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An Investigation of Optimal Power System Designs for a Net Zero Energy House: A Case Study of Kahramanmaraş

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Abstract
This paper aims to optimize the power system design of a vineyard house in Pazarcık, Kahramanmaras. In this process, the electrical energy demand is met by the hybrid Photovoltaic-Wind-Diesel-Battery system because the vineyard house is remote from the electric network. The vineyard house is located in Karagol, southern of Pazarcık. During the summer in Karagol, many people stay in and visit the vineyard houses. However, the vineyard houses are generally unoccupied in winter. Therefore, an economical energy source is required in this process without compromising life quality. Capital costs are high and the running costs are low for stand-alone renewable sources. On the other hand, it is the opposite for stand-alone diesel power generators. This study is designed to take these circumstances into consideration. The optimal design is investigated for a hybrid system of renewable energy sources and a diesel power generator. The Homer software is used during this process. The realized design is evaluated in terms of its technical and environmental aspects. As a result of the study, 6 kW photovoltaic panels, a 1 kW wind turbine, a 1 kW diesel generator, a 2-kW converter, and an optimally sized 8-unit battery system are used to meet the electricity needs of the vineyard house. The renewable energy factor is 99.8% for a vineyard house. This value is an acceptable rate for a net zero energy house. This study shows that the hybrid system meets the house's electric energy demands and has a positive impact on the environment by reducing greenhouse gas emissions.

1. Introduction

The demand for energy in developing countries has been rising due to increased industrial activities and population growth. Therefore, the production of sustainable energy is a necessity for developing countries to meet their energy needs. Despite this, the global consumption of fossil fuels and the production of oil are also increasing day-by-day, leading to excessive greenhouse gas emissions, which has a significant socio-economic impact on the world due to global warming. As a result, it is essential to consider alternative sustainable energy sources in each nation's energy policies. In this context, wind energy and solar energy are among the most effective and efficient renewable energy sources [1]-[4].

The building's massive energy consumption can be attributed to rising living standards and urbanization levels. According to the literature reviewed, the buildings' energy consumption has consisted of a sizeable portion of the energy consumption in the United States, China, and Turkey [5]-[7]. Numerous studies have been conducted on renewable systems such

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as photo voltaic (PV), wind, geothermal, hydro, wave, biomass sources, and hybrid systems made up of a combination of these sources [8]-[16]. Energy systems that combine two or more different energy sources are known as hybrid energy systems. These resources may function in the off-grid or grid-connected modes [17]-[25].

Off-grid diesel generators and solar photovoltaic systems for power generation have different capital and operating costs. Off-grid PV systems have a high initial purchase price and require periodic battery replacements. On the other hand, diesel generators have a lower initial cost but higher fuel and maintenance costs. Off-grid PV systems are widely promoted for use in rural areas to generate cleaner, safer, and more reliable energy [26], [27].

Nowadays, hybrid system installation is completed quickly and easily. If the system is optimized properly, it will be a more effective power source in comparison to others. This situation has led to a great number of hybrid systems being installed around the world. The block diagram of a hybrid wind/PV/diesel system is shown in Figure 1 [28].

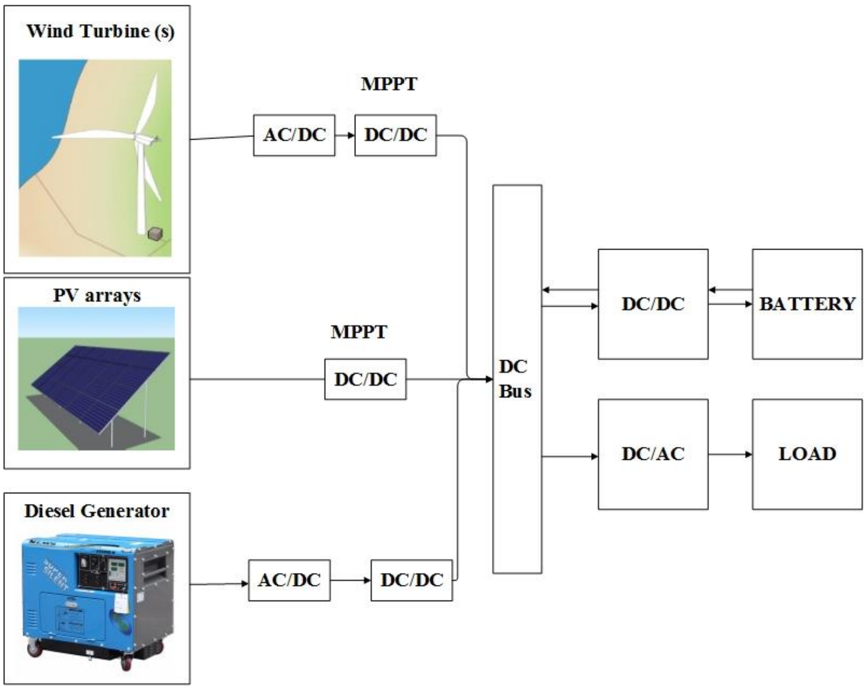

Figure 1. The block diagram of a hybrid wind/PV/diesel system

The aim of the present study is to model a net-zero energy system to meet the demands of a vineyard house. For this purpose, the study was carried out for a vineyard house in Pazarcık (Kahramanmaras). The optimal power system design is realized. The results of the study are evaluated from technical and environmental standpoints, and the energy production of the hybrid system is analyzed to determine whether it is sufficient. Homer optimal sizing software is employed throughout the study.

2. Material and Method

This section is composed of three parts. The first part includes the climate values and site data of Karagol. The second part presents the energy demand of the vineyard house. The third part is composed of the Hybrid Wind-PV-Diesel-battery system simulation with the Homer software.

2.1. Site and Data Collection

The investigation site is located in Karagol, Kahramanmaras, Turkey (Latitude: 37° 29' 06.41” N, Longitude: 36° 46' 57.25 E”, Altitude: 1601m). The solar radiation values and average wind speed of Karagol are given in Table 1. In this table, it can be seen that the average wind speed reached maximum values during the summer months. The global radiation map of Kahramanmaras is given in Figure 2. In this figure, the global radiation values vary approximately between 1600 KWh/m^2-year and 1750 KWh/m^2-year depending on the location.

The global radiation value is approximately 1600 KWh/m^2-year in Karagol.

Table 1. The Solar radiation values and average wind speed of Karagol [29]

	Horizontal Global Irradiation kWh/m^2	Horizontal Diffuse Irradiation kWh/m^2	Horizontal Beam Irradiation kWh/m^2	Ambient Temperature °C	Wind Velocity m/s
January	69.1	30.35	38.7	-1.10	2.2
February	80.6	42.08	38.5	0.49	2.4
March	132.6	59.00	73.6	5.54	2.7
April	165.7	61.72	104.0	9.84	2.7
May	204.1	65.42	138.7	15.37	2.7
June	238.3	62.62	175.7	21.23	3.4
July	247.8	55.82	191.9	25.49	3.6
August	227.9	50.52	177.4	24.85	3.0
September	177.9	41.97	136.0	19.25	2.6
October	129.4	39.13	90.3	13.46	1.9
November	84.9	30.48	54.4	5.58	1.9
December	67.7	27.31	40.3	0.48	2.1
Year	1826.1	566.41	1296.4	11.77	2.6

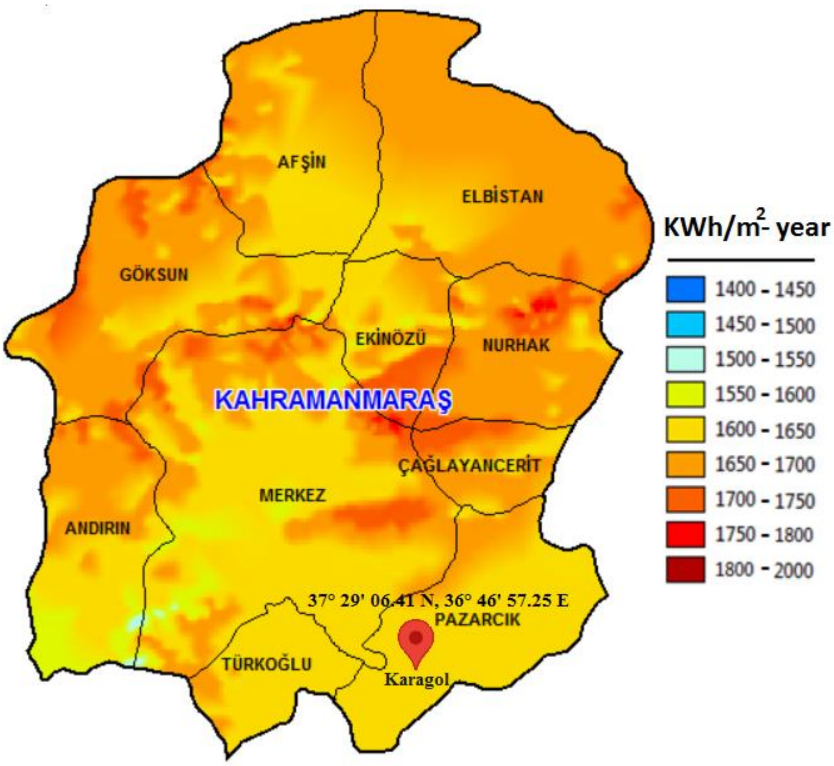

Figure 2. For the map of Karagol, Kahramanmaras (Turkey) [30]

2.2. Energy Demand

There is no national electric grid network connection at this location. Therefore, the house is to be connected to a proposed hybrid system. The hybrid system consists of photovoltaic, wind turbine, and diesel generator. The aim of this system is to economically meet the energy needs compromising the quality of life.

The vineyard houses are completely full during the summer months due to the climate conditions. At this time, energy demand is at a very high level. Table 2 shows the energy demand for a typical vineyard house. By looking at Table 2, it can be seen that the daily, weekly, monthly, and yearly energy needs of the vineyard house are 10.5 KWh, 73.503 KWh, and 315.013 KWh, respectively. For example, 15 pieces of LED lighting are used for approximately 7 hours a day. The daily, weekly, and monthly energy consumption of LED lighting is 1050 Wh, 7350 Wh, and 315000 Wh, respectively. The daily energy distribution profile is shown in Figure 3. The energy demand peaked between 11:00 and 13:00 hours because of the intensive use of dishwashers and washing machines.

In Figure 3, the peak hour demand time coincided with the most productive hours of solar radiation, which reduces the need for batteries, leading to a reduction in energy costs. The primary sources of energy at this timeare sun throughout the day and the wind in the evening.

Figure 4 shows the monthly energy demand profile of the vineyard house. The annual energy demand of the vineyard house is 3832.5 kWh.

Table 2. Energy demand of vineyard house

	Power (Watt)	Piece (s)	Duration of energy consumption (hour/ day or week)	Energy		
			Daily	Daily	Weekly	Monthly
LED lighting	10	15	7 h/day	1050Wh	7350Wh	31500Wh
TV	80	1	4 h/day	320Wh	2240Wh	9600Wh
Computer	80	2	4 h/day	640Wh	4480Wh	19200Wh
Refrigerator	25	1	24 h/day	600Wh	4200Wh	18000Wh
House Appliances	105	5	5 h/day	2625Wh	18375Wh	78750Wh
Washing Machine	1000	1	5.4 h/week	771Wh	5400Wh	23143Wh
Dishwasher	900	1	2 h/day	1800Wh	12600Wh	54000Wh
Other	2694	1	1 h/day	2694Wh	18858Wh	80820Wh
Total				10500 Wh	73503Wh	315013Wh

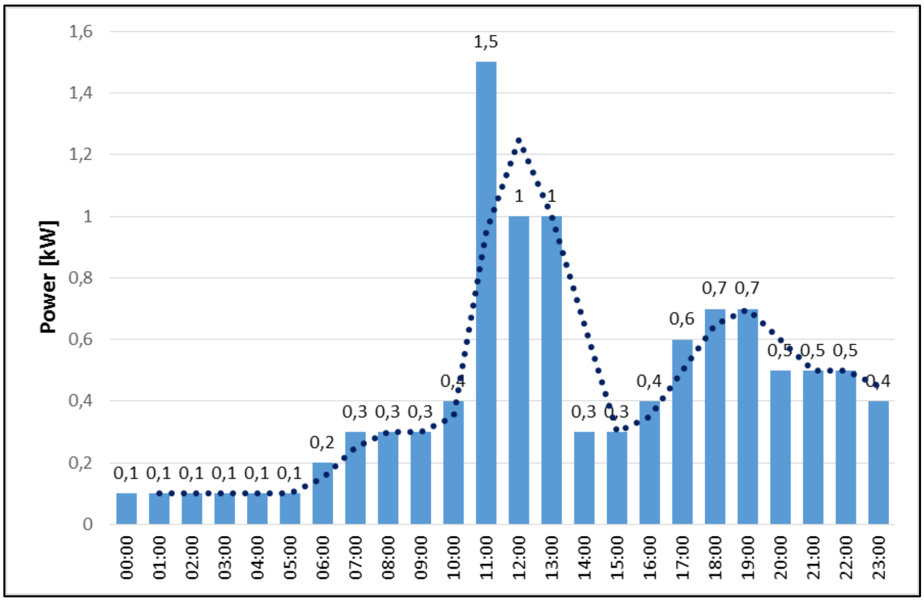

Figure 3. Daily energy demand

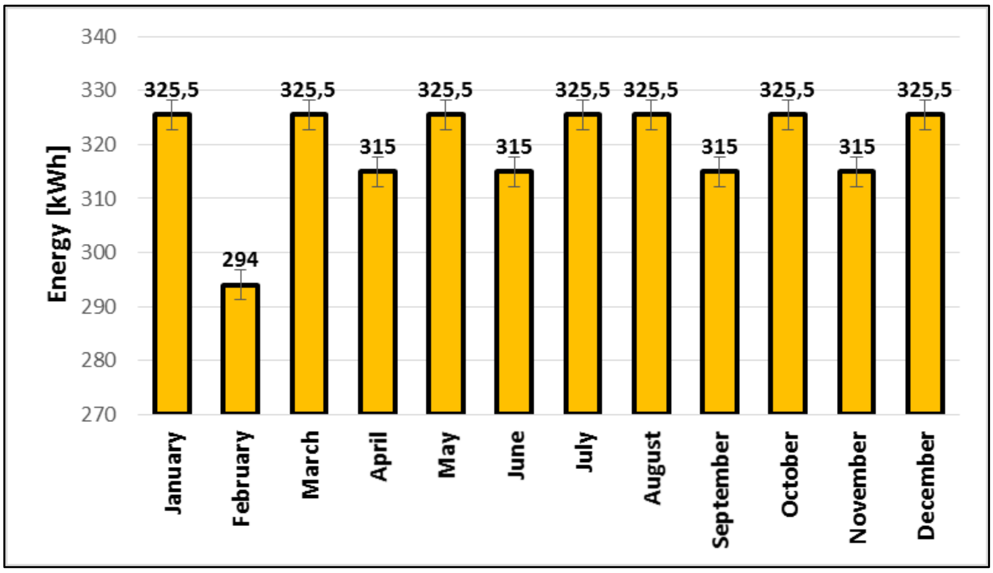

Figure 4. Monthly energy demand

2.3. Optimal Sizing

a global standard in micro grid software. This program is used to design and implement micro grids and distributed power systems. Renewable energy sources, storage, and fossil-based power generation are connected to the power systems in the design process. Simulation and optimization analysis can be performed on the systems designed through the program. The climate and measurement data for the design were sourced from the NASA database.

The energy needs of the vineyard house are met with the hybrid wind-PV-diesel-battery system. The lack of an electricity grid in the vineyard house area explains this. A large amount of the population resides in these houses during the summer season. Thus, there is a need for an economical energy source without sacrificing the quality of life. The capital costs of renewable energy sources alone are very high, while the diesel generator operating costs are even higher. These two systems are used to compose a more economical system design.

Optimal sizing of hybrid wind-PV-diesel-battery systems is considered an economical energy system. The wind-PV-diesel hybrid system for Karagol is realized using Homer optimal sizing software. The wind turbine, PV panels, diesel generator, battery, and converter were modeled and sized using the Homer software program. This model is shown in Figure 5.

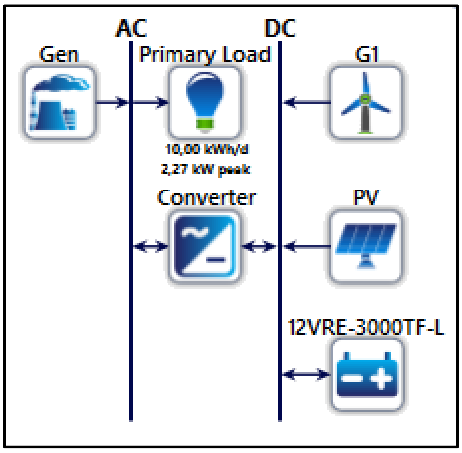

Figure 5. Homer system

The model is designed based on the following assumptions. HOMER's generic diesel generator is used. The diesel price is taken as 1.13 dollars per liter. The generator's lifetime is 15000 hours and the minimum load ratio is 25%. The capacity of the PV panels is 250 W. The current at maximum power point (I_{mpp}) is 8.271 A. Moreover, the voltage at maximum power point (V_{mpp}) is 30.23 V. The converter is 90% efficient and has a 15-year of lifespan. The batteries in this design procedure have a nominal voltage of 12 V with a 245 Ah.

In this optimization, PV panels, wind turbines, power converters, and batteries are used. In this model, various power levels of diesel generators (1,2,3,4,5,6 kW), wind turbines (1, 2, 3, 4 kW), PV panels (0,1,2,3,4,5,6, 7, 8, 9, 10, 11, 12 kW), batteries (0,2,4,6,8,10,12,14,16,18, 20, 22, 24, 26, 28), and converters (1,2,3,4, 5, kW) were tested separately. These combinations help with cost and performance analysis for optimum sizing and 219000 probabilities. Considering the unit cost of energy and capital costs as a result of optimization, the renewable energy factor is calculated as 99.8%. The wind turbine, PV panels, and diesel generator are used in the design. The wind turbine has a capacity of 1 kWp, while PV panels have a capacity of 6 kWp, the diesel generator has a capacity 1 kWp, and the converter has a capacity of 2 kWp. Eight batteries were used to determine dimensions. The total investment cost is \$8,470. And the cost of energy per unit is \$0.264. The Homer software outputs are shown in Figure 6.

Architecture							Cost					System
	PV (kW)	G1	Gen (kW)	12VRE-3000TF-L	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)		Ren Frac (%)
	6,00	1	1,00	8	2,00	LF	0,264 $	12.458 $	308,50 $	8.470 $		100
		4	1,00	10	2,00	CC	1,27 $	59.926 $	4.082 $	7.150 $		35
	8,00	4	1,00		2,00	CC	1,84 $	86.745 $	5.848 $	11.150 $		61
		4	2,00		2,00	CC	5,18 $	244.210 $	18.512 $	4.900 $		0,0

Figure 6. Homer software output

The unit cost of the energy in the PV panels, wind turbine, the total cost of investment, and sizing should be appropriate for real values. The appropriate values from the cost map are shown in Figure 7. In this model, environmental effects have been taken into account as well as the cost of the energy. Renewable sizing fraction and the CO_2 emission must be optimum for the designed system. The optimum point in the renewable energy map is shown in Figure 8.

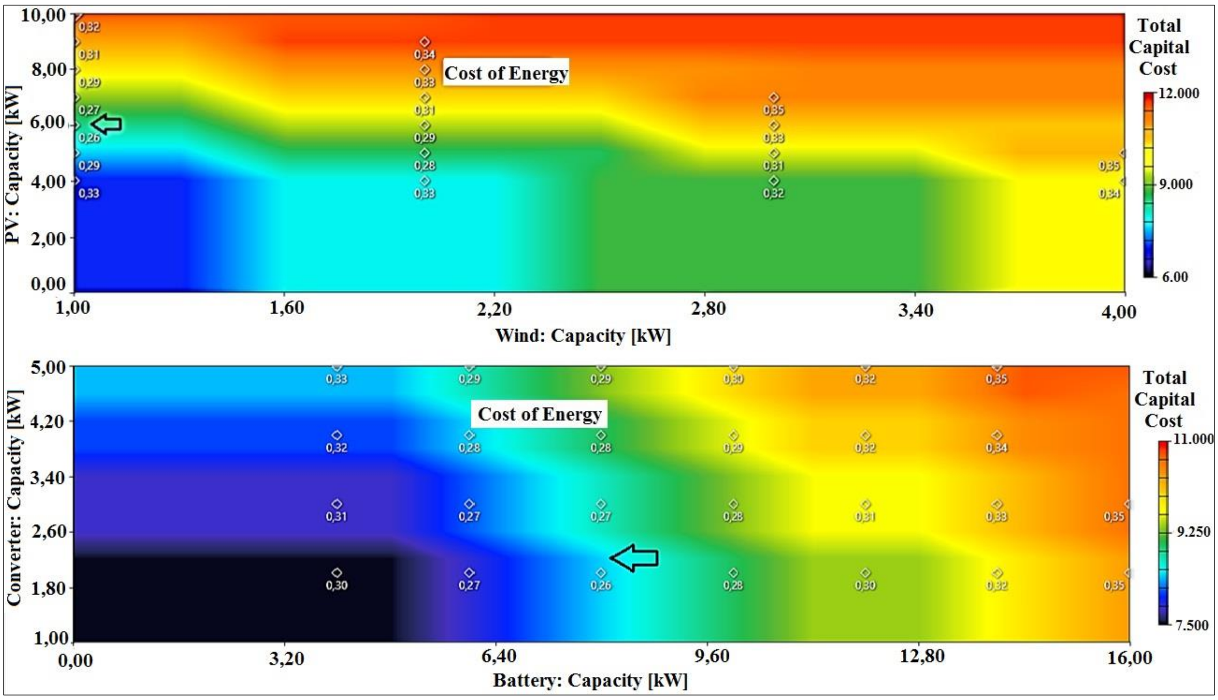

Figure 7. System sizing with the help of cost map

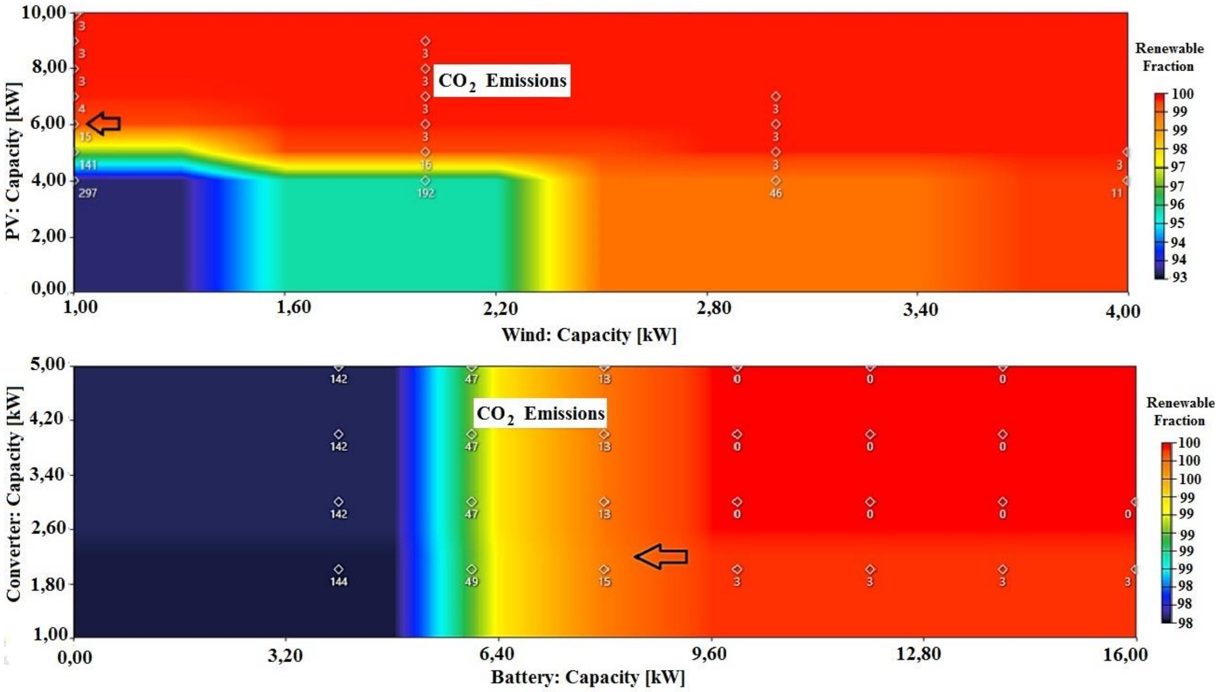

Figure 8. System sizing with the help of renewable energy map

The wind turbine, PV panels, diesel generator, battery, and converter are designed and modeled by Homer software. Figure 9 shows the ideal cost spots. The energy and investment costs are lower at this red circle point. At this point, the total investment cost is 8,470 dollars, and the unit cost of the energy is selected to be $0.264. Figure 10 shows the ideal spots in terms of cost and renewable energy factors.

The 24 solar panels totaling 240 W, 1 kW wind turbine, 1 kW diesel generator, 2 kW converter, and 8-unit 245 Ah batteries make up the optimal hybrid system. PV panels are connected in parallel. Batteries are connected in series in pairs, consisting of four parallel groups. The operating voltage of the battery is 24 volts.

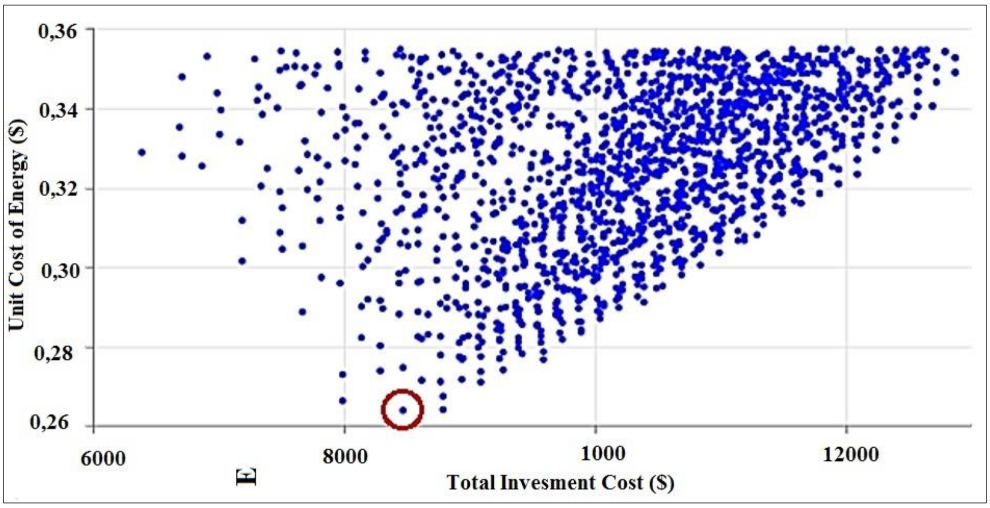

Figure 9. The ideal cost spots

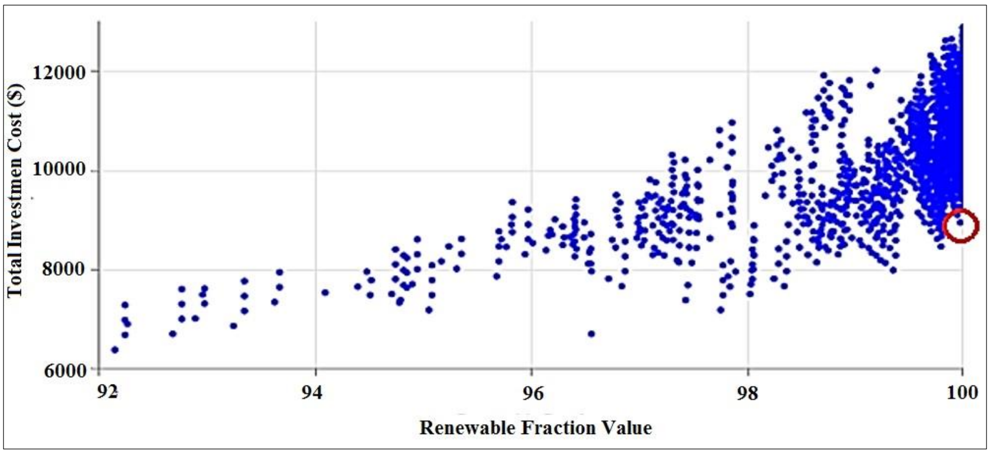

Figure 10. The ideal spots in terms of cost and renewable energy factor

3. Results and Discussion

The investment cost of the wind-PV-diesel-battery hybrid system is $8,470. Nowadays, this cost is considerably high because of the dollar exchange rate. However, the energy demand needs to be met throughout the years. The annual energy demand is 3832.5 kWh, the average daily energy demand is 10.5 kWh, the average hourly energy is 0.44 kW, and the peak energy demand value is 2.38 kW. PV panels have annual energy production of 8817 kWh, a wind turbine has an annual energy production of 589 kWh and a diesel generator has an annual energy production is 8 kWh. The annual energy demand is met by 93.66% from PV panels, 0.8% from the diesel generator, and 6.26% from the wind turbine. Additionally, 1877 kWh of energy is stored in the batteries annually and the 1613 kWh of energy is used from the batteries annually. PV panels have produced 4232 hours and 5.88 kW of electrical energy. The diesel generator used 5.8 liters of diesel for 26 hours of operation per year. The nominal capacity of the battery is 15 kWh and it provided the system with 1613 kWh energy.

An area with strong radiation in the mornings and afternoons and strong winds during the evenings is an excellent candidate for a hybrid wind-PV-diesel-battery system. PV panels will be used to meet energy needs in the morning, and the wind turbine will provide the needed energy during the evening. In cases where the energy requires battery storage, diesel generator will be activated to meet the power need. It is desirable to use more renewable energy sources. The cost-efficient diesel generator will be used very sparingly during the year. Furthermore, the renewable energy factor is calculated at 99.8%. The high amount of unused energy is stored to use during times when adverse weather conditions cause a demand for higher energy. In the summer, the excess energy can be used in areas with irrigation and for other energy needs. Annually, an excess of 5094.8 kWh of energy is produced. This energy is used for irrigation, particularly in rural areas. Another option to reduce excess energy is by selecting smaller PV panels. However, this will not be economical in the long run considering the life span which is 20-25 years. The monthly change of energy sources is shown in Figure 11. Wind speed and change by month according to the amount of radiation are given in Figure 12.

The diagram obtained by modeling of the hybrid system under annual Karagol conditions is given in Figures 13. This figure shows that global solar radiation is rampant in Karagol, especially during the summer. The maximum radiation value is 1.3 kW per meter square. The summer season offers more than 12 hours of radiation each day. Although wind is available throughout the day, it is more abundant in the evening. In the evening, the maximum wind speed is over 17m/s. The hourly maximum output of the PV panels is 5.58 kW.

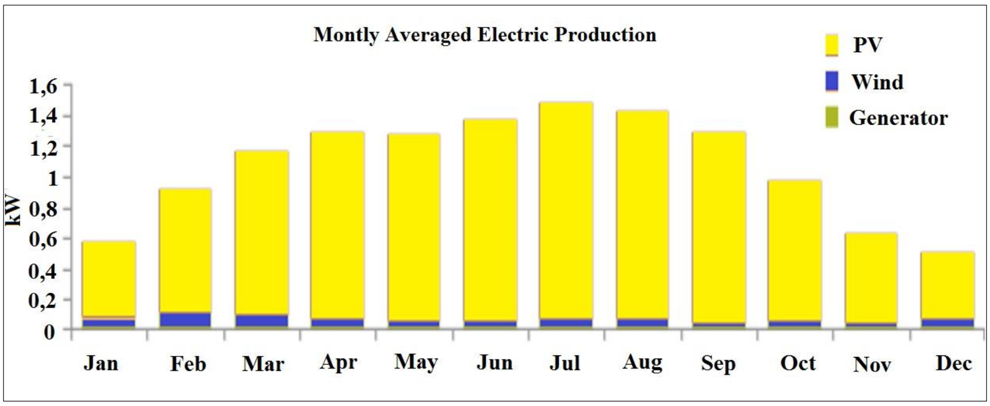

Figure 11. Monthly change of energy sources

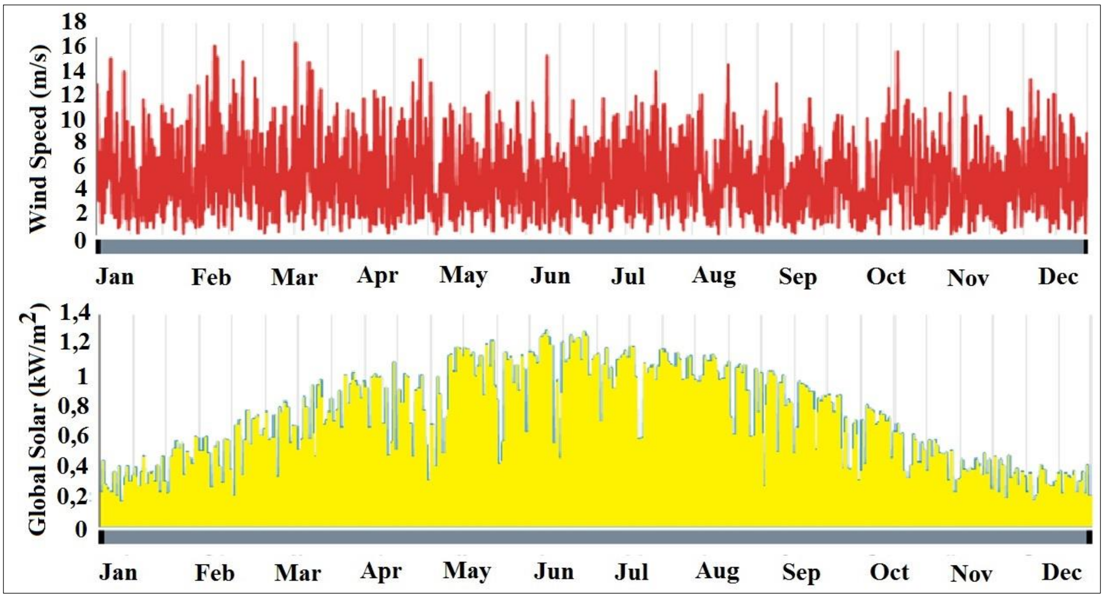

Figure 12. Changing of wind speed and radiation

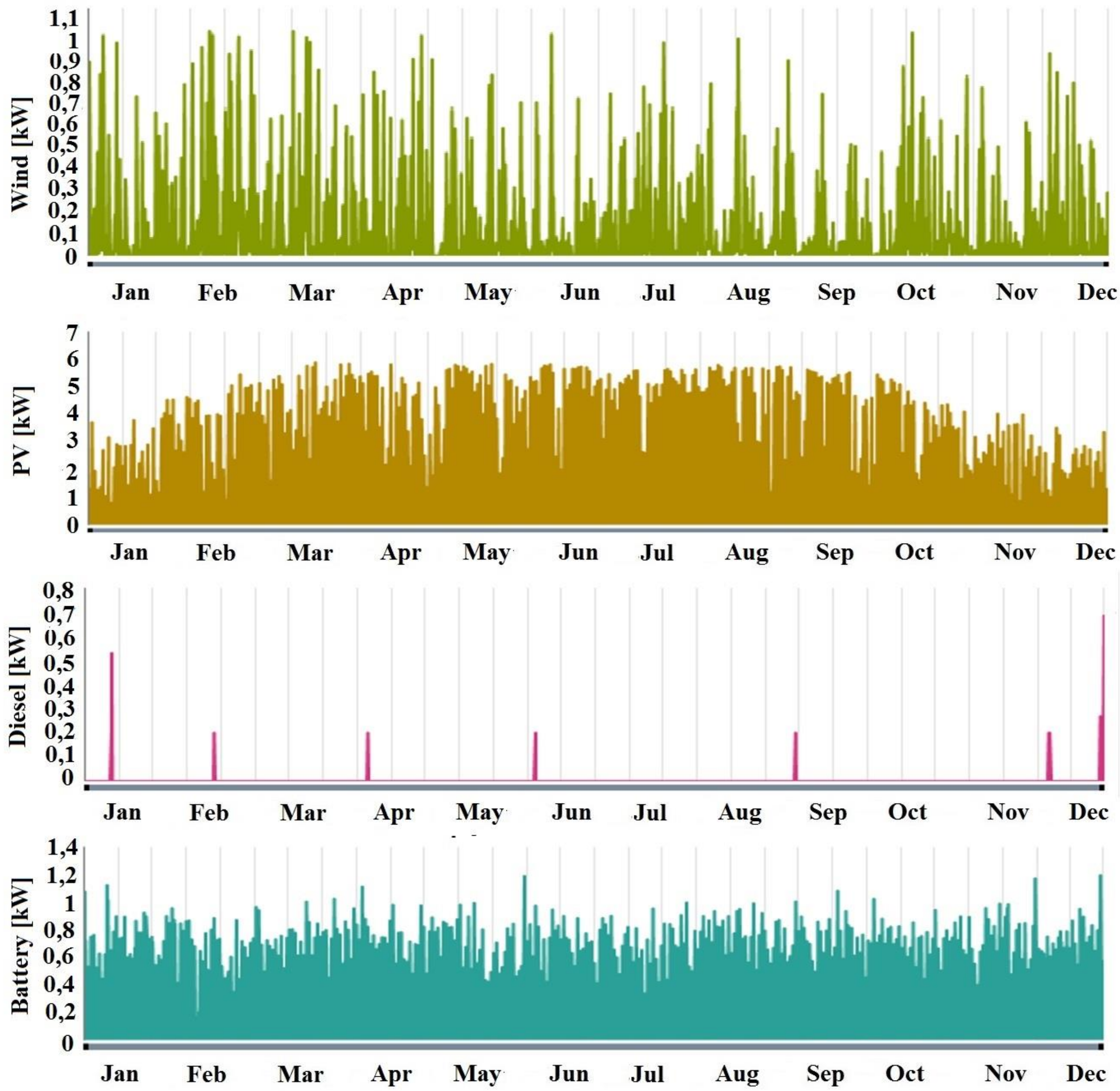

Figure 13. Energy sources for power generation in year

4. Conclusion and Suggestions

In this study, the energy requirement of the vineyard house in Pazarcık, Kahramanmaras (Turkey) is modeled using a wind-PV-diesel-battery hybrid system, as accessing the electricity grid in the remote rural areas of the vineyard houses is not economical. These vineyard houses are generally full during the summer. Therefore, they need a reliable energy source. The use of either a renewable source of energy or a diesel generator alone is not cost-efficient. This study modeled a cost-effective optimal sizing of the hybrid system. The results of the study are listed below:

The optimization result showed that the total investment cost is $8,470 and the unit cost of energy is $0.264.

The hybrid system has 6 kW PV panels and a 1 kW diesel generator, a 1 kW win turbine, a 2 kW converter and 8 units of optimally sized battery system. The vineyard house energy demand will be met throughout the year. Photovoltaic panels produce 8817 kWh, a wind turbine produces 589 kWh, and a diesel generator produces 8kWh energy annually.

The annual energy demand is met by 93.66 % from PV panels, 0.8% from the diesel generator, and 6.26% from the wind turbine. Additionally, the 1877 kWh of energy is stored in the batteries annually. 1613 kWh of energy is taken from the batteries annually. The total annual energy demand is 3832.5 kWh and unused energy is stored in batteries. Total renewable production is 99.92%, and renewable energy factor is 99.8 %.

According to International Energy Agency (IEA) report in Turkey, the production of 1 kWh of electrical energy causes a 489 g release of carbon dioxide (CO_2) emissions. In this context, this installed system meets energy need of the house and provides a significant contribution to the environment.

Future studies will be able to implement it using the different hybrid systems for houses of different locations without an electricity grid connection. Furthermore, more optimal and environmentalist designs can be proposed.

Contributions of the Authors

All authors contributed equally to the study.

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics

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