DETERMINATION OF THE OPTIMUM RENEWABLE POWER GENERATING SYSTEMS FOR AN EDUCATIONAL CAMPUS IN KIRKLARELI UNIVERSITY

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Abstract

This paper is to investigate whether the energy demand of Pinarhisar educational campus in Kırklareli University is fully met by using various types of the renewable power generating systems and also search for the optimum configuration of the hybrid power generating systems. Wind speed and solar radiation data measured in an hourly time-series format are used based on 2 years between 2008 and 2010, respectively. Three different renewable power generating systems, standalone PV- Battery and standalone Wind-Battery and standalone PV-Wind systems, are analyzed in detail by using HOMER software and compared among themselves considering COE, total NPC. Additionally, sensitivity analysis is performed considering three different wind speed values because of the wind's instable nature. According to the study results, the optimal configuration with the lowest total net present cost (NPC) and cost of energy (COE) contains one wind turbine, 36 batteries, a 6 kW converter and the 14kW PV array under the current conditions in Pinarhisar region (average wind speed and average solar global irradiance are almost 3.94 m/s and 4.98 kWh/m^2/d, respectively.). Finally, this study also searches for how much NPC and COE values of the hybrid power generating systems show a tendency of increasing or decreasing remarkably based on the amount of the change in the (variable and unstable stable) wind speed.

Keywords: Renewable Power Generating Systems, COE, NPC, Optimization

Introduction

Renewable energy is a well-established technology, and it is a domestic resource that has the potential to contribute to the supply. It is becoming increasingly evident that renewable energy technologies have a strategic role to play in the achievement of the goals of sustained economic development and environmental protection. Renewable energy sources can be easily converted to the electrical energy. They are inexhaustible and offer many environmental benefits over conventional energy sources. Moreover, each type of renewable energy also has its own special advantages that make it uniquely suited to certain applications. Almost none of them release gaseous or liquid pollutants during operation. In their technological development, the renewable ranges from technologies that are well established and mature to those that need further research and development (Saigh,1999; Wrixon, Rooney and Palz,1993; Boyle, 1998; Kaya,2006; Ulgen and Hepbasli,2003).

Among the renewable energy resources, especially, solar and wind energy are more popular than the other renewable resources. Solar and wind energy systems are considered as promising power generating sources due to their availability and the topological advantages in local power generation. However, neither a standalone solar nor a wind energy system can provide a continuous supply of energy due to seasonal and periodical variations. To overcome this limitation, hybrid power systems (which include one or more renewable energy based generating units such as solar and wind generating units) are combined with battery backups to satisfy the load demand (Moharil and Kulkarni, 2009).

Integrating renewable sources such as wind and/or solar energy into existing diesel plants can achieve considerable fuel savings. Although photovoltaic (PV) or wind power systems are far from being economic in comparison to conventional fossil fuel for providing electricity, they are used in remote areas where it is highly uneconomical to extend the electrical power grid system. Photovoltaic solar energy and wind energy conversion systems have been widely used for electricity supply in isolated locations far from the distribution network or electricity grid. These systems provide a reliable service and can operate in an unattended manner for extended periods of time if they are well designed (Sahin, 2000; Markvart, 1996). Many researchers have contributed papers on solar photovoltaic (SPV), wind and hybrid wind–SPV systems.

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Moharil and Kulkarni presented the performance analysis of solar photovoltaic (SPV) system installed at Sagardeep Island in West Bengal state of India (Moharil and Kulkarni, 2009). Al-Badi assessed the techno-economic feasibility of utilizing a hybrid wind–PV–diesel power system to meet the load of Al Hallaniyat Island, using a Hybrid Optimization Model (Al- Badi, 2011). Balamurugan and his colleagues developed an optimization model for biomass/wind/pv hybrid energy systems to supply the available load demand (Balamurugan et al., 2009). Karaki and his colleagues described the development of a general probabilistic model of an autonomous solar-wind energy conversion system (SWECS) composed of several wind turbines (wind farm), several photovoltaic (PV) modules (solar park), and a battery storage feeding a load. The model took the outages due to the primary energy fluctuations and hardware failure into consideration (Karaki et al., 1999). Shaahid and his colleagues analyzed wind speed and solar radiation data of Rafha, KSA, and assessed the technical and economic potential of hybrid wind-PV-diesel power systems to meet the load requirements of a typical remote village Rawdhat Bin Habbas (RBH) with annual electrical energy demand of 15,943 MWh, using HOMER software (Shaahid et al. 2010). Prasad and Natarajan presented a new method for optimization of a wind–PV integrated hybrid system which is based on deficiency of power supply probability (DPSP), relative excess power generated (REPG), unutilized energy probability (UEP), life cycle cost (LEC), levelized energy cost (LEC) and life cycle unit cost (LUC) of power generation with battery bank. Proposed method is addressed to a specific location and is employed in an iterative scheme (Prasad and Natarajan, 2006). Celik presented yearly system performance of autonomous photovoltaic–wind hybrid energy systems with battery storage and simulated using the predetermined combinations (Celik, 2002). Ulgen and Hepbasli developed a simple model to apply the wind and solar hybrid power generation systems in Izmir, located in the western part of Turkey (Ulgen and Hepbasli, 2003).

In this study, various standalone hybrid system based on wind and solar energy are discussed for the campus of Pinarhisar vocational school of higher education in Kirklareli. Its peak load and average daily load are 5.3 kW per hour and 50 kW per day, respectively. In this context, National Renewable Energy Laboratory's (NREL) HOMER software is used to perform the techno-economic feasibility of hybrid solar and wind energy system based on both solar data and wind data. Additionally, the contribution of solar, wind and battery storage on energy production, cost of energy, and total system cost are examined for various hybrid systems. Furthermore, all hybrid systems are compared with each other regarding the economical parameters (COE, Total NPC) obtained with HOMER. Finally, sensitivity analysis of the hybrid solar-wind energy system is carried out considering various probable wind speed values that covers ones both over and under the average wind speed value.

2. Description of Pinarhisar vocational school of higher education in Kirklareli

Location and Population of the educational campus

Pinarhisar vocational school of higher education is located in the city of Kirklareli in the Northern Marmara region. Its area is 9,000 m^2. Additionally, its student population is about 1000 [16]. The picture of the school building is shown in Figure 1.

Figure 1 The picture of the school building

Load Profiles of the educational campus

Energy requirement of the educational campus is currently supplied by electricity grid. Load data used in this study is obtained from TEIAS. According to the load data, the peak load and average daily load demand of the campus are 5.3 kW per hour and 50 kW per day, respectively. The daily load distribution profile of the campus is indicated in figure 1 created in HOMER software.

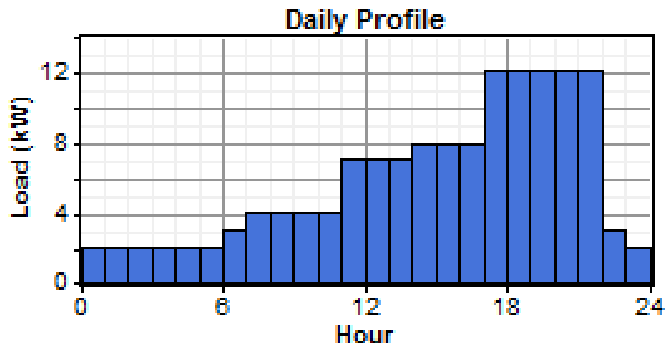


Figure 1 Daily load profile of Pinarhisar vocational school of higher education.

HOMER simulates the operation of a system by making energy balance calculations for each hour in a year (HOMER,2011). The hourly load profiles are not available for a whole year, so HOMER is used to synthesize the load profiles (with randomness) by entering the values for a typical day. Either day-to-day randomness or time-step-to-time-step randomness is taken as 5% in the study.

According to the load data, the minimum load demand occurs between 00:00 and 06:00 o'clock while the maximum value of the load demand is 12 kW/h which occurs between 17:00 and 22:00 due to the existence of the evening education in the school. Load profile of the campus by months is shown in Figure 2.

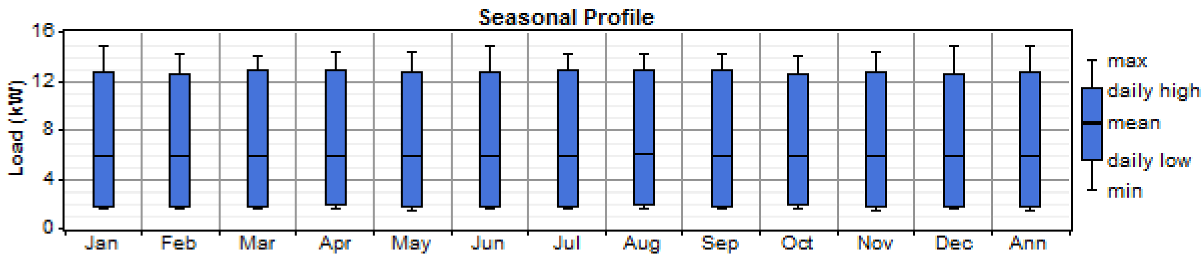


Figure 2 Seasonal load profile of Pinarhisar vocational school of higher education.

Solar Energy Potential of the educational Campus

Solar radiation data of the region where the educational campus is located was obtained from Turkish State Meteorological Service (TSMS) in the year of 2010 (TSMS, 2011). Monthly average solar energy density values are shown in Figure 3. Annual average solar energy density value is calculated as 4.98kWhm^{-2}d^{-1} while the scaled annual average of the clearness index is estimated to be 0.503. HOMER syntheses solar radiation values for each hour of the year by using Graham algorithm. This algorithm produces realistic hourly data, and it can be applied quite easily because it requires only the latitude and the monthly averages.

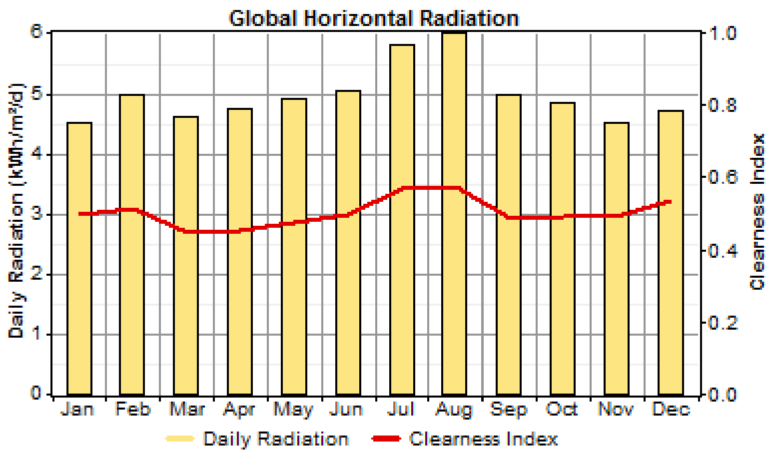


Figure 3 Daily radiation and clearness index profile of the nearest region to the educational campus

Wind energy potential of the educational campus

The hourly wind speed data of the region which is measured at the height of 10m was provided by Turkish Metrological Department. Annually wind speed distribution profile of the nearest region to the educational campus is shown in Figure 4. According to the wind speed data, it is highlighted that wind speed distribution ranges between 3m/s and 5m/s while the regional average wind speed is about 3.94 m/s. Moreover, it is clear that the highest and least wind speed values occur in February and October, respectively.

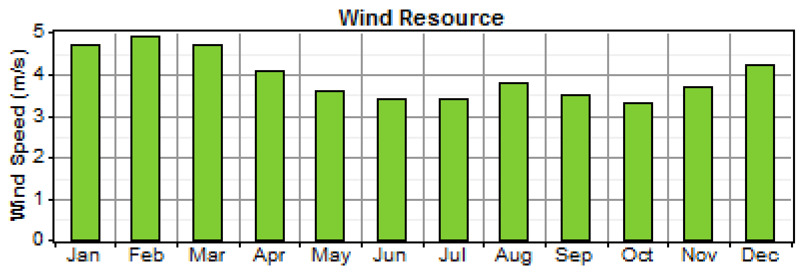


Figure 4 Annually wind speed distribution of the region

Furthermore, Weibul parameters which are called Weibull shape factor, k, and the scale parameter, c, are 2.01 and 4.45 m/s. They are obtained by HOMER software. The wind speed probability density function of the region is shown in Figure 5.

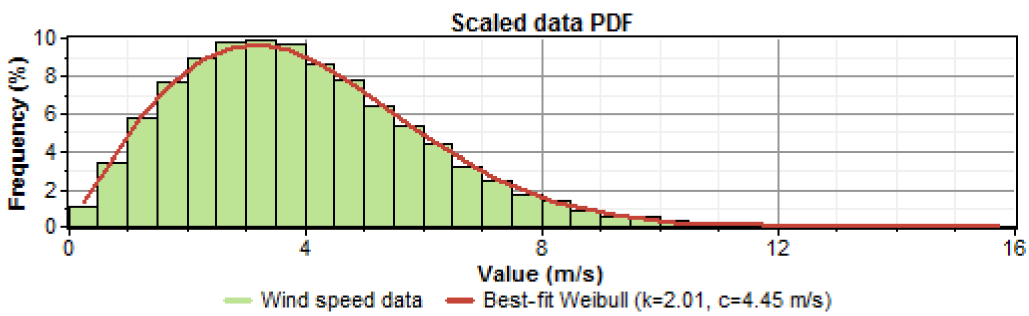


Figure 5 The wind speed probability density function of the region

Component of the Hybrid Systems

In a hybrid PV/Wind energy system, there are four main components such as PV modules, wind turbines (WT), batteries and converter.

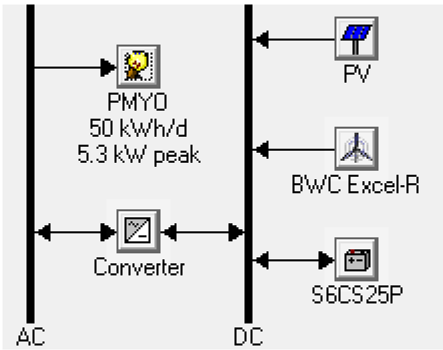


Figure 6 All components of the hybrid system

A hybrid system usually includes generators, photovoltaic modules, wind turbines, inverters and a battery bank. All components of the hybrid system are illustrated in figure 6. In this context, properties of the main components of the hybrid system should be properly determined in order to supply the required user AC load efficiently.

PV Panel

In such a hybrid system, solar energy, one of the abundant renewable energy sources in Turkey, is surely considered as one of the basic load suppliers. Each PV module is rated at 100W, with a 12 V nominal voltage. It should be noted that this PV array can only generate electricity at the day time period from 6 a.m. to 6 p.m. Otherwise, at night period after 6 p.m, there is no electricity generation and thus the output power of the solar energy is 0W. In this period, either the battery or the generators or the wind turbines will take over the task.

For economical analysis, the following assumptions are made by regarding the specifications of PV module available in the reference (CPVM, 2011);

The cost of each kW of PV module is $7200.

The cost of replacement is the same as the initial cost.

Operating and maintenance cost is assumed to be zero since it is negligibly small.

In the HOMER software, the number of the 1kW PV module varies in the range of 0-25 to determine the most feasible configuration of the hybrid system.

Wind Turbine

In the hybrid system, wind energy like solar energy is also one of the abundant renewable energy sources, and, therefore is regarded as one of the basic load suppliers. In order to extract the usable energy form from wind energy, devices such as wind turbines are required and utilized.

If there was a regional AC load demand and wind turbines or PV panels in the hybrid system were generating DC power, the generated DC power firstly would be converted to AC by using inverters, and then it would supply the AC load demand. In the hybrid system, wind turbine is chosen as BWC Excel-R with output power capacity 7.5kW and a lifetime of 20 years (BWC, 2011). Additionally, the initial cost of the wind turbine is $19,000 while its replacement cost equals to 15,000$ and operating and maintenance cost of the described wind turbine is 200$ per year. In the HOMER software, for economical analysis, the number of the wind turbine varies in the range of 0-10 to determine the most feasible configuration of the hybrid system.

Storage battery

The storage battery in the hybrid system is chosen as Surrette 6CS25P. Its nominal capacity is 1156Ah, with nominal voltage of 6V. The amount of energy stored in only one battery is 6.94kWh, which is calculated by multiplying voltage with current capacity. The battery bank is configured to be total 6 strings and two batteries for each sting. Eventually, the battery bank consists of 12 units of battery, with a bus nominal voltage of 12 V. From the datasheet given by the HOMER software, the minimum state of charge of the battery is 40%. Its round trip efficiency is 80%. In HOMER Software, number of battery varies between 12 - 60 batteries with an increment of 12 batteries. The battery's capital cost, replacement cost and operating and maintenance cost are considered to be $ 1100, $ 1000 and $10/year, respectively (DCSS, 2011).

Inverter

Rated power of the inverter is chosen 6 kW because the maximum peak load of 5.3kw per hour must be supplied for the educational campus. It will fully supply both the PV power and the excess power of the wind turbine which will remain after meeting the load demand. Furthermore, the inverter has an efficiency of 90%. Therefore, the supplied power will be less than 6 kW. The initial cost of the inverter is considered to be $900 per kW, which is the same as the replacement cost. In addition, there is no operating and maintenance cost estimated.

Operational principles of the hybrid system

<u>The designed system will take the following principles and assumptions into the consideration:</u>

Wind turbines and PV arrays which are the basic load suppliers, will charge the battery bank when there is an excess power remaining after meeting the load demand.

Since output power of PV modules and wind turbines is in DC mode, they must be converted to the AC power by using an inverter so that it can be utilized to meet the AC load demand.

If PV module and wind turbines cannot meet the demand, the battery bank will not be charged, but will be discharged to supply the demand.

The operating reserve of hourly load is 10%. Meanwhile, the operating reserves of renewable output are 25% for solar output power and 40% for wind output power. It should be noted that operating reserve means safety margin that enables the reliable power supply despite the variability of the electricity load, solar power supply and wind power supply.

In the sensitivity analysis, wind speed value is considered changing in the range of 3– 5m/s (which covers wind speed values which are 30% lower and higher than the current value) because of the wind's variable and unsteady nature.

The project lifetime is considered to be 25 years.

The annual real interest rate is taken as 8% for Turkey.

No cost subsidy available from Turkish government is considered.

Renewable fraction of the hybrid power system is 100%. That is, it is assumed that a hybrid system, in which all energy requirements of the educational campus are supplied by the generated power extracted from wind and solar energy, will be considered.

It completely supports the preservation of the natural environment and endeavors to eliminate pollution.

Results and Discussion

Goal of the optimization process is to determine the optimal value of each decision variables such as the number of wind turbines, the number of batteries, the size of AC-DC converter. In this study, in the optimization process, HOMER simulates many different system configurations, discards the infeasible ones, ranks the feasible ones according to total net present cost, and presents the feasible one with the lowest total net present cost as the optimal system configuration.

In this study, HOMER software is employed to make techno-economical analysis of the hybrid systems considered and also determine the optimum value of the hybrid system components such as wind turbine, battery, PV panel etc. considering two economical parameters, NPC and COE. Besides that, completion of the simulation, by using HOMER software, took only 51 seconds.

For sensitivity analysis, wind speed value is considered changing in the range of 3 – 5m/s (which covers wind speed values which are 30% lower and higher than the current value) because of the wind's variable and unsteady nature. In this simulation, the effect of the varying wind speed values on the cost of the energy generated in the hybrid system is also discussed.

For the current conditions defined as average wind speed and average solar global irradiance are almost 3.94 m/s and 4.98 kWh/m^2/d respectively, according to the simulation results indicated in Figure 8, the optimal configuration (coloured with blue in Figure 8) with the lowest total net present cost (NPC) *contains one wind turbine, 36 batteries, the 6 kW converter and the 14kW PV array*. It is easily noticed from figure 7 and figure 8 that total NPC of the optimal configuration is estimated to be $197,139 and COE is about 1.013$/kWh.

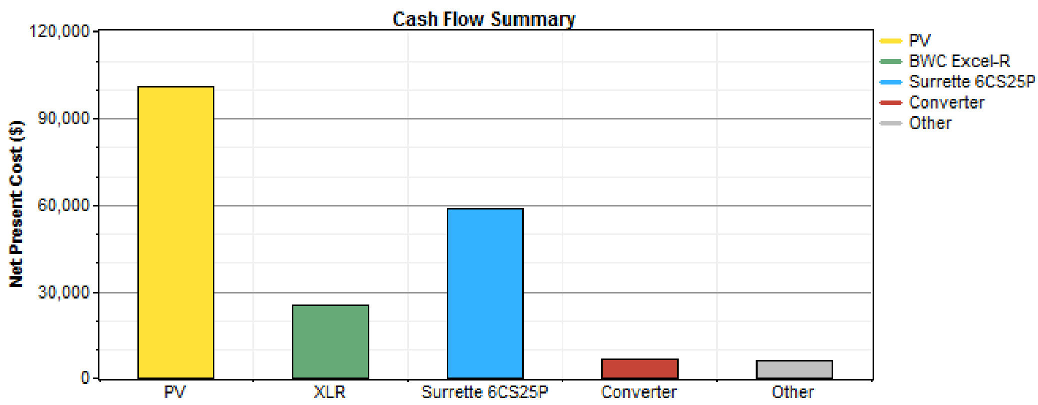
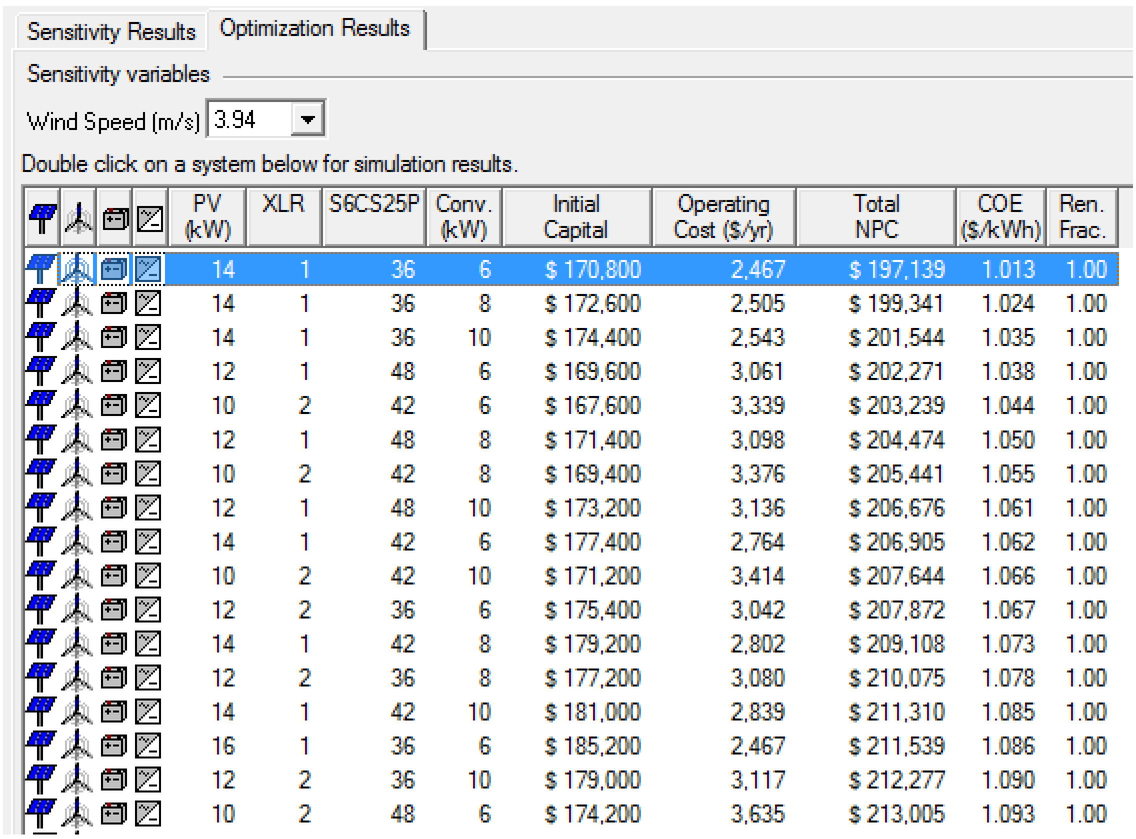


Figure 7 Net present cost value of the hybrid system components

According to the Figure 7, PV panels have the highest cost compared to the other components in the system, which makes up nearly 50% of the total system cost, $197,139. It is followed by the battery cost with nearly $59,000, wind turbine cost with nearly $28,000, converter cost with $3000 and other cost with $3000.



PV (kW)	XLR	S6CS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
14	1	36	6	$ 170,800	2,467	$ 197,139	1.013	1.00
14	1	36	8	$ 172,600	2,505	$ 199,341	1.024	1.00
14	1	36	10	$ 174,400	2,543	$ 201,544	1.035	1.00
12	1	48	6	$ 169,600	3,061	$ 202,271	1.038	1.00
10	2	42	6	$ 167,600	3,339	$ 203,239	1.044	1.00
12	1	48	8	$ 171,400	3,098	$ 204,474	1.050	1.00
10	2	42	8	$ 169,400	3,376	$ 205,441	1.055	1.00
12	1	48	10	$ 173,200	3,136	$ 206,676	1.061	1.00
14	1	42	6	$ 177,400	2,764	$ 206,905	1.062	1.00
10	2	42	10	$ 171,200	3,414	$ 207,644	1.066	1.00
12	2	36	6	$ 175,400	3,042	$ 207,872	1.067	1.00
14	1	42	8	$ 179,200	2,802	$ 209,108	1.073	1.00
12	2	36	8	$ 177,200	3,080	$ 210,075	1.078	1.00
14	1	42	10	$ 181,000	2,839	$ 211,310	1.085	1.00
16	1	36	6	$ 185,200	2,467	$ 211,539	1.086	1.00
12	2	36	10	$ 179,000	3,117	$ 212,277	1.090	1.00
10	2	48	6	$ 174,200	3,635	$ 213,005	1.093	1.00

Figure 8 Many different system configurations simulated by HOMER software

Furthermore, for the current wind speed (3.94m/s) and solar irradiance (4.98 kWh/m^2/d) conditions described before, when discussing ***the power generating systems with <u>only one type-renewable energy source (Only wind energy or solar energy)</u>***, following simulation results for system configurations can be attained as tabulated in table 1. It is easily highlighted from table 1 that NPC and COE values of the standalone power generating systems with only one renewable energy source is more than the hybrid system (including two renewable energy sources), that is, they are not cost-effective. Besides that, when comparing these two standalone power generating systems with only one renewable energy generator in terms of COE and total NPC, it should be underlined that the standalone power generating system with 7.5kW wind turbine (WT) costs

%60-65 higher than one with PV panels. *Shortly, the standalone power generating system including both of renewable energy generators is supposed to become cost-effective.*

Table 1 For V=3.94m/s, optimal number of the components in three different standalone power generating systems and economical comparison of these power generating systems.

1kW-PV (Pieces)	7.5kW-WT (Pieces)	6.94kW-Battery (Pieces)	Converter (kW)	Total NPC ($)	COE ($/kWh)
14	1	36	6	197,139	1.013
16	-	60	6	225,470	1.158
-	10	60	6	361,605	1,856

Because of the wind's variable and instable nature, average wind speed value of the region can become under or above the current wind speed value measured. Therefore, in this study, some wind speed values like 3m/s and 5m/s are also discussed. For sensitivity analysis, when effects of the varying wind speed values on the COE and total NPC of the power generating system with optimal configuration are analyzed, following simulation results in table 2 are obtained by means of the HOMER software.

Table 2 For V=3m/s and V=5m/s, optimal number of the components in different standalone power generating systems and economical comparison of these power generating systems.

1kW-PV (Pieces)	7.5kW-WT (Pieces)	6.94kW-Battery (Pieces)	Converter (kW)	**Total NPC ($)**	**COE ($/kWh)**
		V=3m/s			
14	1	48	6	**216,671**	**1.112**
16	-	60	6	**225,470**	**1.158**
		V=5m/s			
10	1	42	6	**178,105**	**0.914**
-	5	42	6	**206,639**	**1.061**
16	-	60	6	**225,470**	**1.158**

According to the Table 2, it is easily highlighted that when wind speed value showed a tendency of increasing by 25%, the cost of energy generated in these standalone power generating systems would reduce by almost 17%. Added to this, following outputs can also be achieved:

For V=3m/s, There is no optimal configuration for power generating system with only wind energy generator obtained by the HOMER software in spite of increasing the number of wind turbines to 25 in the HOMER. It means that there would be no power generating system (with only wind energy generator) configuration to fully meet the energy requirement of the educational campus.

For V=5m/s, COE and total NPC of the power generating system *<u>with only wind energy generator</u>* would reduce by nearly 38%, comparing to those of the power generating system (including both wind energy generator and PV panel) obtained when V=3.94m/s.

For even all cases, as seen in Table 1 and Table 2, optimal number of components in the power generating system with only PV panel is the same and of course, COE and total NPC are the same.

For the conditions described as V=3.94m/s and 4.98 kWh/m^2/d, the most suitable and applicable power generating system for the educational campus considered in the study should contain both PV panels and wind turbines, not only one.

Conclusions

These following basic outputs can be drawn from the simulation data obtained by employing the HOMER software:

This study seeks for the hybrid systems which completely support the preservation of the natural environment and endeavors to eliminate pollution. To do this, renewable fraction of the hybrid power system is considered as 100%.

<u>For the current conditions defined as average wind speed and average solar global irradiance are almost 3.94 m/s and 4.98 kWh/m^2/d respectively</u>, according to the simulation results, for Pinarhisar educational campus, the optimal configuration with the lowest total net present cost (NPC) contains *one wind turbine, 36 batteries,*

the 6 kW converter and the 14kW PV array. Total NPC of the optimal configuration described in the previous item is estimated to be $197,139 and its COE is about 1.013$/kWh.
When a sensitivity analysis is made in terms of some wind speed values like 3m/s and 5m/s, it can be clearly seen that when wind speed value showed a tendency of increasing, the cost of energy generated in these standalone power generating systems would reduce remarkably.
For a lower wind speed value like 3m/s, *no optimal configuration for power generating system with only wind energy generator* would be computed by the HOMER software in spite of increasing the number of wind turbines till 25. It means that there would be no power generating system (with only wind energy generator) configuration to fully meet the energy requirement of the educational campus.
For a higher wind speed value like 5m/s, COE and total NPC of the power generating system *with only wind energy generator* would reduce by nearly 38%, comparing to those of the power generating system with both wind energy generator and PV panel obtained when V=3.94m/s.
For the conditions described as V=3.94m/s and 4.98 kWh/m^2/d, the most suitable and applicable power generating system for the educational campus considered in the study should contain both PV panels and wind turbines, not only one.
For even all cases analyzed in the study, optimal number of components in the power generating system with only PV panel is the same and of course, COE and total NPC are the same.

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