**Research Article**

# Technical and economic evaluation of a standalone and on grid hybrid renewable energy: A case study at Eskişehir Technical University

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**ABSTRACT**

Because of high-energy demand, population increase and exhaustion of fossil fuels, renewable energy is being utilized around the world especially for hybrid systems. The hybrid system should be optimally sized hence the aim of the study is to determine the technical and economic evaluation of a standalone and on grid hybrid system to supply power to the Department of Electrical and Electronics Engineering in Eskişehir Technical University. Hybrid optimization model for multiple energy resources (HOMER) program is used to achieve the optimal configuration of the standalone and on grid hybrid system and these systems are compared to each other to see the most economical one according to the net present cost (NPC) and cost of energy (COE). The result revealed that the most optimal configuration of the two systems is PV/Grid hybrid system with 198kW PV panel and the grid. It has NPC and COE of $1.68M and 0.176$/kWh but is not environmentally friendly as a standalone system due to low renewable fraction (RF). Overall, by using hybrid renewable energy systems (HES), the study is trying to solve the problem of reliability, cost and environmental concerns of the conventional energy sources.

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## INTRODUCTION

In 21st century, energy demand is high due to population increase and urbanization. The main challenge is to meet the rising energy demand without interfering with the resources. In the last decade, temperature has increased leading to debates on global warming between countries. High-energy demand is met through fossil fuels. This conventional source releases greenhouse gases, which is harmful to the atmosphere [1]. In order to meet the high demand of energy, the share of renewable energy sources (REs) needs to be increased. Therefore, is considered as a good substitute to conventional sources because they are clean, eco-friendly and reduce pollution. So, it promotes the sustainability of a nation [2–4]. Nevertheless, the major challenge of REs is that they are intermittent meaning they highly depend on the atmospheric condition leading to fluctuation of energy production. They also have high

initial capital cost. To avoid this problem, the REs should be combined with the conventional energy sources by utilizing the strength of one energy source to balance the weakness of the other making it a hybrid energy system (HES).

To avoid this problem, the REs should be combined with the conventional energy sources by utilizing the strength of one energy source to balance the weakness of the other making it a hybrid energy system (HES). If a higher capacity renewable energy resource is used, the total amount of carbon dioxide is reduced [5].

The most important advantages of HES are reliability, price reduction, efficiency improvement and less air pollutant as compared to stand alone renewable systems [6, 7]. Recently, the use of hybrid renewable energy systems is becoming popular as a substitute to fossil fuel usage [5]. The challenge of HES is to come up with the optimal size and configuration of the system to meet the load demand at lowest cost and achieve an economically attractive system [7, 8]. Since there are few studies comparing techno-economic feasibility analysis of a standalone and grid connected hybrid system. The paper focuses on the technical and economic evaluation of HES with and without the utility grid using HOMER software to find the optimal configuration and cost-effective system as well as environmentally friendly to supply power to an Electrical and Electronics Department in Eskişehir Technical University.

Several studies have been realized to examine technical and economic evaluation of HESs. Some of them are given below:

In [1] they conducted a technical and economic evaluation of PV/diesel genset/on grid hybrid system using HOMER program to supply power to an institution of Engineering in New Delhi/India. The result showed that, PV/Grid configuration was the most economical one with least COE of 0.12 $/kWh. This is the same as the cost of grid electricity but with time grid price is expected to increase, hence making PV/Grid connected system more economical.

In [5] the feasibility of adding a renewable source to a village in Iran that was powered by diesel generator and connected to the grid using HOMER software was examined. Firstly, the paper examines how economical it would be to supply the village with the diesel genset and add renewable resources. On the other hand, they explored how the renewable energy resources can be combined with the utility grid to achieve an inexpensive and eco-friendly hybrid system. The results showed that combination of renewable energy to the diesel only system before and after the arrival of the grid could have lowered the expenses and reduced emissions.

In [6] studied a technical and economic study of different hybrid renewable energy using HOMER pro program to achieve an optimal configuration to supply power to a remote area in Sri Lanka. PV/WT/DG/battery having 20 kW solar panel, 40 kW wind turbine, 20 kW diesel genset and 40 battery banks was the most economical hybrid configuration and supplied power with 0.36 $/kWh COE. The energy price was more expensive than the grid price in Sri Lanka but due to lack of utility grid in the study area, the hybrid system would improve the rural lifestyle and reduce greenhouse gas emissions.

In [9], they performed techno-economic study of a hybrid renewable energy system for remote area in Sinai, Egypt. HOMER software was used to get an optimal configuration based on NPC and COE. They found that a HES, which consists of a 10kW PV panel, 7.5kW wind turbine, 2.8kW diesel generator and 20 batteries (360 Ah), supplied power to the load demands. The NPC and COE of the system was $113,256 and 0.179$/kWh respectively, hence, PV/Wind/Diesel/Battery system is considered more economical and reduced the $CO_2$ emissions.

In [10], it talks about how technical and economic evaluation of PV/Wind/battery/grid hybrid system was performed using HOMER software to electrify an institution of Research and Technology in Tunisia. The results presented NPC and COE of $44,705 and 0.224$/kWh and a maximum renewable fraction (RF) of 78%, but after considering sensitivity analysis based on the speed of wind, global solar insolation, cost of grid power and sellback cost. PV/grid hybrid system turned out to be the most economical configuration with $27,986 NPC and 0.140 $/kWh COE. The technical and economic study of standalone PV/diesel genset/battery hybrid system was analyzed to provide energy to a remote area in Eastern part of Iran [11]. They used the HOMER program for simulation purposes. The system's NPC, RF and air pollutant were used as a criterion to determine the most feasible system. The program indicated that a standalone hybrid system with 15 kW PV panel, 20kW diesel genset and 20kW inverter was the cost-effective system with NPC, COE and RF of $309,034, 0.464 $/kWh and RF of 30%. But adding 10 batteries to the system reduces NPC to $286,315 and COE to 0.430 $/kWh but increases RF to 35% making it more feasible. They finally concluded that PV/diesel genset/battery standalone configuration is not only economical but also a perfect candidate to provide power to rural areas in Iran.

A related approach of technical and economic study of two different hybrid renewable energy systems using the HOMER program was done by [12]. The results indicated that HES that used battery as energy storage was cost effective with NPC of $581,916 and COE of 0.359 $/kWh while the system that used hydrogen as energy storage was eco-friendly but not cost effective with NPC of $603,856 and COE of 0.373 $/kWh. The system that used hydrogen was the best system from the environmental point of view due to lack of emissions.

Mondal et al. [13] conducted a HOMER simulation to determine the potential of HES to provide power to a remote village in Ethiopia with lowest cost of energy (COE) and the system is compared with a diesel only system. The
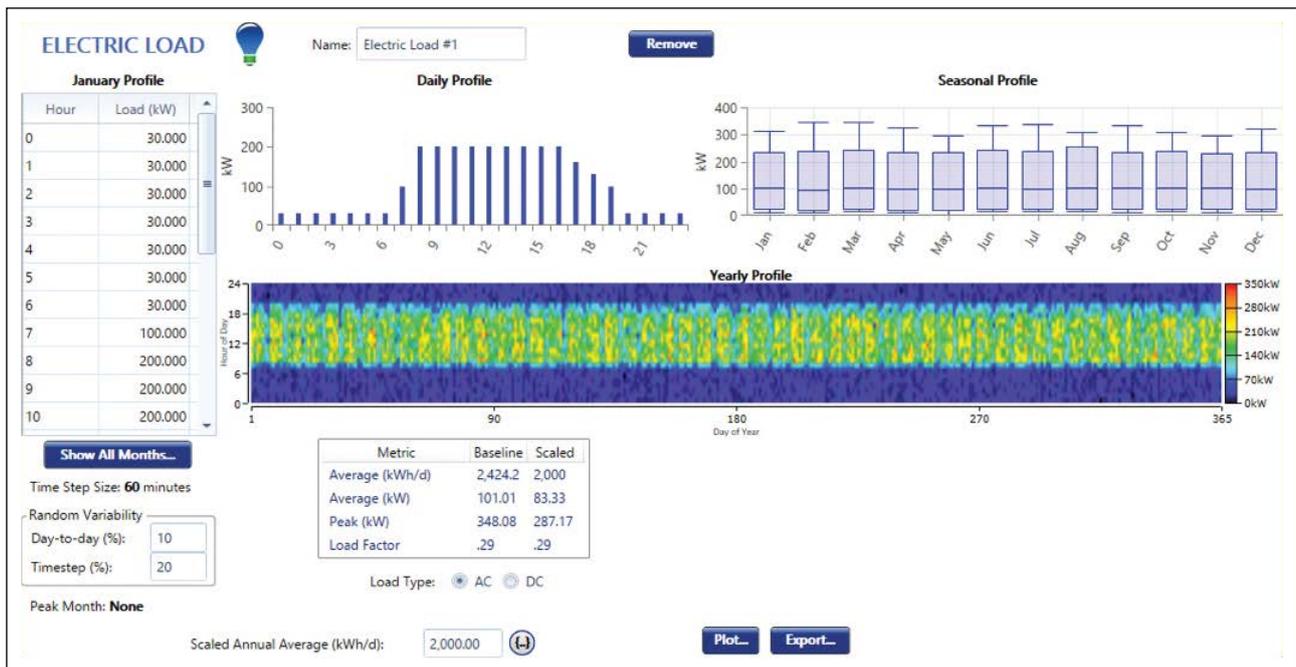
**Figure 1**. Load profile for the study area.

researchers learnt that PV/WT/DG/battery configuration had the least NPC and COE of $82,734 and 0.207 $/kWh respectively. The system cuts 37.3 tons of $CO_2$ when compared to diesel genset system, hence renewable HES is considered the best system especially in remote areas.

The aim of the study is to examine the technical and economic evaluation of various HES with or without the utility grid using HOMER software to find the most economical and eco-friendly hybrid system. This way the study promotes the use of hybrid renewable energy for government, commercial and residential buildings in Turkey. The sections of this work are organized as follows: In the current section describes the introduction and literature review, section 2 describes the methodology, Section 3 covers the results and discussion, and conclusion is presented in section 4.

## METHODOLOGY

Modelling of renewable energy systems are extremely dependent on meteorological data and load profile, so the relying of the system can be increased by using more renewable energy sources. To have a continuity of power, it is always good to rely on two or more energy sources. This study considers several different configurations of hybrid renewable systems and compares them using the HOMER pro program for simulation, optimization and sensitivity analysis. The software was developed by the National Renewable Energy Laboratory (NREL) of USA. It simulates a standalone and an on-grid energy system based on input parameters such as load profile, renewable resources, and the component's technical and economic specifications. The

program runs the simulations of all possible combinations and gives the results according to the most cost-effective ones that can meet the load demand by arranging them in terms of their NPC in ascending order. The system with the lowest NPC is the optimal hybrid configuration [8, 14, 15].

### Load Profile

The Department of Electrical and Electronics Engineering in Eskişehir Technical University is used as a case study. The average electrical load for the department is taken as 2MWh/day. Grid-connected and a standalone HES is simulated using the HOMER. Load profile is given in Figure 1.

### Available Renewable Energy Resources

**Solar Energy:** The solar irradiance was obtained from NASA surface meteorology. Figure 2 shows the monthly solar radiation and clearness index values. The highest solar radiation is experienced in the month of July and the lowest in the month of December. From the Figure 2, the average daily solar radiation in all of the year is 4.26 kWh/m²/day.

**Wind Energy:** The related wind energy data is download from NASA surface meteorology. The Figure 3 shows that the highest wind speed is experienced in month of February and lowest in May. The figure also shows that the average wind speed at 50 m is 4.76 m/s. In winter the wind speed is high while in summer it is low which is the opposite of the solar insolation, this means that PV and Wind energy complement each other.

### Components Considered for the Standalone and On Grid HES in HOMER Software

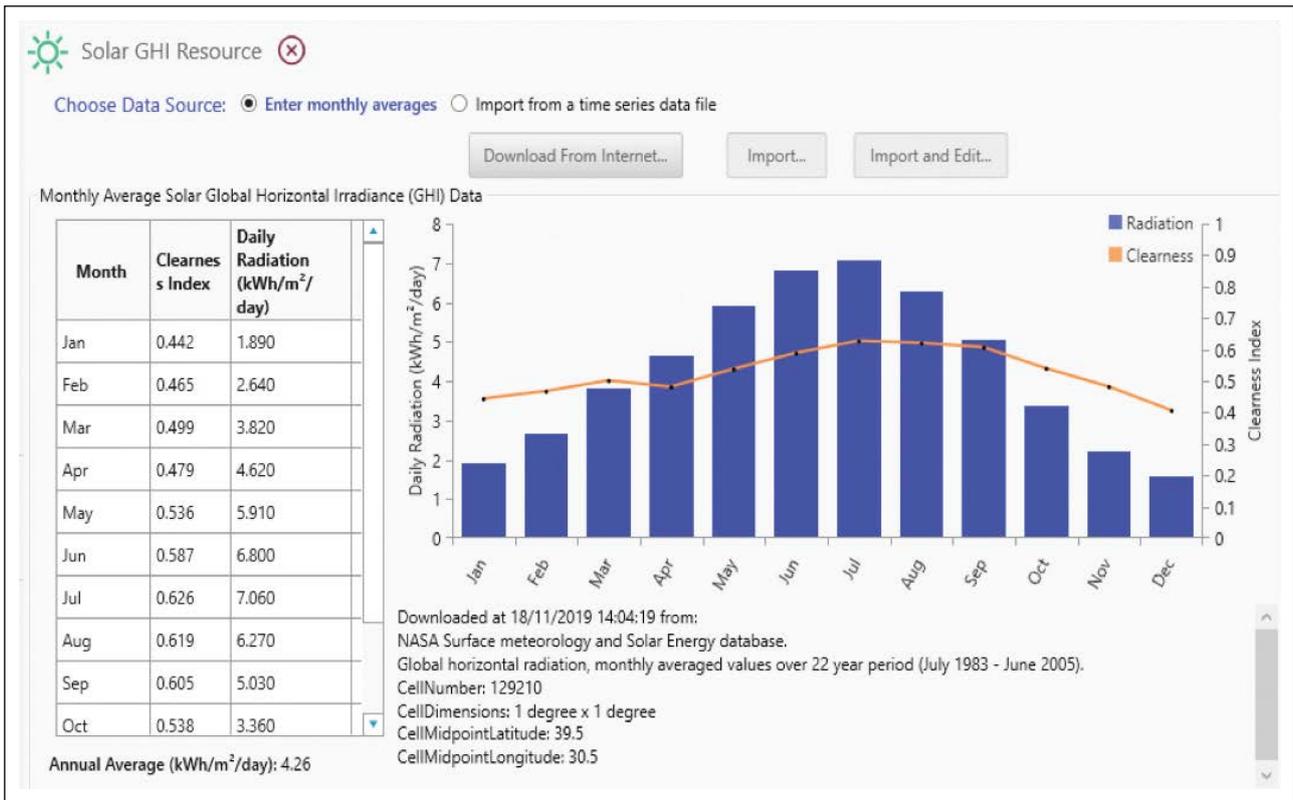The two Figures 4 and 5 show a list of components

**Figure 2**. The monthly solar radiation and clearness index values.



**Figure 3**. Average monthly wind speed for Eskişehir region.

considered in the simulation of the HOMER program to determine the optimum HES for our case study. This way, the best-suited combination to serve the department's load demand can be obtained.
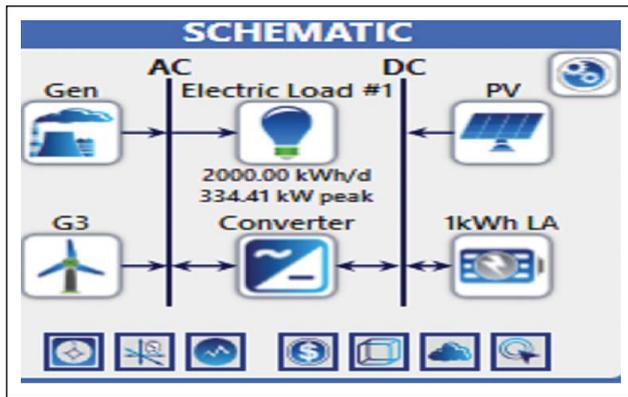
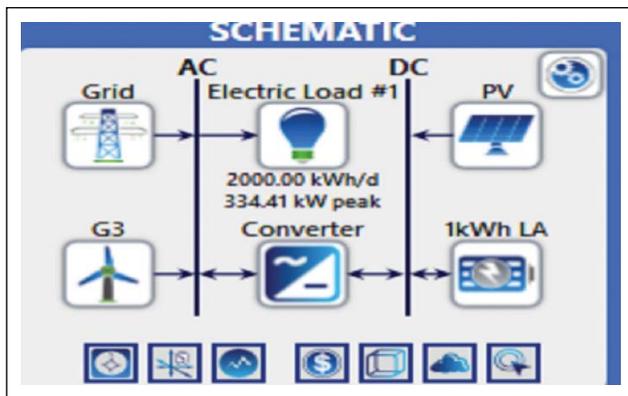**Figure 4**. Standalone hybrid energy system.



**Figure 5**. On Grid hybrid energy system.

**Technical and Economic Specifications of Hybrid Components**

In Turkey, the cost of buying electricity from the grid is 0.18 $/kWh, the selling price to the grid is 0.13 $kWh and the diesel price of 1.13 $/L which is specified into HOMER software. Some input parameters such as average wind speed, average solar radiation and load demand as well as the technical specifications and cost details of diesel generator, wind turbines, PV modules, battery banks and power converter are added to the software. The HOMER software uses this input to performs simulations, optimizations and sensitivity analysis and come up with the most optimum configuration according to their NPC and COE [9]. The five components used as inputs to the software are described below:

**PV panel:** It is Generic flat plate PV manufactured by Generic. The maximum temperature the solar cell can reach is 470C and its efficiency is 13%. The Capital cost includes transport, mounting, wiring and installation of the system. The derating factor is made up of wiring losses, shading, dust cover and aging. Technical and economic parameters are demonstrated in the Table 1 [9].

**Wind turbine:** It is considered HOMER's generic 3 kW wind turbine with an elevation of 17 meters. The technical and cost parameters of the wind turbine are presented in Table 2.

**Table 1.** Technical and economic specifications of solar panel

| PV system | |
| --- | --- |
| Type of model | Generic flat plate PV |
| Peak power (kW) | 1 |
| Efficiency (%) | 13 |
| Capital cost ($) | 2500 |
| O&M cost ($) | 2% of the capital cost |
| Derating factor (%) | 80 |
| Life time (years) | 25 |

**Table 2.** Technical and economic specifications of wind turbine

| Wind turbine | |
| --- | --- |
| Type of model | Generic wind turbine |
| Rated power (kW) | 3 kW |
| Capital cost ($) | 18000 |
| O%M cost ($/year) | 180 |
| Hub height (m) | 17 |
| Life time (years) | 20 |

**Table 3.** Specifications of battery storage

| Battery storage | |
| --- | --- |
| Nominal voltage (V) | 12 |
| Nominal capacity (kWh) | 1 |
| Minimum state of charge (%) | 40 |
| Capital cost ($) | 300 |
| Replacement cost ($) | 300 |
| O%M cost ($/year) | 10 |
| Life time (years) | 15 |

**Battery bank:** It is used for the system is a generic 6 V lithium-ion battery and energy storage is 1 kWh and 167 Ah nominal capacity. Technical and economic specifications of the battery are presented in the Table 3 [9].

**Diesel generator model:** HES often requires diesel genset for backup [16]. HOMER's generic diesel genset is used. Diesel price of 1.13 $/L is applied by considering the price of diesel in Turkey. Technical and economic parameters are given in Table 4 [17].

**Converter model:** It is required for HES to convert power from AC to DC. It can be an inverter or rectifier. The converter considered is HOMER's generic converter. The technical and economic parameters of the converter are presented in Table 5.

**Grid:** When the load demand is met, the excess power is sent to the utility grid and when there is shortage in renewable power, it is purchased from the utility grid. The price of the utility power is 0.18 $/kWh while the sell back price is 0.13 $/kWh.

**Table 4.** Cost data for diesel genset

| Diesel genset | |
|---|---|
| Size kW | 1 |
| Capital cost ($) | 500 |
| Replacement cost ($) | 500 |
| O&M cost ($/hr) | 0.03 |
| Fuel price ($/L) | 1.13 |
| Life time (operating hours) | 15000 |
| Minimum load ratio (%) | 25 |

**Table 5.** Techno-economic specifications of the selected converter

| Converter | |
|---|---|
| Size (kW) | 1 |
| Capital cost ($) | 300 |
| Replacement cost ($) | 300 |
| O&M cost ($/year) | 0 |
| Life time (years) | 15 |
| Efficiency (%) | 95 |

**Table 6.** Optimization results for different standalone HES configuration

| PV (kW) | WT (kW) | DG (kW) | Battery (no) | DS | NPC ($) | COE ($/kWh) | RF (%) |
|---|---|---|---|---|---|---|---|
| 555 | 0 | 320 | 1.546 | LFS | 4.28 M | 0.454 | 76.7 |
| 559 | 1 | 320 | 1.521 | LFS | 4.29 M | 0.455 | 76.8 |
| 0 | 0 | 320 | 0 | LFS | 6.82 M | 0.722 | 0 |
| 1.769 | 0 | 0 | 8.777 | LFS | 10.6 M | 1.12 | 100 |

**Dispatch strategy (DS):** Aside from selecting different components, HOMER makes numerous decisions concerning the working together of components and if the power be sent to the grid or purchased from the grid, whether batteries be charged or discharged and when the generator should operate all these decisions take place for every hour of the day.

HOMER has two dispatch strategies. The load following strategy (LFS) and cycle charging strategy (CCS). LFS is a DS where diesel generator generates the required power when operating and the batteries are charged by the renewables. While CCS is a dispatch where diesel generator operates at a maximum capacity and the excess energy is used to charge the batteries. Therefore, for our proposed HES, LFS is adopted where the batteries will be charged by the renewables to minimize emissions and reduce fuel price [16, 18].

**Technical and economic evaluation criteria:** HOMER program uses technical and economic specifications and input parameters to come up with the optimal hybrid configuration. The optimal configuration is arranged according to Net Present Cost (NPC) and COE.

**NPC:** The major technical and economic evaluation criterion of the HOMER program is NPC. It is defined as the cost of installing and operating a hybrid system during its lifespan. It consists of all the profits and costs in a Project's lifespan, with future cash flows discounted to the present value [8, 16]. The formula for NPC is presented in the equation below.

$$NPC = \frac{TAC}{CRF\,(i,N)} \tag{1}$$

where TAC is the annualized cost of the hybrid system and CRF (i, N) is the capital recovery factor (CRF), i is ac-

tual interest rate and N is the project lifespan [7]. Formula for CRF is presented in the equation below:

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

Levelized COE: It is an average cost per kWh of the electricity produced by hybrid renewable energy systems. It is also a ratio of the annualized system cost by the total electricity generated [16]:

$$LCOE = \frac{TAC}{E} \tag{3}$$

where E is the total electrical energy produced (kWh).

## RESULTS AND DISCUSSION

Simulation results from HOMER software are presented and discussed in this section. The program executes simulations to come up with the most cost-effective hybrid system in terms of NPC and COE. The optimization results of both the standalone and the grid connected HES are analyzed and compared. HOMER ranks the optimal systems according to NPC and COE in ascending order, the most economical system is shown at the top and its able to satisfy the load demand with the lowest NPC.

### Standalone Hybrid System

The optimization configuration of a standalone hybrid renewable energy system consisting of optimal systems, DS, NPC, COE and RF is given in Table 6. The optimal system is capable of satisfying the load demand of study location in Eskişehir Technical University.

As can be seen from the optimization results, PV/DG/Battery is the most cost-effective system with 555 kW solar
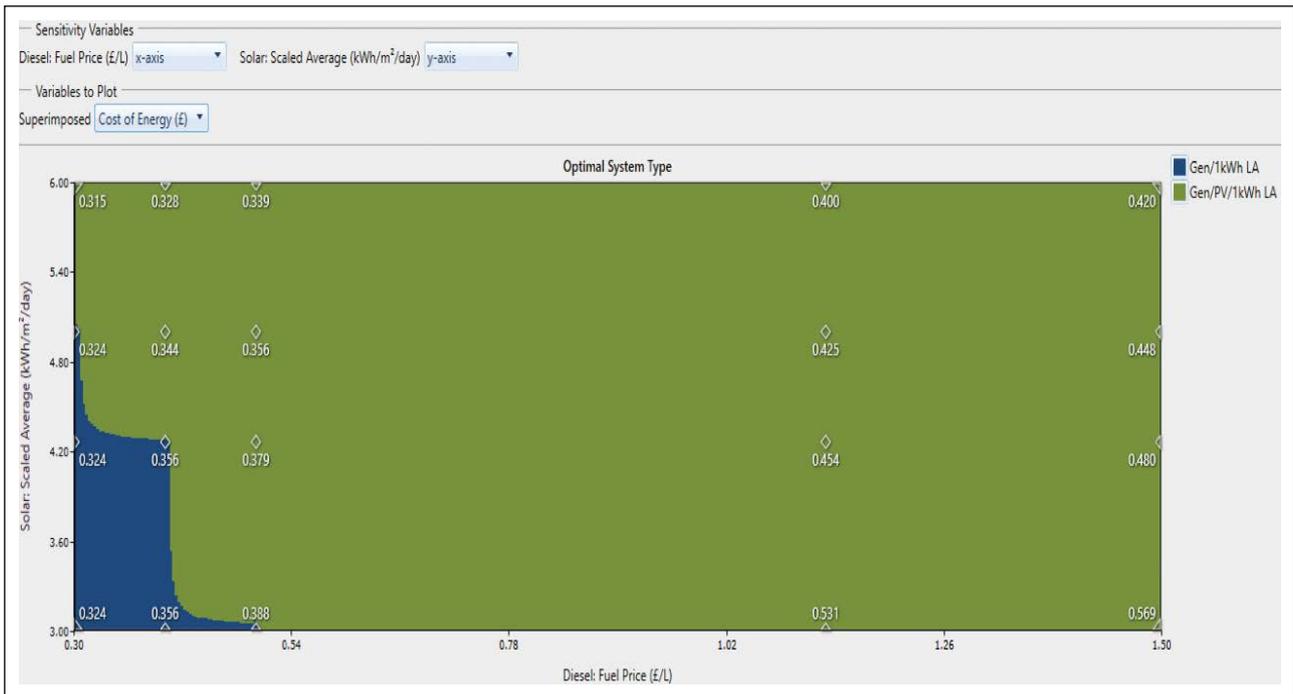
**Figure 6**. Monthly electricity production for the PV/DG/battery hybrid system.

**Table 7.** Optimization results for different grid connected HES configuration

| PV (kW) | WT (kW) | Grid (kW) | Battery (no) | DS | NPC ($) | COE ($/kWh) | RF (%) |
|---------|---------|-----------|--------------|-----|---------|-------------|--------|
| 172 | 0 | 999.999 | 0 | LFS | 1.65 M | 0.173 | 35.7 |
| 169 | 2 | 999.999 | 0 | LFS | 1.66 M | 0.175 | 35.3 |
| 0 | 0 | 999.999 | 0 | LFS | 1.70 M | 0.180 | 0 |

panel, 320 kW diesel genset and 1,546 strings of batteries. The system has NPC and COE of $4.28 M and 0.454 $/kWh and it can supply electricity to meet the load demand of a department in Eskişehir Technical University. The system uses a load-following DS to reduce the usage of diesel generator. The system has a high RF of 76.7% making it consumes less diesel (55,048L/year) hence decreasing the operation of the generator.

The next economical hybrid configuration is PV/WT/DG/Battery system with 559 kW PV panel, 1 kW wind turbine, 1,521 batteries and 320 kW diesel generators and NPC of $4.29 M and COE of 0.455 $/kWh. It has low RF when compared to the first system hence releases more $CO_2$ emissions because the DG operates more.

The third economical hybrid configuration is the diesel only system which supplies electricity at a COE of 0.722 $/kWh while the hybrid system with 100% renewable resources supplies electricity at a COE of 1.12 $/kWh. Therefore, the renewable system with a diesel generator is more economical than the system with the renewable energy only or generator only and environmentally friendly than diesel only system. The most optimal hybrid configuration is not only economical but also emits less $CO_2$ when compared

to the diesel only system (144.095 and 792.5 tons of $CO_2$). Therefore, it is a cost-effective system from a reliability, economic and environmental standpoint.

**Electricity production:** Electricity generation from PV/DG/Battery hybrid configuration is shown in Figure 6. The system produced an annual electricity production of about 777.669 MWh. The PV panel and the generator produces 82 and 18% of electrical energy annually. The system has a RF 76.7% and excess electricity of 15.1%.

**Sensitivity analysis:** HOMER pro uses algorithms to find the optimal hybrid configuration based on inputs by the user. Some of this input may have uncertainties especially solar insolation, wind speed and diesel price values. So, simulations are done to determine these uncertainties and how it affects the NPC and COE. Sensitivity analysis eliminates all infeasible combinations and ranks the viable system according to their NPC and COE to satisfy load demand. The values considered for the diesel price are $0.3, $0.4, $0.5, $1.13 and $1.5 and for solar radiations are 3.0, 4.26, 5.0 and 6.0 kWh/m²/day and a constant wind speed of 4.76 m/s.

**Global solar radiation and diesel price:** Electricity generated by solar panels is dependent on the intensity of

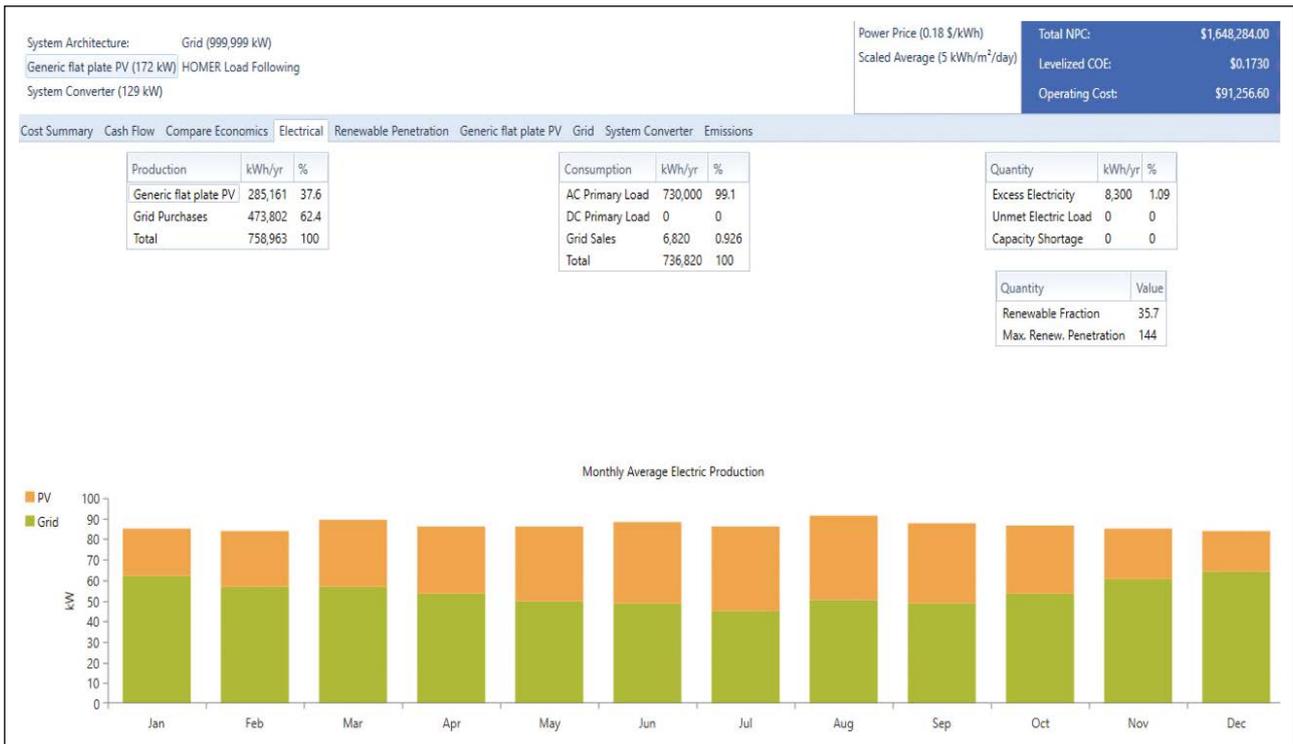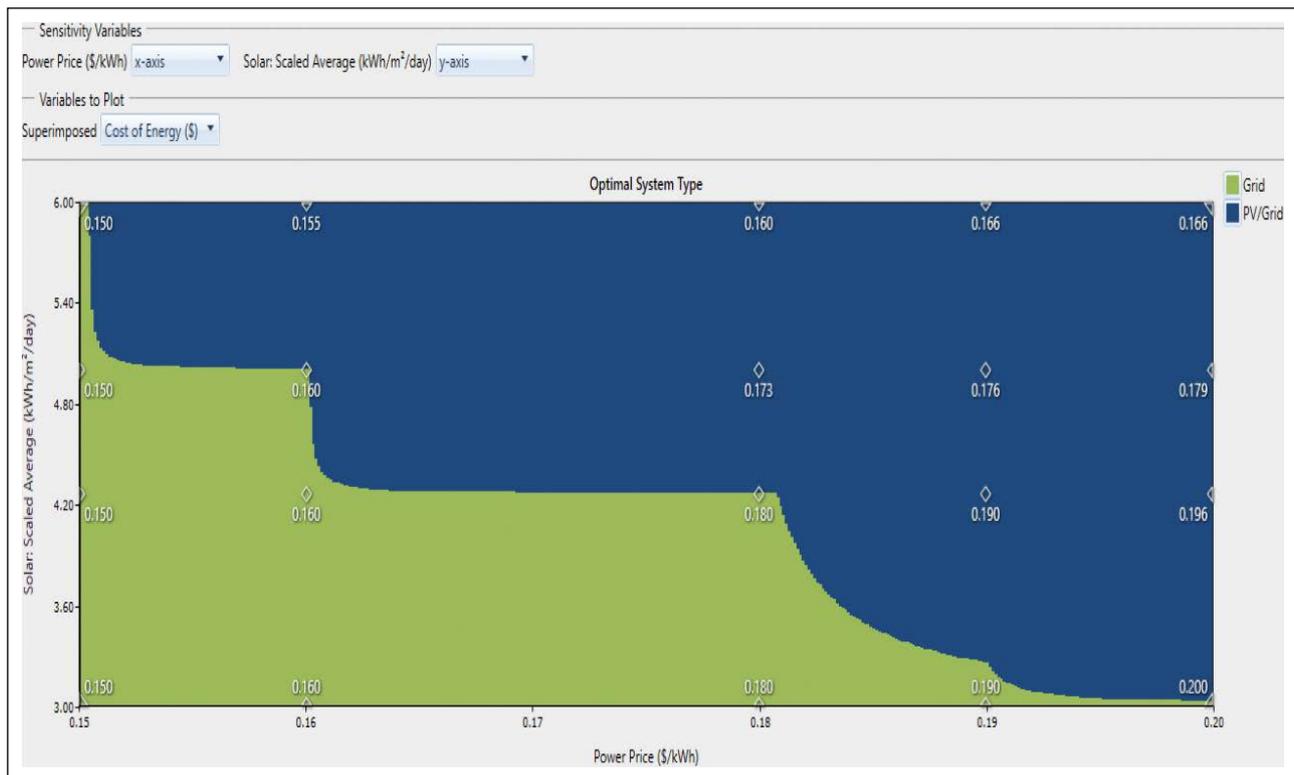**Figure 7**. Sensitivity analysis on COE.



**Figure 8**. Average monthly electricity generation from PV/On grid hybrid system.

solar energy. Figure 7 shows sensitivity analysis on COE for different solar irradiation and price of diesel with 4.76 m/s speed of wind.

The Figure 7 illustrates that PV/DG/battery hybrid system is the most favorable system type for most parts of sensitivity variables excluding the blue area. Because of this, PV/DG/battery hybrid combination is the cost-effective configuration. The DG/Battery becomes the optimal system type for diesel price less than 0.5L and solar insolation less than 4.20 kWh/m²/day. As can be seen from Figure 7,

**Figure 9**. Sensitivity analysis on COE.

when the solar insolation rises, the COE declines. This is due to rise in the renewable percentage since more energy comes from renewables, the diesel generator will provide less power hence less fuel. The figure also shows that as the diesel price increases, the COE also increases. Changes in the COE for the variations in solar radiation within the range of 3.0–6.0 kWh/m²/day is about 0.015 $/kWh which is negligible but for the variations in diesel price within the range of 0.3–1.5 $/L is 0.217 $/kWh. This means that diesel price has more effect on the COE than the solar radiation. Therefore, the most optimal system occurs at high solar radiation and low diesel price. Table 7 shows the optimization results of a grid connected hybrid system.

**Grid connected hybrid energy system:** The optimization results for different grid connected HES configuration is presented in Table 7.

The most cost-effective system as can be seen from the table is PV/Grid hybrid energy system, which consists of 172 kW PV and the grid with NPC and COE of 1.65M, $0.173/kWh. The system has a RF of 35.7%, which reduces $CO_2$ emissions, but the RF is low due to the grid price being cheap and low solar radiation. As the grid price becomes expensive, the RF increases. The battery is not being used since the grid provides power at night and due to economic consideration. The grid connected hybrid system is cost effective and emits less $CO_2$ when compared to the grid only system (299 and 461 tons of $CO_2$). The system creates more emissions than the standalone hybrid system due to low RF.

The second optimal system is PV/WT/grid design which has 169 kW PV panel, 2 kW wind turbine and the grid with NPC of $1.66M and a COE of $0.175/kWh. It has lower RF of 35.3% and it is cost effective when compared to the PV/on grid hybrid system. Hence, PV/On Grid is the most economical while the second system is slightly environmentally friendly.

**Electricity production:** The PV/grid connected hybrid system produces 759 MWh/year to meet 730 MWh/year load demand. The PV only produces 37.6% of the required energy while the other 62.4% is purchased from the Grid. The excess electricity is minimal because of the low RF of 35.7%. When the PV/Grid interactive and the PV/DG/Battery standalone HES is compared, the standalone system has high excess electricity due to high RF because the system has to be oversized to maintain the continuity of power supply as the grid is not available. The Figure 8 shows the PV/Grid interactive hybrid system's monthly average electricity distribution throughout the year.

Sensitivity analysis and global solar radiation and grid price: Sensitivity analysis is used to help examine the effects in variability of the renewable energy resources and grid price on NPC and COE. The values used for the grid price are $0.15, $0.16, $0.18, $0.19, $0.20 and for solar radiation are 3.0, 4.26, 5.0, 6 kWh/m²/day with wind speed of 4.76 m/s. Figure 9 shows the effect of sensitivity analysis on COE for different grid price and solar insulation. From this Figure, the PV/Grid hybrid energy system is the most

**Table 8.** Economical comparison between the optimal configurations of hybrid system

| Optimal system configuration | Net present cost ($) | Operating cost ($/yr) | Cost of energy ($/kWh) | RF | $CO_2$ emissions |
|---|---|---|---|---|---|
| **PV/Diesel/Battery** | **4.28M** | **168,958** | **0.454** | **76.7** | **144 tons** |
| PV/Wind/Diesel | 4.29M | 168,430 | 0.455 | 76.8 | 140 tons |
| **PV/Grid** | **1.65M** | **90,960** | **0.173** | **35.7** | **299 tons** |
| PV/Wind/Grid | 1.70M | 91,196 | 0.177 | 35.3 | 301 tons |

economical system type for most sensitivity analysis considered except the green area. On the other hand, the Grid only system becomes the optimal system type for solar radiation between 3.0–4.20 kWh/m²/day and the grid price less than 0.18 $/kWh. The results also show as the grid price increases, the NPC and COE increases but when solar radiation increases, the NPC and COE decreases while the RF increases.

**Comparing the optimization results of the standalone and on grid hybrid system:** Economical comparison between the optimal configurations of hybrid system is shown in Table 8.

From Table 8, the PV/Grid hybrid system is the most preferred one because it has low NPC and COE while the PV/WT/Diesel/Battery hybrid system is the least cost-effective system but environmentally friendly due to higher RF. The PV/Grid hybrid system has lower RF because the grid price of our case study is cheap and the area has low solar radiation, but as the grid price increases so do the RF and eventually leading to less $CO_2$ emissions.

## CONCLUSIONS

Technical and economic evaluation of an off grid and standalone hybrid renewable energy system was studied using the HOMER pro program to perform simulation and come up with the most cost effective and environmentally friendly configuration for Eskişehir Technical University. The maximum load demand of the Department of Electrical and Electronics Engineering is 2MWh/day. HOMER optimization results presented the optimal configuration of PV/Diesel Gen/Battery, which can supply enough power to the load demand while the optimal configuration for the on-grid hybrid system was PV/Grid configuration. Out of the two systems, the PV/Grid hybrid system is the most economical hybrid system due to low NPC and COE (1.68M and 0.176 $/kWh) when compared to the off-grid hybrid system (4.29M and 0.455$/kWh). The PV/Grid hybrid system is more economical but not environmentally friendly due to low RF (35.4%) leading to high $CO_2$ emissions (302 tons) while the standalone hybrid system released less $CO_2$ emissions (110 tons) and has a quick payback period of 4.4 years compared to on grid system with 12 years of payback period.

Sensitivity analysis showed that as the global solar radiation increases, NPC and COE decreases, on the other hand as the cost of diesel and grid energy increase, NPC and COE also increase. So, in the future, as the cost of diesel and grid energy continue to increases hybrid renewable energy systems will become more attractive and cost effective, hence promoting the adaptation of renewable energy. To conclude, the technical and economic evaluation is vital to find optimal configuration of hybrid energy system.

To conclude, the PV/Grid hybrid system is the most economical but not environmentally friendly when compared to the standalone alone hybrid system. Therefore, the choice is with the customers whether in terms of cost or environmental benefits. In the future, hybrid renewable energy system will be the solution to energy problems since it combines both renewable and non-renewable energy sources [14].

After performing the technical and economic evaluation of both the standalone and grid connected hybrid system for the case study, the paper recommends both the standalone and grid connected hybrid system in Eskişehir region due to low NPC and COE for the grid connected system and low $CO_2$ emissions for the standalone hybrid system but mostly depends on whether your concern is financial or environmental pollution. Further studies can be realized on technical and economic evaluation of hybrid renewable energy systems using hydrogen production instead of batteries.

## AUTHORSHIP CONTRIBUTIONS

Concept: H.K.A., Ü.B.F.; Design: H.K.A., Ü.B.F.; Supervision: H.K.A., Ü.B.F.; Data collection and/or processing: H.K.A., Ü.B.F.; Analysis and/or interpretation: H.K.A., Ü.B.F.; Literature search: H.K.A., Ü.B.F.; Writing: H.K.A., Ü.B.F.; Critical review: H.K.A., Ü.B.F.

## DATA AVAILABILITY STATEMENT

The published publication includes all graphics and data collected or developed during the study.

## CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

## ETHICS

There are no ethical issues with the publication of this manuscript.

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