integrating WVO can highly improve the charging reliability.

In [13], an experimental analysis for several types of biofuels (fresh vegetable oil, waste vegetable oil, waste animal fat (WAF), biowaste vegetable oil, and biowaste animal fat) has been done. In addition, the analysis has been carried out for the diesel fuel using a single-cylinder diesel engine through direct injection at different injector pressures. The main

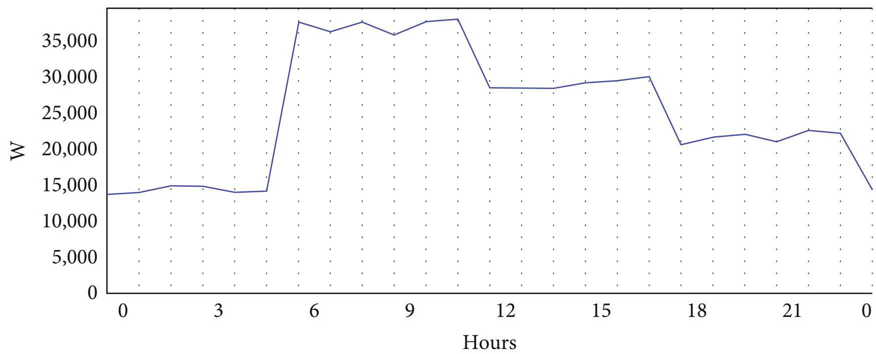

Figure 3: Actual load profile.

objective was to trace the behavior of each fuel at different nozzle pressures and relate the type of the fuel and pressure with combustion efficiency, engine speed, and fuel consumption. The findings were hopeful since the diesel engine could operate satisfactorily using fuels derived from VO, WVO, and WAF under the proper conditions. Moreover, biodiesel behaves identically as diesel fuel in many aspects.

The study in [14] emphasized the importance of using bio-WVO in Jordan. A detailed analysis of several types of biofuels, which were derived from palm WVO using a single-cylinder-direct injection diesel engine, has been performed. Besides, the performance of the different blends is compared with the behavior of the conventional diesel. The measured parameters included coolant and exhaust temperatures, brake torque, fuel-to-air ratio, engine speed, and exhaust emissions including carbon monoxide, carbon dioxide, unburned hydrocarbons, sulfur dioxide, and smoke. The findings were promising since the blends overcame the conventional diesel in most respects, in which it was found that with blends, the engine operated smoothly without any significant problems. Furthermore, the blend presented better thermal efficiency, lower fuel consumption, and lower emissions including unburned hydrocarbons and carbon monoxide. Based on the results, it can be concluded that biodiesel and its blends, which are derived from WVO, have a high potential as alternative fuels for the diesel engine.

The paper in [15] describes the sizing of a hybrid system consisting of solar PV, diesel engine generator (DEG), and battery bank. The simulation for the system has been done in different scenarios by changing the sharing percentage of solar photovoltaic (SPV) to get the needed parameters such as peak power rating of SPV, DEG size, and energy supplied by SPV for battery charging. The purpose of this study was to overcome the problem of intermittent availability and low energy density of solar radiation. The results showed that the PV/diesel generator (DG)/pottery system is a continuous source of electricity, but also it is costly compared to the standalone PV or DG system. However, many updates need to be considered to make renewable energy studies up to date. For instance, the cost analysis conducted in [15] was made based on 4000 USD/kWp as a cost of each kW, but nowadays, this cost decreased to around 600 USD/kWp. This presents a huge difference in the up-to-date calculations. Moreover, the cost of diesel fuel increases from 2010 to 2019. So, the cost

Table 5: Variability percentages.

Variability	Value
Daily variability	2%
Hourly variability	5%
Minute variability	90%
Correlation minutes	0.9

Table 6: Load demand characteristics.

Maximum value (W)	39,590
Average value (W)	25,836

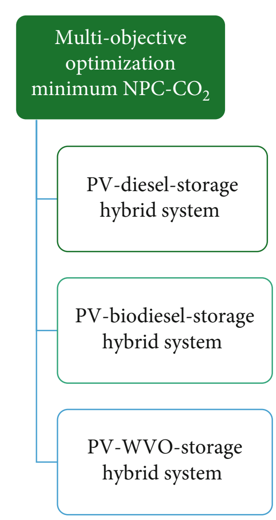

Figure 4: Optimization scenario diagram.

Table 7: Commercial tariff in Jordan.

The kWh range	Tariff
1-2000 kWh	120 fils = 0.16 €
Greater than 2000 kWh	17.5 fils = 0.23 €

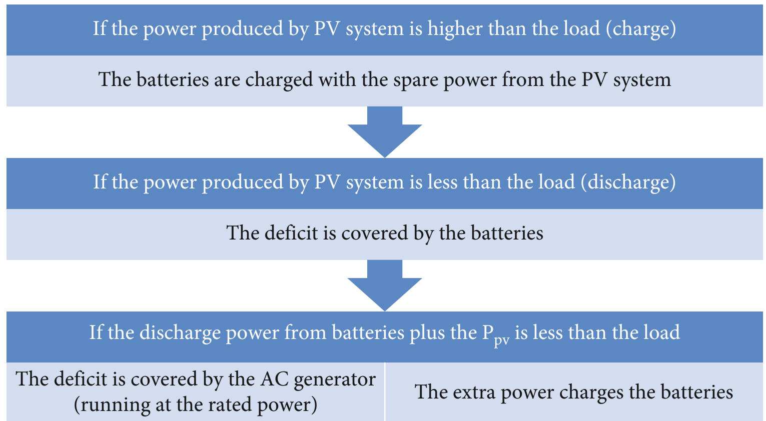

Figure 5: Control strategy of operation.

of diesel fuel needs to be updated. These two cost issues will be updated in this paper.

In [16], the possibility of using PV-diesel hybrid system including batteries has been investigated. This is to operate telecommunication stations in remote areas in Greece. A preliminary design approach was made using HOMER and PVSYST commercial software for a typical telecommunication base station. The optimization results showed that the system consists of 1 diesel generator (20 kVA), a 9 kWp PV plant (crystalline type), and two battery banks each with 1200 Ah and a 15 kW two-way inverter.

The authors in [17] investigated a PV-biodiesel hybrid energy system for a cement technology institute. The main purpose of the research is to examine the reliability of the power supply, pollutant emissions, and coal reserves. The biodiesel was used for ecological reasons. The modeling and simulation processes were made using HOMER software. The optimized configuration was a 25 kW PV array, 8 kW biodiesel generator-1, 20 kW biodiesel generator, 10 kW rectifier, and 10 kW inverter. As a result, savings of 55,080 kg of coal can be achieved and an addition of 27.744 tons of CO_2 to the atmosphere per year could also be avoided. The reliability is improved from 93.15% to 100%.

Shafiq et al. [18] discussed the importance of integrating renewable-based charging stations to promote renewables and reduce CO_2 emissions. The study was performed in Azad and Kashmir, Pakistan, where solar energy has great potential, and the charging station is supposed to be used for electric bike charging. A significant greenhouse gas reduction is achieved along with concentrating on technical studies like reliability, economic aspects, and environmental benefits.

The work presented in [19] is carried out to investigate the socioeconomic aspects of using electric vehicles in Jordan. The researchers studied the mentality of Jordanian citizens about using electric cars and illustrated the obstacles that prevent the mushrooming of electric cars and other points related to the government legislation. Eight questions were directed to vehicle owners and buyers. The recap of the whole results is that the majority of Jordanian society still lacks information about the real image of an EV. Also, they think that the price of EVs is expensive compared to other countries. However, most of them believe that EVs are environmentally friendly and they have good performance. On the other hand, the majority of Jordanian EV owners ensure that they are facing some drawbacks such as the availability of the charging stations and the maximum driving range of EVs.

In [20], SPV systems in EV charging stations have been discussed to permanently cover particular load demand in Romania. The researchers used (iHOGA) software to get the optimal configuration of the PV system. The optimization process was contingent upon three main indicators that are classified as technical, financial, and environmental indicators. The technical point of view indicates that the system can cover the station with the required power without any interruption even in the worst scenarios. In addition, the findings state that the system has lower CO_2 emissions compared to the conventional stations. However, the system has a financial drawback due to the high levelized cost of energy compared to the national distribution network.

Iqbal et al. provided a frequency control research article that discusses the insurance of more secure and economical operation through the electrical system. Battery life degradation is considered in the cost analysis where the minimum frequency control is considered as the objective function in the optimization process [21].

In [22], the authors discussed the random charging behavior of electric cars, the thing that creates power problems for the operator especially when talking about large electric cars. A forecasting model is developed that can make better expectations for electric car charging to make the best supply and demand schemes.

A smart renewable charging station has been suggested in [14]. This work considered the construction of a connection between a solar EV charging station and smart houses with PV systems. The EV charging station purchases energy from the smart houses and provides it to the EVs at a lower price. What is more, extra power stored by the charging station sells the stored power to the smart houses at peak demand times. The chosen optimization parameter was the maximum profit. The process of optimization was made using the Tabu search optimization algorithm. Furthermore, the optimization results showed that the system reached the

Table 8: Optimization outputs of PV-diesel-battery hybrid system.

No.	NPC (€)	CO_2 emissions (kg/year)	Renewable fraction (%)	Lev. cost E. (€/kWh)	Total PV capacity (kWp)	AC generator (VA)	No. of AC generator	Total battery capacity (kWh)
1	781,473.6	15,140.58	97.79	0.14	212.500	15,000	2	604.800
2	779,606.9	15,294.17	97.72	0.14	212.500	31,000	1	604.800
3	837,106.3	14,586.54	98.25	0.15	212.500	15,000	2	680.400
4	835,071.9	14,679.99	98.21	0.15	212.500	31,000	1	680.400
5	896,423.4	14,383.76	98.57	0.16	212.500	15,000	2	756.000
6	1,015,044	14,045.57	99.17	0.18	212.500	15,000	2	907.200
7	1,013,250	14,106.14	99.14	0.18	212.500	31,000	1	907.200
8	623,146.2	18,709.53	95.98	0.11	212.500	31,000	1	428.400
9	615,245.4	19,983.27	95.32	0.11	216.750	31,000	1	403.200
10	619,030.3	19,590.92	95.58	0.11	221.000	15,000	2	403.200

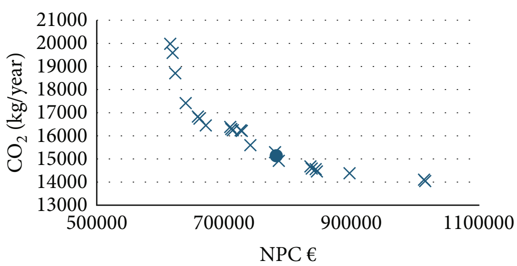

Figure 6: NPC-CO_2 emissions/multiobjective optimization.

Table 9: Energy balance for one year/PV-diesel-battery hybrid system.

No.	E_{PV} (kWh/year)	E_{Excess} (kWh/year)	$E_{Battery}$ (kWh/year)	$E_{AC\,gen}$ (kWh/year)
1	303.656	49.921	127.049	5.010
2	303.656	50.078	127.003	5.177
3	303.656	48.784	127.864	3.960
4	303.656	48.873	127.848	4.061
5	303.656	48.008	128.341	3.240
6	303.656	46.557	129.344	1.890
7	303.656	46.620	129.310	1.953
8	303.656	54.282	124.088	9.114
9	309.729	61.950	122.428	10.602
10	315.803	67.390	122.278	10.020

required target and resulted in massive profits. Table 2 shows a summary of other related work on hybrid charging stations.

The advantage of using solar energy came from reducing the dependency on fossil fuels; however, combining biodiesel became the most sustainable solution when the infrastructure of PV systems has limitations, considering applying the sustainability concept and being environmentally friendly [29].

Another benefit of integrating biodiesel from WVO is having lower cost or even a free source of fuel compared to oil which reduces the payback period and having a high NPC which makes it a promising solution, especially for the expanding trend on EVs [30].

Renewable hybrid systems are effectively used in another applications rather than charging the electric vehicles. In [31], the idea of using the hybrid renewable energy system is applied to discuss an important another application which is water desalination in Jordan. The best scenario is achieved by having solar PV, wind, and diesel generator with a battery storage. The NPC of the system is 11,086,499 USD with COE of 0.063 USD/kWh and 417,752 kg/year of CO_2 emissions. Another important hybrid renewable energy system application is efficiency improvement and emission reduction of buildings. As discussed in [32], a hybrid system of solar PV, wind, and battery storage is used for reducing the electricity bill in a hotel in Jordan. The achieved optimum scenario resulted in having 0.042 USD/kWh. Furthermore, the application of renewable hybrid system is also applied on designing irrigation system energy supply; a research article is published that introduced a 60 kW distributed generation. The energy price is achieved to be 0.091 USD and 15,847 kg/year of CO_2 emissions [33].

In this paper, a hybrid PV diesel system combined with battery storage has been investigated for the goal of scheming an EV charging station. The main objective of utilizing biodiesel in this research is to enhance the storage flexibility when integrated with the variability of the PV system. Additionally, exploiting the abundant waste from the restaurant industry instead of being thrown off has a more reliable power supply by using biodiesel integration which can be stored considering the raw material or after processing. The main difference between this report and the previous ones is the distribution of load on two diesel generators (small and large) instead of a single generator which is perfect from an energy efficiency point of view since the rated load must be close to the maximum load of the generator, in addition to the use of biodiesel instead of conventional diesel.

This article describes firstly the main operational data that have been considered in building the iHOGA model and then discusses the model and the suggested scenarios and finally result generation along with their discussions.

The software is developed using C++ by the Electrical Engineering Department at the University of Zaragoza, Spain. The software can deal with different loads such as electrical load (DC and/or AC), hydrogen load, and a load of water from a reservoir; also, the software allows the user to choose several types of optimization in addition to a wide variety of integration choices (PV, wind, hydraulic turbine, battery bank, battery charge controller, AC generator, inverter, fuel cell, H2 tank, electrolyzer, and thermoelectric generator). iHOGA software uses two genetic algorithms, the main algorithm and the secondary algorithm. The first provides an optimum configuration of PV panels, AC generators, batteries, and the inverter to minimize total system costs; on the other side, the secondary algorithm tries to find the appropriate control strategy for minimum costs and any configuration provided from the first algorithm.

2. System's Data

2.1. Load Profile. The load profile is represented by stipulating a particular electric car with the specifications shown in Table 3. The suggested distribution of daily demand is seen in Table 4 and Figure 3. Those assumptions are made based on the capacity of the suggested charging station. Cars with different battery capacities can be considered in comparison with the suggested Nissan—40 kWh by estimating the charging time and the needed capacity, taking into account the maximum benefit from the solar energy and considering minimum dependency on diesel generators. The charging station will serve EV owners during working hours; as has been estimated by several EV owners, the supply at the time period is matching approximately the needs considering it as a public station.

Variability percentages, in Table 5, are inserted into the suggested load through iHOGA software to simulate the actual case. The characteristics of the actual load demand are given in Table 6 which in turn considers the fluctuations that can happen while charging.

2.2. Solar Irradiance. The potential of solar radiation in Jordan is the propitious point which in turn encouraged many investments in solar electrical and thermal systems. In Jordan, sunny days are around 300 days with an average of 6-7 kWh/m^2 solar irradiance [34]. Solar energy occupies the main contribution to the renewable energy generation mix which is around 20% [35].

The hourly solar irradiance data can be obtained using the solar resource tab provided by iHOGA software. This is done after determining the location investigated in this paper on the iHOGA map. These data can be downloaded from PVGIS, Renewable Ninja, or NASA solar resources. Once the hourly irradiance data is obtained, the global irradiance on a tilted surface is obtained using a 1st-order autoregressive function [36].

3. Methodology

3.1. iHOGA Software. The simulation and optimization processes were performed using iHOGA software. iHOGA is a software specialized in the modeling of electrical energy system consumption along with water consumption if pumped to a tank or reservoir. It can be utilized to simulate different electrical power generators like photovoltaics, hydropower, and diesel that should be existed in the system. Further, it is possible to apply the required optimization for cost and CO_2 emissions of both off- and on-grid systems [37]. iHOGA is a genetic algorithm-based program to figure out the optimal sizing of an energy system including diesel generators; iHOGA uses a control strategy that can be defined by the program for precise NPC analysis and also has the ability to perform the multiobjective optimization which is not offered by other programs like the well-known HOMER [25, 38].

3.2. Design Scenarios. Several design scenarios are discussed in this paper as shown in Figure 4. This is done depending on two main factors, which are the type of fuel and the type of optimization.

Table 10: Best solution/PV-diesel-battery hybrid system/multiobjective.

PV system size	212.5 kWp
Panel type	PV panels Munchen: MSP250AS-3 (250 Wp)
Module configuration	17s.× 50p
Azimuth angle	0
Tilt angle	60
Renewable energy share (PV)	97.8%
Battery type and capacity	LG Chem: RESU10 (189 Ah)
Battery configuration	9s.× 8p
AC generator	AC gen diesel 15 kVA
Number of AC generators	2
Inverter type	Generic: 50 K CH
Rectifier	Included in the bidirectional inverter
PV battery charge controller	Included in the bidirectional inverter
Unmet load	0%
Levelized cost of electricity	0.14 €/kWh
Control strategy	Cycle charging, continue up to SOC_{stp}, SOC min batteries = 10%

Table 11: Cost breakdown/PV-diesel-battery hybrid system.

Total cost of the system (NPC)	781,473 €
Cost of PV (NPC)	150,578 €
Cost of batteries (NPC)	525,552 €
Cost of AC generator (NPC)	10,290 €
Fuel cost (NPC)	25,355 €
Inverter cost (NPC)	54,849 €
Others	14,849 €

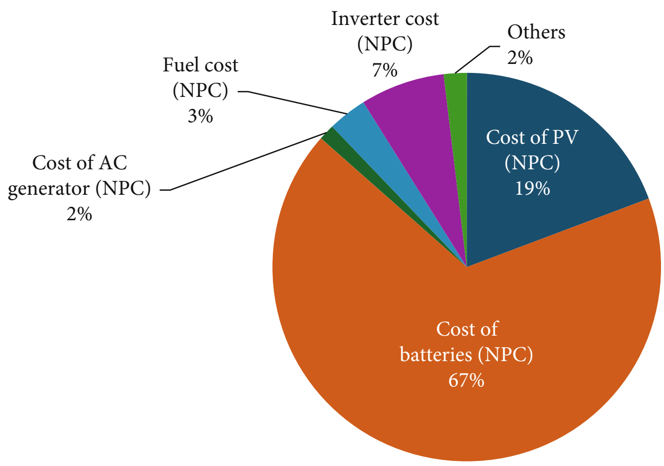

Figure 7: Cost breakdown/PV-diesel-battery hybrid system.

The concept of this research is to utilize the waste vegetable oil (WVO) of a group of restaurants using a diesel generator with a PV system and battery bank to charge electric cars. The WVO can be used in two forms, which are direct burning of WVO and converting the WVO to biodiesel. The target is to minimize the NPC and total CO_2 emissions together so that the best combination is related to the two parameters instead of one. In other words, it is interested in both parameters. The choice of multiobjective optimization must be selected inside the software.

Referring to the discussed hybrid charging stations in previous studies, the method that is discussed in this paper is effective in having a reliable power supply in a country that has good solar radiation, but from a reliability point of view, it should be supported by other energy sources where the NPC and CO_2 emissions are the main considerations, especially when talking about the high fuel costs and being environmentally friendly along with using electric vehicles. Previous studies discuss supporting rural areas, having the best profit and the best solar type solution along with other renewables, supporting house supply for charging electric vehicles or using solar wind hybrid systems without biofuel [28, 39–41]. Furthermore, iHOGA has been efficiently used in discussing the optimal configuration of PV systems but considering technical and financial issues that are related to PV supply [20].

3.3. Optimization Process and Mathematical Modeling

3.3.1. Evaluate All Combination Optimization Method. The multiobjective optimizations take the net present cost (NPC) to be optimized for the whole system. The CO_2 emissions are considered in the multiobjective selection which is used in this paper.

To perform the optimization process, the following assumptions are made. First, the maximum unmet load is assigned to be zero, so it is guaranteed that there will be no shortage periods. Second, the maximum number of days of autonomy is supposed to be all the year due to the usage of diesel generators where the coverage is assumed to be for the whole year. Third, the minimum renewable fraction is assigned to be zero. Fourth, the maximum levelized cost of energy is selected based on the Jordanian commercial tariff as shown in Table 7 [42].

The assumed charging capacity for the station is 14 cars per day with 40 kWh each as an average; the selected battery capacity is considered taking into account the available capacities in the market. Two variants of PV modules are considered for selection, Munchen MSP250AS-3 and Canadian CS3U-335 with 250 and 336 Wp each, respectively. It is assumed that lithium-ion batteries are for the operation due to a high number of charging and discharging (6000) cycles; the types are triple power 6.3, LG chem RESU6.5, and RESU10 with 63, 126, and 189 Ah each, respectively. The Scheiffer 2007 model is used since it is the recommended one considering the average temperature values and the corrosion rate. It is worth mentioning that the sizes are listed in the listed results.

The control strategy manages when the battery bank and diesel generator must supply the load and what level the battery bank should be charged. Cycle charging is used as a control strategy to manage the system to utilize the maximum benefits from the integrated model. Also the option of "continue up to SOC_{stp}" is activated; the flow chart of controlling the battery charging considering PV and the electrical generator is shown in Figure 5.

The average monthly load consumption (L_m), the monthly cost of electricity (E_m), and the average tariff of electricity (T_E) are calculated as shown in Equations (1)–(3). The cost analysis are based on the tariff values shown in Table 7.

$$\begin{aligned} L_m &= \text{number of cars per day} \times \text{battery capacity} \times 30 \\ &= 14 \times 40\,\text{kWh} \times 30 = 16{,}800\,\text{kWh}, \end{aligned} \tag{1}$$

$$E_m = 2000 \times 0.16 + 14{,}800 \times 0.23 = 320 + 3404 = 3724\,€, \tag{2}$$

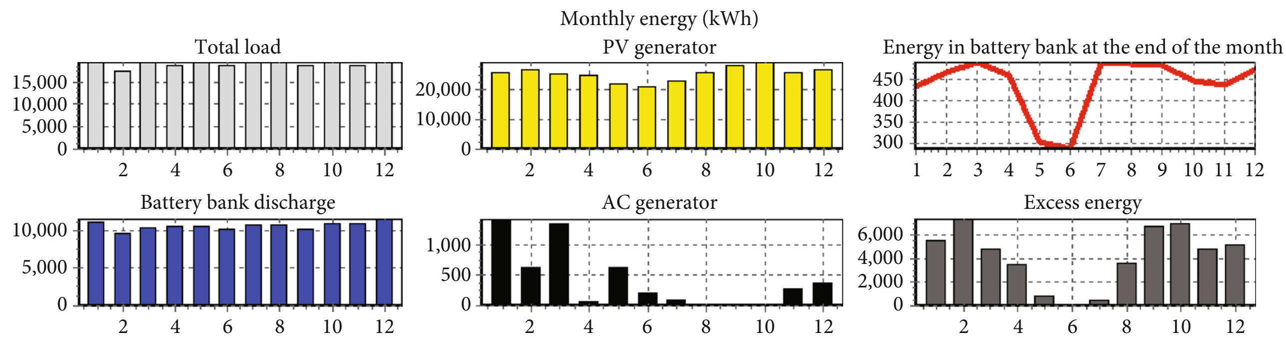

Figure 8: Monthly energy data/PV-diesel-battery hybrid system.

Table 12: Optimization outputs of PV-biodiesel-battery hybrid system.

No.	NPC (€)	CO_2 emissions (kg/year)	Renewable fraction (%)	Lev. cost E. (€/kWh)	Total PV capacity (kWp)	AC generator (VA)	Number of AC generator	Total capacity battery (kWh)
1	624,408.2	15,392.35	96.09	0.11	212.500	15,000	2	428.400
2	621,474.1	15,488.09	96.01	0.11	212.500	31,000	1	428.400
3	669,488.6	13,936.95	96.75	0.12	216.750	15,000	2	453.600
4	840,217.4	13,206.29	98.42	0.15	216.750	15,000	2	680.400
5	637,960.3	14,902.37	96.75	0.11	216.750	15,000	2	453.600
6	738,321.6	13,609.92	97.57	0.13	221.000	15,000	2	529.200
7	653,550.2	14,851.87	97.07	0.12	221.000	31,000	1	478.800
8	786,804.9	13,353.09	98.2	0.14	225.250	15,000	2	604.800
9	786,651.6	13,445.86	98.23	0.14	229.500	31,000	1	604.800
10	628,064.1	15,231.32	96.64	0.11	229.500	15,000	2	428.400

$$T_E = \frac{E_m}{L_m} = \frac{3724\,€}{16800\,\text{kWh}} = 0.222\,€/\text{kWh}. \quad (3)$$

The cycled energy is calculated among the battery lifetime for each depth of discharge as follows [36]:

$$E_{\text{cycled}_i}(\text{kWh}) = \text{Cn}\,(\text{Ah}).\text{Vn}\,(\text{V}).\frac{\text{DOD}_i(\%)}{100}.\frac{\text{Cycles}_i}{1000}, \quad (4)$$

where Cn is the nominal capacity in Ah, Vn is the nominal voltage in volt, and DOD is the depth of discharge.

The output power from the PV panels is calculated based on the number of both parallel and series modules and the solar duration time.

$$P(t) = \text{Isc}.G(t).\text{Vn}_{\text{panel}}.N\text{modules}_{\text{series}}.N\text{modules}_{\text{parallel}}.\text{Eff}, \quad (5)$$

where the Isc is the short circuit current in Amps, $G(t)$ is the irradiation of a surface in kW/m^2, and Vn is the nominal voltage on volt.

The maximum levelized cost of energy must be around 0.222 €/kWh. So, it is suggested to be 0.28 €/kWh to give the software a good range (0-0.28 €) to make comparisons and see the solutions that are close to the optimum one.

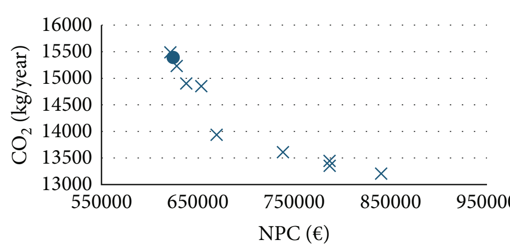

Figure 9: NPC-CO_2 emissions/multiobjective/PV-biodiesel-battery hybrid system.

The user has to assign the type of optimization method using the box of the main algorithm of iHOGA. It could be a genetic algorithm or an evaluation of all combinations. In the second choice, the number of possible combinations (N_C), when all components are selected, will then be calculated using the following [36].

$$N_C = N_{\text{PV Type}}(1 + N_{\text{PV\_max}} - N_{\text{PV\_min}}) * N_{\text{Batt Type}}(1 + N_{\text{Batt\_maxp}} - N_{\text{Batt\_minp}}) * N_{\text{ACG}}, \quad (6)$$

where $N_{\text{PV Type}}$ is the number of PV panel types, $N_{\text{PV\_max}}$ is the maximum number of PV panels connected in parallel, $N_{\text{PV\_min}}$ is the minimum number of PV panels connected

Table 13: Energy balance for one year/PV-biodiesel-battery hybrid system.

No.	E_{PV} (kWh/year)	E_{Excess} (kWh/year)	$E_{Battery}$ (kWh/year)	$E_{AC\,gen}$ (kWh/year)
1	303.656	54.545	123.716	8.850
2	303.656	54.706	123.725	9.021
3	309.729	58.999	124.616	7.350
4	309.729	54.938	127.514	3.570
5	309.729	58.999	124.616	7.350
6	315.803	63.054	125.731	5.490
7	315.803	64.286	124.939	6.634
8	321.876	67.637	126.368	4.080
9	327.949	73.610	126.238	3.999
10	327.949	77.442	123.352	7.590

in parallel, N_{Batt_maxp} is the maximum number of batteries connected in parallel, N_{Batt_minp} is the minimum number of batteries connected in parallel, and N_{ACG} is the number of AC generator types.

The target is to minimize the NPC and total CO_2 emissions together. So, the best combination is a Pareto point including the two aforementioned objective functions. The choice of multiobjective optimization must be selected inside the software.

3.3.2. Net Present Value (NPV). The net present value (NPV) is one of the objective functions to be optimized in this paper. It is computed during the system's life span for each year in the cash flow, and it is updated to the present time as shown in the following [36].

$$\begin{aligned} \mathrm{NPV}_{i,k} = &\sum_j \left(\mathrm{Cost}_j + \mathrm{NPC}_{\mathrm{rep}_j} + \sum_{y=1}^{\mathrm{Life_{HS}}} \left(\mathrm{Cost}_{\mathrm{O\&M\_}j} \frac{(1+\mathrm{Inf_{gen}})^y}{(1+I)^y} \right) \right) \\ &+ \sum_{y=1}^{\mathrm{Life_{HS}}} \left(\frac{\mathrm{Cost}_{F_y}}{(1+I)^y} \right) + \sum_{y=1}^{\mathrm{Life_{HS}}} \left(\frac{\mathrm{Cost}_{\mathrm{purch\_}E\mathrm{\_}y}}{(1+I)^y} \right) \\ &- \sum_{y=1}^{\mathrm{Life_{HS}}} \left(\frac{\mathrm{Incomes}_{\mathrm{sell\_}E\mathrm{\_}y}}{(1+I)^y} \right) - \sum_{y=1}^{\mathrm{Life_{HS}}} \left(\frac{\mathrm{Incomes}_{\mathrm{sell\_}H2\mathrm{\_}y}}{(1+I)^y} \right) \\ &+ \mathrm{Cost_{INST}}, \end{aligned} \tag{7}$$

where y is the year number.

3.3.3. Levelized Cost of Energy (LCOE). The levelized cost of energy (LCOE) can be calculated during the plant's lifetime using the following.

$$\mathrm{LCOE}_{i,k} = \frac{\mathrm{NPC}_{i,k}}{\sum_{y=1}^{\mathrm{Life_{HS}}} \left[\sum_{t=0}^{8760\,\mathrm{h}} E_{\mathrm{load}_y}(t) \cdot (1+\mathrm{Inf_{gen}})^y / (1+I)^y \right]}, \tag{8}$$

where $E_{\mathrm{load}_y}(t)$ is the load consumption per year step, $\mathrm{Inf_{gen}}$ is the annual expected inflation, and y is the year number.

3.3.4. Fuel Consumption of the Diesel Generator. The software gives the option of reading and editing the fuel consumption coefficients A and B which are related to the following.

$$\text{Fuel consumption } (L/h) = \mathrm{Pn} \times B + P_o \times A, \tag{9}$$

where Pn is the nominal power (kW), P_o is the operational power at a certain instant (kW), B is the nominal power coefficient (L/kWh), and A is the operational power coefficient (L/kWh).

The coefficients are selected from the database of the program to be 0.246 and 0.08145 for A and B, respectively.

4. Results

In this section, optimization results are presented for different multiobjective choices considering the NPC and CO_2 emissions.

4.1. Diesel Fuel. The NPC cost ranges from 615,245.4 € to 1,015,044 €, while the CO_2 emission value ranges from 14,045.57 kg/year to 19,983.27 kg/year for the 6th and 9th combinations, respectively. On the other side, the LCOE ranges from 0.11 € to 0.18 € for the 10 combinations as shown in Table 8.

The bold point in Figure 6 underlines the optimum value for the couples of NPC and annual CO_2 which represents 781473.6 € and 15140.58 kg/year. It is worth noting that any motion to the right of the optimum point will cause a sharp change in the NPC; on the other side, any motion to the left of the optimum point will cause a sharp change in the CO_2 emissions.

According to the analysis of the PV size, the ranges are from 212.5 kWp to 221 kWp where the number of panels in series is constant (17) and the variation in the size is due to the change in the number of panels in parallel which ranges from 50 to 52.

The total capacity of the battery bank ranges from 403.200 kWh to 907.200 kWh where the numbers of batteries in series are not the same for all combinations due to the differing battery type and capacity where there are two capacities (63 Ah and 189 Ah).

Table 14: Best solution/PV-biodiesel-battery hybrid system.

PV system size	212.5 kWp
Panel type	PV panels Munchen: MSP250AS-3 (250 Wp)
Module configuration	17s.× 50p
Azimuth angle	0
Tilt angle	60
Renewable energy share (PV)	96.09%
Battery type and capacity	Batteries Solax: triple power 6.3 kWh (63 Ah)
Battery configuration	4s.× 17p
AC generator	AC gen diesel 15 kVA
Number of AC generators	2
Inverter type	Generic: 50 K CH
Rectifier	Included in the bidirectional inverter
PV battery charge controller	Included in the bidirectional inverter
Unmet load	0%
Levelized cost of electricity	0.11 €/kWh
Control strategy	Cycle charging continues up to SOC_{stp}, SOC min batteries = 10%

The optimal capacity of the diesel generator is 15 kVA with 509 operating hours of generation and 3641 L/year of fuel consumption. Further, the maximum operating time and fuel consumption are 1027 hr and 3472 L/year. The hours of operation and fuel consumption ranges are 96 hr-1027 hr and 619 L/year-3472 L/year, respectively.

According to Table 9, the energy generated by the PV power plant ranges from 303.656 kWh/year to 315.803 kWh/year. The excess energy varies between 46.557 kWh/year and 67.390 kWh/year for the 6th and 10th combinations, respectively; regarding the stored energy, it ranges from 122.278 kWh/year to 129.344 for the 10th and 6th combinations. The energy delivered by the AC generator ranges from 1.890 kWh/year to 10.602 kWh/year for the 6th and 9th solutions, respectively. The specifications of the best solution are shown in Table 10.

Both Table 11 and Figure 7 show the cost breakdown for the hybrid PV, diesel, and battery configuration, and it can be seen that the cost of batteries appears as the dominant compared to other system costs.

According to Figure 8, the AC generator works long times in January and March; medium times in February, May, November, and December; and few times in April, June, and July and does not work yet in August, September, and October.

4.2. PV-Biodiesel-Battery Hybrid System. The NPC cost ranges from 621,474.1 € to 840,217.4 €, while the CO_2 emission value is between 13,206.29 kg/year and 15,488.09 kg/year for the 4th and 2nd combinations, respectively. On the other side, the levelized cost ranges from 0.11 € to 0.15 € for the 10 combinations as shown in Table 12. It is worthwhile mentioning that the combination with the maximum NPC resulted in a minimum CO_2 release and vice versa.

Table 15: Cost breakdown (best solution)/PV-biodiesel-battery hybrid system.

Total cost of the system (NPC)	624,408.2 €
Cost of PV (NPC)	150,578 €
Cost of batteries (NPC)	349,014 €
Cost of AC generator (NPC)	12,886 €
Fuel cost (NPC)	43,673 €
Inverter cost (NPC)	54,849 €
Others	13,408 €

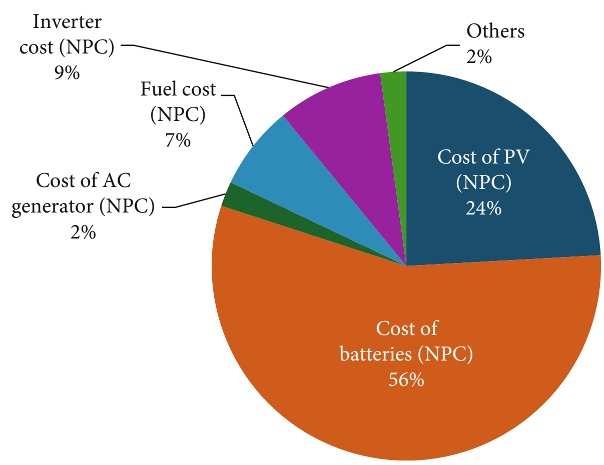

Figure 10: Cost breakdown (best solution)/PV-biodiesel-battery hybrid system.

The bold point in Figure 9 represents the optimum values for the NPC and annual CO_2 emissions which are 624,408.2 € and 15,392.35 kg/year. It is worth noting that moving to the right of the optimum point will cause a sharp change in the NPC; on the other side, any motion to the left of the optimum point will affect largely CO_2 production.

Further, the PV array size ranges from 212.5 kWp to 229.5 kWp where the number of series panels is constant (17). However, size variation is due to the variant number of parallel panels which range from 50 to 54.

The total capacity of the battery bank ranges between 428.4 kWh and 680.4 kWh. What is more, the number of series connected batteries diverges from one combination to another due to the different types of batteries and their capacities (63 Ah and 189 Ah).

The best solution for the diesel generator size is 15 kVA with 903 hours of operation and 3009 L/year fuel consumption. However, the peak time of operation and fuel consumption are 903 hr and 3067 L/year, respectively. The hours of operation and fuel usage vary from 196 hr to 903 hr and 1214 L/year to 3067 L/year, respectively.

According to Table 13, the energy generated by the PV generator ranges from 303.656 kWh/year to 327.949 kWh/

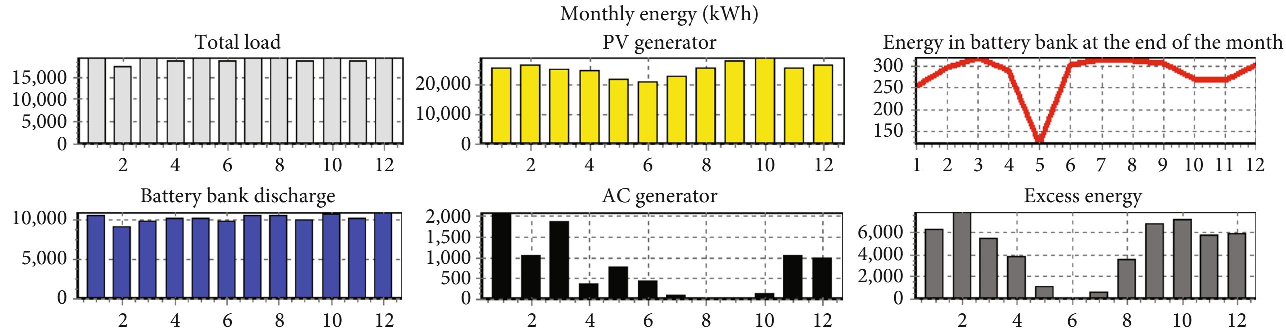

Figure 11: Monthly power data/PV-biodiesel-battery hybrid system.

Table 16: Optimization outputs/PV-WVO-battery hybrid system.

No.	NPC (€)	CO_2 emissions (kg/year)	Renewable fraction (%)	Lev. cost E. (€/kWh)	Total PV capacity (kWp)	AC. generator (VA)	No. of AC generator	Total battery capacity (kWh)
1	615,310.3	18,844.68	96.09	0.11	208.250	15,000	2	453.600
2	611,959.8	19,034.74	96	0.11	208.250	31,000	1	453.600
3	582,158.5	20,931.78	94.98	0.1	212.500	31,000	1	403.200
4	1,304,024	15,360.32	99.5	0.23	212.500	56,000	2	1285.200
5	1,361,070	15,261.43	99.68	0.24	212.500	56,000	2	1360.800
6	630,768.7	18,101.05	96.61	0.11	212.500	31,000	1	4788.00
7	909,299.3	15,988.42	98.21	0.16	216.750	56,000	2	7560.00
8	601,706.9	20,765.73	95.22	0.11	216750	40,000	1	4284.00
9	1,118,426	15,393.59	98.72	0.2	216.750	82,000	2	8568.00
10	635,159.8	17,551.85	96.93	0.11	216.750	15,000	2	4788.00

year and the excess energy ranges from 54.545 kWh/year to 77.442 kWh/year for the 1st and 10th combinations, respectively; regarding the stored energy, it ranges from 123.352 kWh/year to 127.514 for the 10th and 4th combinations. The energy delivered by the AC generator ranges from 3.570 kWh/year to 9.021 kWh/year for the 4th and 2nd solutions, respectively. The specifications of the best solution are in Table 14.

Moving to the biodiesel variant, the batteries improved to 57% compared to other system components as illustrated in Table 15 and Figure 10.

According to Figure 11, the AC generator works long times in January and March; medium times in February, May, December, and November; and few times in April, June, July, and October and does not work yet in August and September.

4.2.1. PV-WVO-Battery Hybrid System. The NPC ranges from 582,158.5 € to 1,361,070 €, while the CO_2 production ranges from 15,261.43 kg/year to 20,931.78 kg/year for the 5th and 3rd combinations, respectively. On the other side, the levelized cost varies from 0.11 € to 0.24 € for the 10 combinations as shown in Table 16.

The optimum value for the NPC and annual CO_2 couple is 615,310.3 € and 18,844.68 kg/year, as represented by the bold point in Figure 12. It is worth noting that any deviation from the optimal point results in a significant change either for the NPC or the CO_2 release.

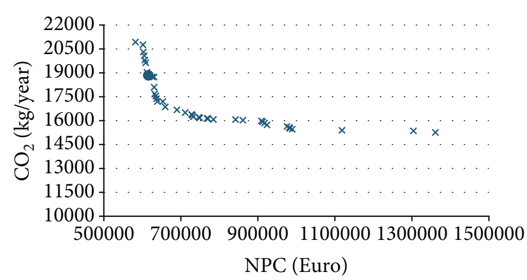

Figure 12: NPC-CO_2 emissions/PV-WVO-battery hybrid system.

The lower and upper limits of the PV array size are 208.250 kWp to 216.750 kWp, respectively. The number of series connected panels is constant (17), and the variation in the size is due to the change of the number of parallel panels which ranges from 49 to 51.

The total capacity of the battery bank ranges from 403 kWh to 1360.8 kWh where the combinations are not with the same numbers of series batteries. The reason behind that is the different battery types and capacities where there are three capacities (63 Ah, 126, and 189 Ah).

Table 17: Energy balance for one year/PV-WVO-battery hybrid system.

No.	E_{PV} (kWh/year)	E_{Excess} (kWh/year)	$E_{Battery}$ (kWh/year)	$E_{AC\,gen}$ (kWh/year)
1	297.583	48.080	124.326	8.850
2	297.583	48.259	124.364	9.052
3	303.656	56.796	122.020	11.377
4	303.656	45.828	130.254	11.29
5	303.656	45.407	130.409	0.720
6	303.656	52.905	124.998	7.688
7	309.729	54.980	128.484	4.056
8	309.729	62.229	123.506	10.817
9	309.729	53.788	128.976	2.910
10	309.729	58.200	125.088	6.960

The best solution for the diesel generator size is 15 kVA with 902 hr and 3009 L/year for the number of operating hours of generation and fuel consumption, respectively. The longest time of operation and highest fuel consumption are 902 hr and 3868 L/year where their ranges are 20 hr-902 hr and 271 L/year-3868 L/year, respectively.

According to Table 17, the energy generated by the PV system ranges from 297.583 kWh/year to 309.729 kWh/year, and the excess energy is between 45.407 kWh/year and 62.229 kWh/year for the 5th and 8th combinations, respectively. Regarding the stored energy, it ranges from 122.020 kWh/year to 130.254 for the 3rd and 4th combinations. The energy delivered by the AC generator varies from 0.720 kWh/year to 11.377 kWh/year for the 5th and 3rd solutions, respectively. The specifications of the best solution are listed in Table 18.

Table 19 and Figure 13 show the cost breakdown for WVO along with PV and battery sources.

According to Figure 14, the AC generator works long times in January and March; medium times in February, May, June, December, and November; and few times in April, July, and October and does not work yet in August and September.

Table 18: Best solution/PV-WVO-battery hybrid system.

PV system size	208.25 kWp
Panel type	PV panels Munchen: MSP250AS-3 (250 Wp)
Module configuration	17s.× 49p
Azimuth angle	0
Tilt angle	60
Renewable energy share (PV)	96.09%
Battery type and capacity	Batteries Solax: triple power 6.3 kWh (63 Ah)
Battery configuration	4s.× 18p
AC generator	AC gen diesel 15 kVA
Number of AC generators	2
Inverter type	Generic: 50 K CH
Rectifier	Included in the bidirectional inverter
PV battery charge controller	Included in the bidirectional inverter
Unmet load	0%
Levelized cost of electricity	0.11 €/kWh
Control strategy	Cycle charging continues up to SOC_{stp}, SOC min batteries = 10%

Table 19: Cost breakdown (best solution)/PV-WVO-battery hybrid system.

Total cost of the system (NPC)	615,310.3 €
Cost of PV (NPC)	147,763 €
Cost of batteries (NPC)	368,621€
Cost of AC generator (NPC)	12,881 €
Fuel cost (NPC)	17,705 €
Inverter cost (NPC)	54,849 €
Others	13,491 €

5. Discussion

The generator is the key component of the system since it serves the charging station in critical situations such as period 7-10 AM especially in winter, and on the days that have low irradiation, the generator supports the PV system and tries to charge the batteries; also, during the night, it sometimes carries the whole demand. The generator in the three scenarios worked a few hours in July, August, September, and November due to the high available energy from the PV generator during these months. On the other hand, the generator works at significant intervals due to the lower available energy that comes from PV generator compared to the previous months and adds to the number of night hours in winter, so the generator supports the charging station at these periods.

It is worth mentioning that the dilemma in all scenarios is the battery bank cost since it represents 53%-57% of the NPC of the hybrid system although the diesel generator

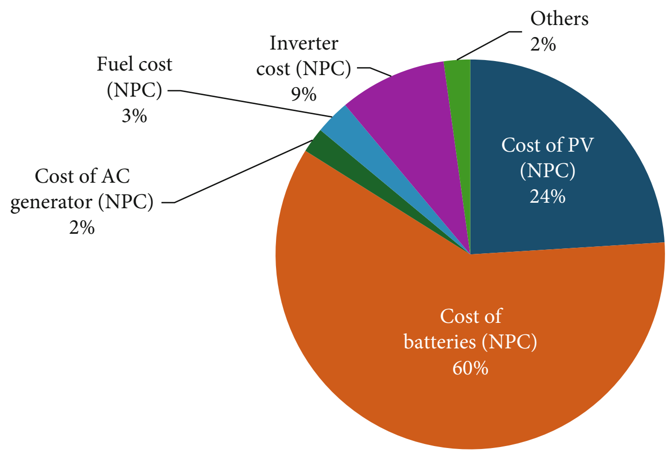

Figure 13: Cost breakdown (best solution)/PV-WVO-battery hybrid system.

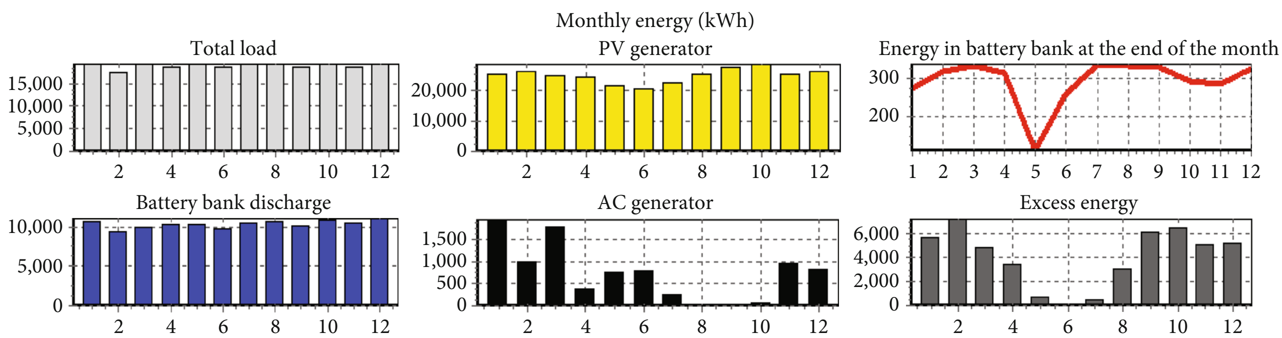

Figure 14: Monthly energy data/PV-WVO-battery hybrid system.

contributes to reducing the reliance on the battery bank by around 25%. It is not enough to make these hybrid systems compensate the conventional power plants.

If it is assumed that the same load is covered by a conventional power plant (oil, gas, or coal) in the best situation, the CO_2 emissions are 0.5 kg CO_2/kWhe [43], so the total CO_2 emissions will be around 113 ton CO_2/year compared to 19.98, 15.48, and 20.9 ton CO_2/year for the three hybrid systems (diesel, biodiesel, and WVO, respectively) which has lower impacts on the environment compared to conventional power plants.

Locally, the cost of generating one kWhe is 0.15 € [44] compared to 0.11, 0.11, and 0.1 € the three hybrid systems (diesel, biodiesel, and WVO, respectively), so the NPC of conventional plants that covers the same load is around 8549690 € compared to 582158.5 €, 621474.1€, and 615245.4 € for the three hybrid systems (diesel, biodiesel and WVO, respectively).

The main function of multiobjective optimization is to observe a midpoint that satisfies simultaneous low-cost and CO_2 emissions. The best combination in the first scenario (diesel) is 781473.6 € and 15140.58 kg CO_2/year as shown in Figure 12. It is notable that when moving to the right of the optimum value, the NPC increases sharply. However, moving left to the optimum point increases the annual CO_2 emissions. Also, the same is applied to the 2nd and 3rd scenarios which have the combinations 624,408 € and 153,92 kg CO_2/year and 615,310 € and 18,844.68 kg CO_2/year for biodiesel and WVO, respectively, as shown in Figures 8 and 10.

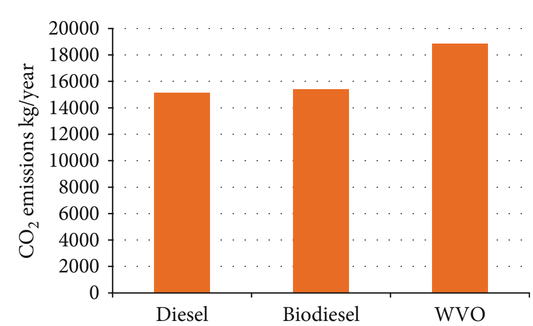

Figure 15: CO_2 emissions/multiobjective optimization.

Figure 15 illustrates that the multiobjective optimization contributed in reducing the yearly CO_2 emissions for the three scenarios. The reduction was significant for systems operating with diesel and WVO (-24%, -10%) due to the high CO_2 emissions for these fuels. On the other hand, the effect was lower on the system that works with biodiesel (0.6%), since biodiesel fuel has lower CO_2 emissions compared to both diesel and WVO.

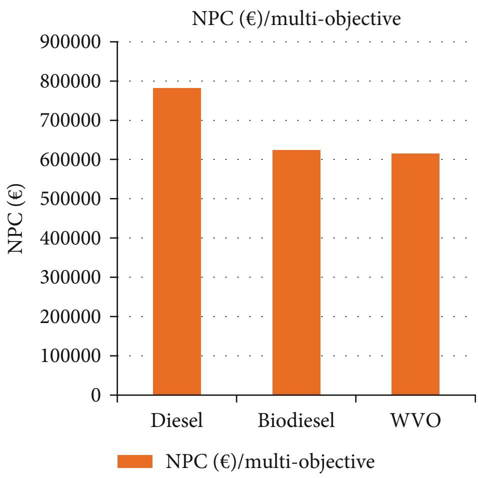

Figure 16: NPC/multiobjective optimization.

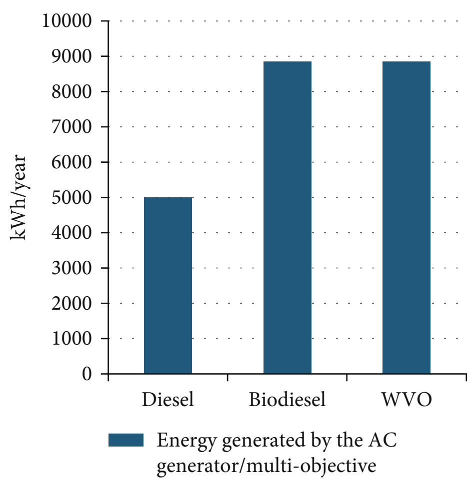

Figure 17: AC generator energy/multiobjective optimization.

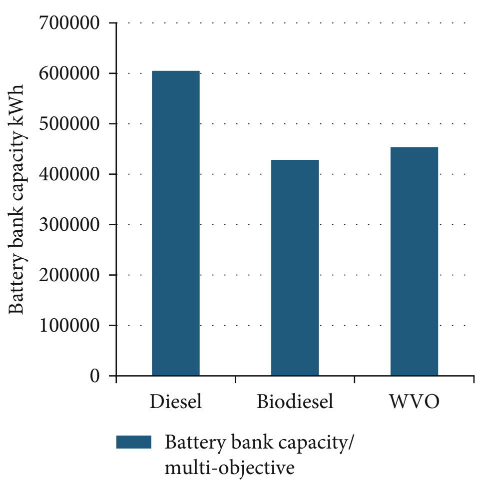

Figure 18: Battery bank capacity/multiobjective optimization.

Figure 16 presents the consequence of CO_2 emission reduction in increasing the NPC for the three scenarios, where a significant increase of 27% is experienced by the diesel system. The explanation for this increase is due to the high cost and CO_2 emissions of diesel systems. However, biodiesel registered a fine increase due to the low CO_2 emissions for biodiesel fuel. Lastly, WVO showed a low-to-medium rise although it has high CO_2 emissions, but it is relatively not expensive.

The results show that the multiobjective optimization resulted in reduced reliance on the diesel generator (Figure 17). In particular, this decrease is noticeable for the systems that work with diesel and WVO fuels in which this reduction appears as an increase in the battery bank capacity (Figure 18). On the other side, the PV-biodiesel-storage system has no change in the battery bank system.

6. Conclusion

The transportation sector in Jordan is experiencing a mature penetration of electric vehicles (EVs), necessitating significant effort to establish the necessary infrastructure. Thus, setting up EV charging stations is crucial in this context. Furthermore, these charging stations' use of renewable energy technology promotes their widespread use. This paper's analysis demonstrated that an environmentally beneficial source of electricity is an EV charging station that runs on a PV-biodiesel-battery hybrid system where the overall generation from the three sources, including the excess expected energy, is around 500 kWh/year. This is because, for the same load demand, its low CO_2 emissions (15 tons/year) are less than those of the typical scenario (113 tons/year). Additionally, the results reveal that the new generation of EV charging stations outperforms the conventional stations in terms of economic benefits, where the levelized cost of energy (LCOE) is 0.11 €/kWh for the new generation compared to around 0.16 €/kWh for traditional ones; this is verified to be lower than the value that have been achieved by Kokchang et al. [24] which is 0.12 €/kWh at the best case. The cost is also lower than the traditional cost that have been found by Shafiq et al. [26] which is 0.2 €/kWh; this is reduced to be 0.015 €/kWh as mentioned, but this is considered only on the on-grid PV system without storage. Also, when comparing the achieved COE here, it is much lower than the COE that is utilized in the best scenario in Vermaak et al. [27] (0.45 €/kWh) where the PV-wind-battery hybrid system is considered. The same thing is applied when comparing it to 0.17 €/kWh which is achieved by Badea et al. [20].

Based on the multiobjective optimization carried out with iHOGA software, all three hybrid system choices show favorable financial and environmental indicators, with some of them performing better financially and others better environmentally. The PV-WVO-battery hybrid EV charging station has low NPC but relatively high CO_2 emissions. Despite having a somewhat high NPC, the PV-diesel-battery hybrid EV charging station might be a good option for nations with low oil prices. Therefore, based on the available information, choosing an EV charging station that uses a PV-biodiesel-battery hybrid system is the most sensible alternative. When compared to a standalone system, the battery system accounts for 56% of the system's total cost, which is a reasonable amount. Furthermore, dependable functioning is ensured by the expertise of utilizing an AC generator coupled with a PV system. Any energy production shortfall from the PV generator or batteries is made up by the AC generator, particularly during the night and early morning hours when solar radiation is not present.

Further future discussion will consider including the biomass combustion, biogas, and wind energy and also link that to the best distribution along with the GIS technology to have the optimum access and with the needed reliability of power supply.

Data Availability

Data is available on request.

Conflicts of Interest

The authors declared that there is no conflicts of interest.

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