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An Environmentally Friendly University Library Based on Renewable Hybrid Energy Systems

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Abstract:

This paper presents a techno-economic analysis of hybrid renewable energy systems (HRES) to supply the electrical load requirements of the Central Library of Istanbul Esenyurt University located in Istanbul, Turkey. The standalone HRES (PV/Wind/Fuel Cell/Electrolyzer, PV/Fuel Cell/Electrolyzer and Wind/Fuel Cell/Electrolyzer etc.) considered in the analysis were comprised of different combinations of PV modules, Fuel Cell and wind turbines supplemented with hydrogen storage. Meanwhile, wind and solar energy potential in Esenyurt region in Istanbul is fairly appropriate for supplying energy requirements of some places with no high electricity load like libraries. In this study, the HOMER software is used as the assessment tool to determine the optimal configuration of HRES taking total net present cost (NPC) and cost of energy (CoE) into consideration. As a result, it is determined that the optimal system configuration of standalone Wind/PV/Fuel Cell/Electrolyzer hybrid renewable power generation system with the lowest total NPC consists of 25kW PV array, 40kW Wind turbine, 20kW Fuel Cell, 25kW power converter, 50kW electrolyzer and 100kg hydrogen tank and also that total NPC and CoE of the optimal configuration are estimated to be $809,442, $2.040/kWh, respectively. Renewable fraction of the hybrid system is 100%. Electricity generated through this hybrid system is completely clear and no harmful emission gases in this hybrid system are generated and there is no contribution of the HRES to the pollution of environment.

Keywords: Hydrogen storage, University library, Solar energy, Wind energy, Hybrid renewable energy systems

Abbreviations:

$C_{a,t}$: total annualized cost [$/year]
C_{NPC} : net present cost
CoE : cost of energy
CRF : capital recovery factor
$E_{p,AC}$: AC primary load served [kWh/year]
$E_{p,DC}$: DC primary load served [kWh/year]
$E_{g,s}$: total grid sales [kWh/year]
f : the annual inflation rate
HRES : hybrid renewable energy system
i : the real interest rate,
i_0 : the nominal interest rate
NPC : net present cost [$]
R_p : project lifetime [year]

1. Introduction:

Recently, efficient utilization of domestic wind and solar energy potential in some places like schools, libraries, universities, etc. has been more popular. Therefore, a remarkable energy saving in these places is fulfilled since the required electricity demand is provided from regional indigenous renewable energy resources instead of the grid. Furthermore, there is a considerable amount of renewable energy potential such as wind and solar energy in the Marmara region of Turkey. So far they have been slightly utilized for generating electricity and they are usually used for the following primitive purposes: heating water and mechanical energy obtained from the kinetic energy inside wind. But, they can be utilized for electricity generation by using the hybrid renewable energy systems (HRES) technologies that consider renewable energy sources as main power suppliers during electricity generation[1].

HRES are fairly useful method for the following reasons: assessment of the regional renewable energy potential, reduction in energy dependency and also green energy generation. They contain renewable based power suppliers such as wind and solar energy to meet the great variety of electricity demands, small or large demand. Furthermore, they are considered as reasonable solution ways for the power supply problems of remote areas with no grid connection. But, all the renewable energy systems do not always generate sufficient electricity energy to supply the demand depending on climate and weather conditions. Hence, the standalone PV or wind system is completely useful to keep the energy balance of the system for the time periods when there are sufficient amount of solar or wind energy. Therefore, if renewable energy resources are used, usually, a backup energy source and/or an energy storage system is needed. In case the renewable energy is unavailable, the backup energy source supplies energy. Conversely, power supply from Diesel generators is independent of climate and weather and is predictable. Even so, the use of Diesel generators has major drawbacks such as high operation and maintenance costs and air pollution by CO_2 emission. Fuel cell should be preferred alternatives to diesel generators because of the disadvantages mentioned above[2–7].

In the last couple of decades, HRES technologies and their applications have been heavily investigated. Some of the recent studies handled this issue considering economic and environmental parameters. In the following sentences, a brief literature review is presented to summarize the recent studies in the field of HRES technologies and their applications. Dalton et al., provided a feasibility analysis of renewable energy supply for a standalone supply large-scale hotel. They determined by analyzing HOMER software with the use of the power load data from a hotel located in a subtropical coastal area of Queensland, Australia. They highlighted that large-scale systems over 1000 kW were more efficient and economical than multiple small-scale systems ranging between 0.1 and 100 kW[8]. Corsini et al., examined a hydrogen-based system and a desalinated water-production system, as two effective alternatives for renewable energy seasonal buffering by converting the available renewable energy surplus on the Ventotene Island. Although the studied buffering systems had different purposes, all of the scenarios led to fuel oil savings greater than 60%[9]. The unit sizing, optimization, energy management and modeling of the hybrid renewable energy system components are examined by Bajpai and Dash. Developments in research on modeling of hybrid energy resources, backup energy systems, power conditioning units and techniques for energy flow management were discussed in detail[10]. Zoulias and Lymberopoulos evaluated a techno-economic analysis of the integration of hydrogen energy technologies in renewable energy-based standalone power systems on the Kythnos island[11]. They obtained results that the replacement of fossil fuel based gensets with hydrogen technologies is technically feasible, but still not economically viable, unless significant reductions in the cost of hydrogen technologies are made in the future[12]. Kilinci et al., modelled a hybrid renewable energy system using hydrogen energy as energy storage option for the Bozcaada Island in Turkey. They presented two scenario and investigated from the techno-economic point of view by using HOMER tool is used to define the optimum size of the equipment based on the geographical and meteorological data of the island.

They resulted that the increasing potential of the renewable energy sources, such as annual average wind speed or solar radiation, decreases both CoE and NPC[13]. Marchenko and Solomin examined a green power supply system which includes photovoltaic converters, wind turbines, batteries for electric energy storage and a system for hydrogen production, storage and energy use in the area of Baikal Lake. They resulted the electric energy storage is most efficient for short-term time intervals whereas an increase in the duration of continuous energy "standstills" up to several days makes the storage of hydrogen more cost-effective[14]. Khare et al., proposed renewable power generating system for auditorium of Police station Sagar at central India. For this hybrid system the meteorological data of solar insolation, hourly wind speeds are taken at the site considered. The pattern of load consumption is studied and suitably modeled for optimization of the hybrid energy system using HOMER software. Based on optimization result, it has been found that replacing conventional energy sources by solar-wind- PV/Wind/Fuel cell/Hydrogen tank system will be a feasible solution for distribution of electric power for standalone application[15]. Silva et al., presented a comparative study between the technologies and potential configurations meeting the needs of isolated communities in the Amazon through simulations based on HOMER software. The use of a PV/Fuel Cell/Battery system to supply electric power in an isolated community in the Amazon region. They showed that the optimal system initial cost, net present cost, and electricity cost with the hydrogen storage system was US$87,138; US$102,323; and US$1.351/kWh, respectively [16]. Fazelpour et al., determined the required energy for a household in Tehran and they used HOMER software in the analyses for both technical and economic criteria. They classified five feasible systems and identified the most economic system. Among five hybrid systems, they determined the wind-hydrogen-battery hybrid system, with a total net present cost of $63,190 and a cost of energy of US$0.783/kWh, as the most economical[17].

In this study, wind and solar energy potentials of the nearest region to Istanbul Esenyurt University library are presented. Then, in the HOMER software program[18,19], number or amount of the components in the standalone HRES are assigned in a range to determine the best configuration. After evaluating all the possible configurations depending on the total NPC and CoE, the best configuration for the HRES are determined. Eventually all the results obtained from the calculations in the HOMER software are analyzed economically and environmentally.

2. Load Profile:

The Central Library is located in Central Campus of Istanbul Esenyurt University, Istanbul, Turkey. The central library has an exhibition hall, a conference hall, two reading halls, a high-speed Internet access center, and a section for rare books and collections, and serves between 08:00 and 20:00 hours a day. The building of The Central Library of Istanbul Esenyurt University is demonstrated in Fig 1[20].

Fig 1. Central Library of Istanbul Esenyurt University, Turkey

The load of the central library was identified accurately and it is expected that the HRES designed in this study will meet the maximum load of 9.1 kW and 110 kWh consumed for the artificial lighting systems, the main system room, computers, and some auxiliary electronic equipment. As the daily energy consumption of the central library is shown in Fig 2. The HOMER software can synthesize the 8760 hourly electrical loads values for a whole year, use this hourly loads profile and add random variability factors, namely time-step-to-time-step variability and day-to-day variability. For the evaluation purposes, the time-step-to-time-step variability and day-to-day variability values were set to 12.2% and 8% respectively[21].

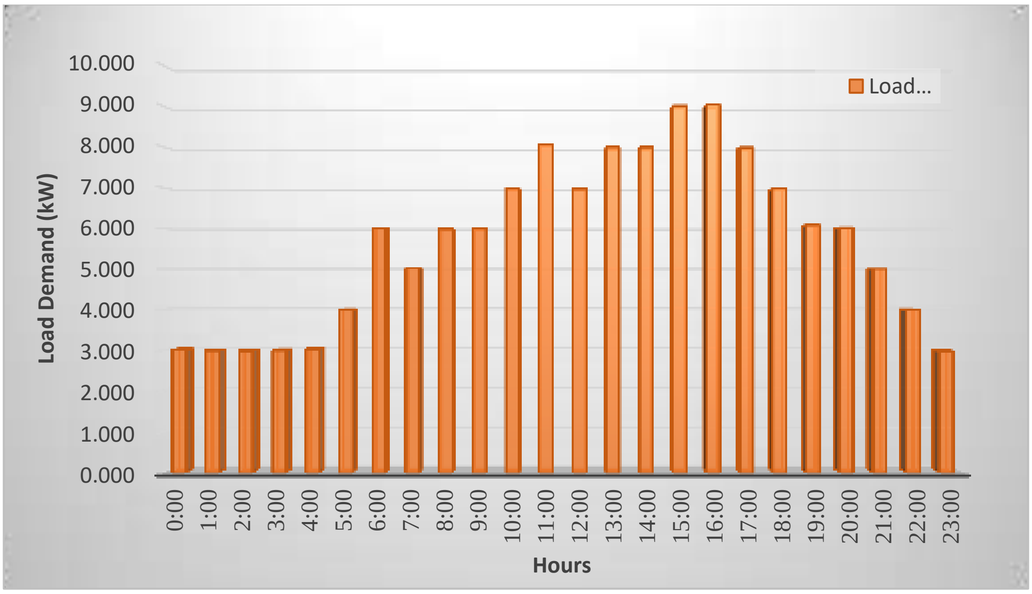

Fig 2. Load demand of the Central Library of Istanbul Esenyurt University

3. Wind and solar energy resources:

The average monthly solar radiation data in central library of Istanbul Esenyurt University, Turkey which is located at 41° 1' 13'' N of latitude and 28° 41' 14'' E of longitude was obtained from the Atmospheric science Data Center of NASA[22,23]. In HOMER Software, the hourly solar radiation data was generated using the monthly solar data by means of the Graham algorithm. An annual average solar radiation value of central library of Istanbul Esenyurt University is 4.28 kWh/m^2/day. Fig 3 shows the average monthly solar radiation data and the solar radiation's clearness index values according to the months.

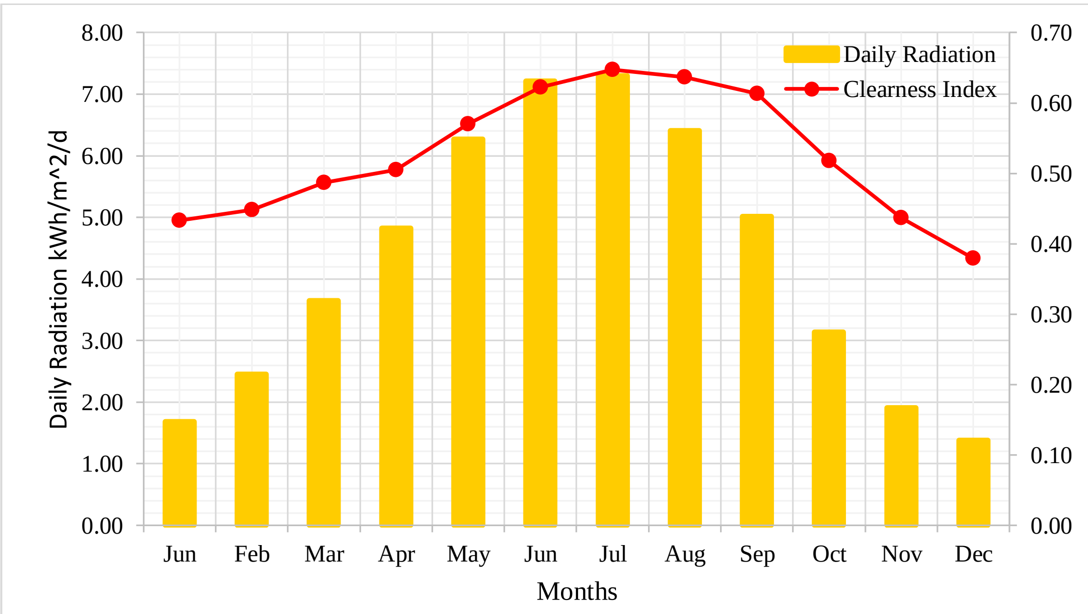

Fig 3. The average monthly solar radiation data and clearness index values of central library of Istanbul Esenyurt University

The clearness index gives information about the clearness of the atmosphere and also expresses the amount of the solar radiation that is able to reach to the earth surface. It is a dimensionless number varying between 0 and 1[18]. The hourly wind speed data of Esenyurt - Istanbul province is measured at the height of 50m and is provided by General Directorate of Renewable Energy[24]. Annual wind speed distribution profile of Esenyurt - Istanbul province is shown in Fig 4. Considering the wind speed data, it can be emphasized that wind speed distribution ranges between 4.40m/s and 7.20m/s whereas the regional average wind speed is around 5m/s. Furthermore, it can easily be seen that the least and the highest wind speed values occur in May and September, respectively. The surface roughness of the site is 0.001 as a result of the calculations depending on the wind speeds at different heights.

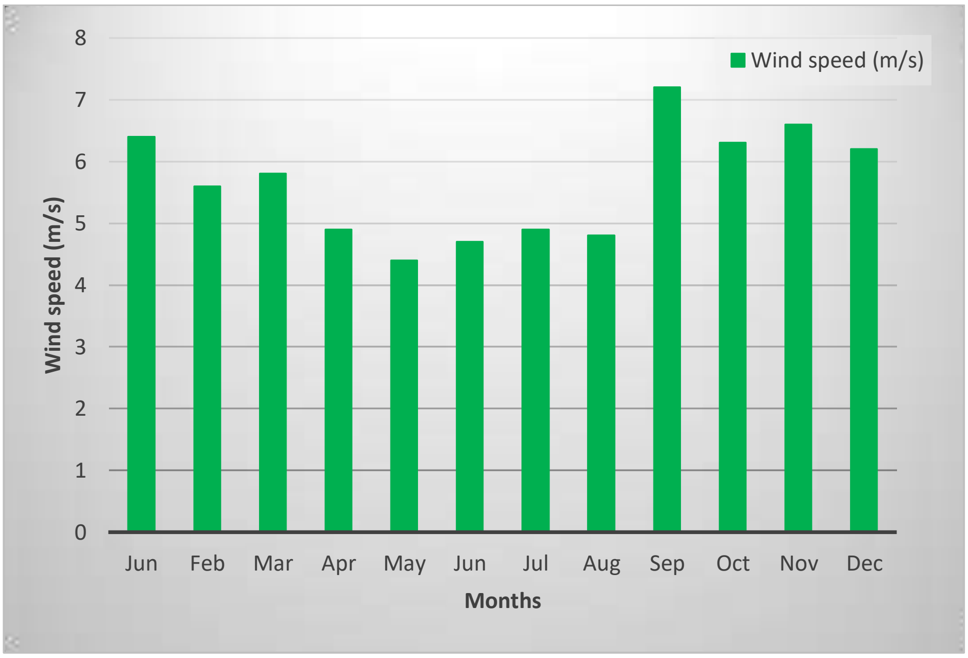

Fig 4. Annually wind speed distribution profile of Esenyurt - Istanbul province

4. Costs and Technical Details:

4.1.1 Calculation of the annual real interest rate for Turkey:

One of the inputs of the HOMER software is the annual real interest rate. The annual real interest rate is related to the nominal interest rate by Equation (1):

$$i = \frac{i_0 - f}{1 + f} \qquad (1)$$

Where, i is the real interest rate, i_0 is the nominal interest rate (the rate at which you could get a loan), and f is the annual inflation rate.

For Turkey, $i_0 = 9.25\%$ (25.01.2018) and $f = 8.5\%$ (annual inflation rate in 2017) are used. With these values, using Equation (2), the real interest rate is found 0.69% [16-18].

$$i = \frac{i_0 - f}{1 + f} = 0.0069 \quad \rightarrow \quad i = 0.69\% \qquad (2)$$

In the simulations, the real interest rate was set to 0.69%.

4.1.2 Levelized cost of energy

The HOMER software defines the levelized CoE as the average cost/kWh of useful electrical energy produced by the system. The CoE can be calculated using Equation (3).

$$CoE = \frac{C_{a,t}}{E_{p,AC} + E_{p,\mathrm{DC}} + E_{g,s}} \quad (3)$$

Where, $C_{a,t}$ is total annualized cost [$/year], $E_{p,AC}$ is AC primary load served [kWh/year], $E_{p,DC}$ is DC primary load served [kWh/year], $E_{g,s}$ is total grid sales [kWh/year]. The total annualized cost is the sum of the annualized costs of each system component, plus the other annualized cost. Since the HOMER software uses it in the calculation of both the levelized CoE and the total NPC, it is an important value [16, 17][1,25].

4.1.3 Net present cost (NPC)

The present value of the cost of installing and operating a power system over the lifetime of a project is NPC and is also known as lifecycle cost. The expected lifetime of the project analyzed in this study is considered as 20 years. The total NPC is the main economic output of the HOMER software. Based on NPC, all the systems are ranked and with the purpose of finding the NPC all other economic outputs are calculated. Equation (4) can be used to calculate the NPC[1,25]:

$$C_{NPC} = \frac{C_{a,t}}{CRF(i, R_p)} \quad (4)$$

where, CRF is capital recovery factor, R_p is project lifetime [year]. The CRF is a ratio used in the calculation of the present value of an annuity. The CRF is given by Equation (5).

$$CRF(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (5)$$

where N is number of years.

Information about the cost and the technical detail of the main components of HRES is given below. Additionally, the project lifetime is 20 years. The annual real interest rate was set to 9.25% for Turkey[26]. It should be noted that no cost subsidy is available from the government of Turkey.

4.2 PV Panel:

In Turkey, solar energy is one of the most abundant renewable energy sources. Hence, it is selected as one of the basic load suppliers of the proposed system. Each PV module is rated at 1000W, with a nominal voltage of 12V. Model name of the PV modules is generic flat plate with a derating factor of 80% and slope of 21%. Efficiency of PV module is 13% and lifetime of PV module is 20 years. It should be mentioned that the PV array can efficiently generate power during the daytime, from 6 am to 6 pm. Hence, during the night-time, from 6 pm to 6 am, the output power of the solar energy system is almost 0W. To balance this gap, during the night-time, energy will be supplied by either or a combination of the wind turbines, the generators, or the battery. The costs of the capital, replacement, and operating and maintenance of the PV panel are $3000, $2250 and $10/year, respectively[27]. In the HOMER software, PV panel powers change with increment of 5kW from 0kW to 80kW and the most feasible configuration of the hybrid power system is determined by the economy analysis.

4.3 Wind turbine:

In Turkey, wind energy is another abundant renewable energy source. Hence, it is also selected as one of the basic load suppliers of the proposed system. Basically, wind turbines convert wind energy into usable forms of energy. There are many kinds of wind turbines with 20kW of power capacity. Power curves of wind turbines are demonstrated in the Fig 5. In this study, the most appropriate turbine model is selected among the six different wind turbines with 20kW output power.

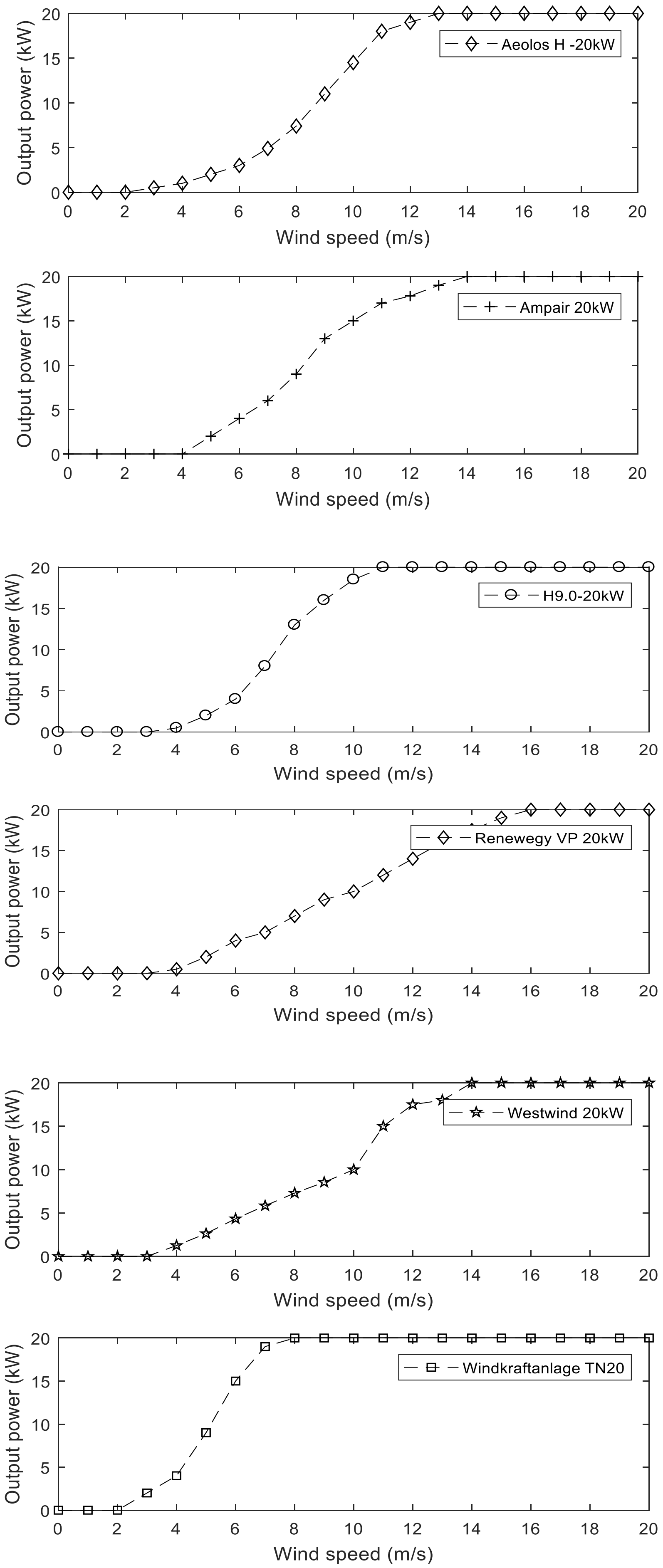

Fig 5. Power Curves of Wind Turbines

In most literature, the following equation is used to simulate the electrical power output of a model wind turbine,

$$P_e = \begin{cases} 0 & v < v_c \\ P_{eR}\dfrac{v - v_c}{v_R - v_c} & v_c \le v \le v_R \\ P_{eR} & v_R \le v \le v_F \\ 0 & v > v_F \end{cases} \quad (6)$$

where P_e is electrical power output of a wind turbine, P_{eR} is the rated electrical power, v_c is the cut-in wind speed, v_R is the rated wind speed, v_F is the cut-off wind speed. However, the average power output. The capacity factor, CF, is defined as the ratio of the average power output over a time period versus the rated electrical power[28,29]

$$CP = \frac{\sum_{i=1}^{17520} P_{e_i}}{17520.P_{eR}} \quad (7)$$

The total generated power by each wind turbine are calculated using the wind speed data between 2014 and 2016 in Esenyurt, Istanbul. The total generated power from the wind turbines and capacity factor are demonstrated in the Table 1.

Table 1 The total generated power from the wind turbines and capacity factor

Model of wind turbine	Aeolos H -20kW [30]	Ampair 20kW [31]	H9.0 20kW [32]	Renewegy VP 20kW [33]	Westwind 20kW[34]	Windkraftanlage TN20kW [35]
Total generated power (kWh)	49.579	51.633	60.184	45.802	49.689	86.728
Output power x 17520 (kWh)	350.400	350.400	350.400	350.400	350.400	350.400
Capacity Factor	14%	15%	17%	13%	14%	25%

When comparing the total power generated from the same power different type of wind turbines, the wind turbine which generates the most energy and has the highest capacity factor should be selected. In this context, it is seen that Windkraftanlage TN20kW is the most suitable wind turbine for Istanbul Esenyurt University Library. Rated power of the wind turbine is about 20kW and its hub height is 50m. Its lifetime is 25 years. The costs of the capital, replacement, and an annual operating and maintenance of the wind turbine are $29000, $25000 and $400, respectively. In the HOMER software, the number of the wind turbines ranges from 0 to 4 and the most feasible configuration of the hybrid power system is determined by the economy analysis[35].

4.4 Power Converter:

Output power of the power converter is 25 kW. It will entirely supply both the PV power and the excess power of the wind turbine that will remain after the load demand is met. Moreover, the power converter has a conversion efficiency of 90%. Hence, the supplied power will be less than 20 kW. The initial and replacement cost of the inverter are $800 and $600, respectively. In addition, operating and maintenance cost and lifetime are about $5/year and 15 years [36].

4.5 Fuel Cell:

The cost of fuel cell varies greatly depending on type of technology, reformer, auxiliary equipment and power converters. At present, a fuel cell cost varies from $3000 to $6000 kW^{-1} [37]. Here, the capital, replacement and operational costs are taken as $3000, $2500 and $0.020/h for a 1kW system, respectively. Four different sizes of fuel cells are taken in the simulation process: 0 (no fuel cell used), 5, 10, 20 and 40 kW. Meanwhile, lifetime and efficiency of the fuel cell are taken as 40,000 h and 50%, respectively.

4.6 Hydrogen tank:

Cost of a tank with 1 kg of hydrogen capacity is assumed to be $1300. The replacement and operational costs are taken as $1200 and $15 $year^{-1}$, respectively. Five different sizes (0, 20, 40, 60, 80 and 100 kg) are included to widen the search space for a cost effective configuration, and the lifetime is also considered as 25 years[37].

4.7 Electrolyze:

Currently production cost of electrolyzers is between $1500 and $3000 kW^{-1}. With improvements in polymer technology, control systems and power electronics it is expected that costs would reduce much in 10 years [8]. In this analysis, various sizes of electrolyzer (0-50 kW) are considered. A 1 kW system has a capital cost of $2000, a replacement cost of $1500 and an operational and maintenance cost of $20. Meanwhile, lifetime is considered as 25 years with efficiency 75%.

5. HRES modellings and operating characteristics:

HRES provides the best conditions for the system operating characteristics by combining two or more renewable power generating technologies. They also offer the advantage of dealing with the diurnal and seasonal characteristics of the available renewable energy sources [23,24]. The standalone PV/wind/Fuel Cell/electrolyzer HRES designed by means of the HOMER software is demonstrated in Fig 5.

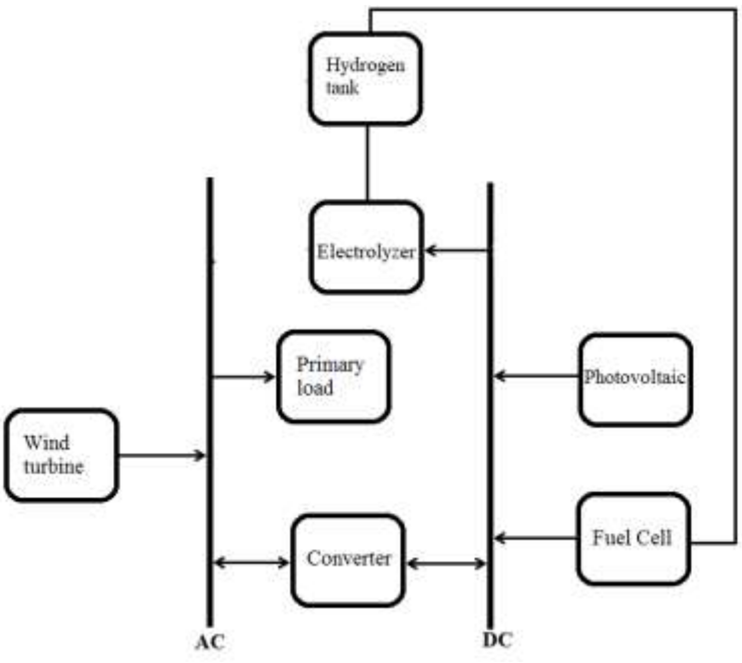

Fig 5. The configuration of the proposed standalone hybrid PV/wind/Fuel Cell/ electrolyzer HRES

The HOMER software takes the following inputs into consideration for the techno-economic analysis: the loads, costs and technical details of components, renewable energy resources availability. Moreover it simply makes simulation of the operating system providing that energy balance is kept during all the time steps. For each step, the energy flows in the system components are calculated by comparing the electric load demand to the generated energy. Added to them, a decision on how to operate the power generators and whether to charge or discharge the batteries is made in each step. Then, the most feasible system configuration and whether the electric load demand could be supplied under the available conditions are determined. Furthermore, it calculates the different type of costs including capital, replacement, operation and maintenance costs to determine the total cost of the considered HRES[10].

The operation principles of the HRES are mentioned below in details.

- ❖ The wind turbines produce alternative current (AC) and supply direct power to the load without having to be diverted.
- ❖ As output power of PV arrays is in DC mode, by using a power converter, it must be converted to the AC power in order to utilize it to meet the AC load demand.
- ❖ PV array and wind turbine are the main load suppliers. After supplying the load demand, if there is remaining excess power, they are going to the electrolyzer, which generates hydrogen for storage in the hydrogen tank. The fuel cell generates electricity using the stored hydrogen as fuel.
- ❖ If the PV module and wind turbines cannot meet the existing demand, the fuel cell will generate electricity to supply the demand.
- ❖ The operating reserve of hourly load is 10% and the operating reserves of renewable output are 40% for wind output power and 25% for solar output power. Note that the operating reserve can be described as safety margin which enables the reliable power supply in spite of the variances in the solar power supply, wind power supply and electricity load.

6. Results and Discussions

The aim of the optimization process is to assess and determine the optimal value of a set of decision variables including the capacity of wind turbines, PV arrays, Fuel Cell, hydrogen tank and power converters as well as electrolyzer. Thanks to the HOMER software, in the optimization process, several different system configurations can be simulated, the infeasible configurations can be discarded, the feasible configurations can be ranked based on the total NPC, and finally the most feasible one with the lowest total NPC and CoE as the optimal system configuration can be viewed[18]. In this study, three different standalone HRES (PV/Wind/Fuel Cell/Electrolyzer, PV/Fuel Cell/Electrolyzer and Wind/Fuel Cell/Electrolyzer) are considered and analyzed using the HOMER software to determine the optimal hybrid power systems for the Central Library of Istanbul Esenyurt University.

In the current case where average solar irradiance and average wind speed are almost 4.28 kWh/m^2/d and 5.64 m/s, respectively;

The optimal system configuration with the lowest total NPC consists of 25kW PV array, 40kW Wind turbine, 20 kW Fuel Cell 25kW, power converter 20kW, 50kW electrolyzer and 100kg hydrogen tank. It is easily noticed from Fig 6 that total NPC of the optimal HRES configuration is anticipated to be $809,442 and CoE is about $2.040/kWh. Besides, the share of the wind turbine in the total cost is the highest with 46% followed by PV panel with 35%, and Fuel Cell with 19%. The total annual electricity production is about 97,514.000kWh consisting of 34,129.9 of PV array and 44,856.44 of wind turbines and 18,527.66kWh. Fig 6 shows the monthly average electricity production from different system components in the optimal HRES.

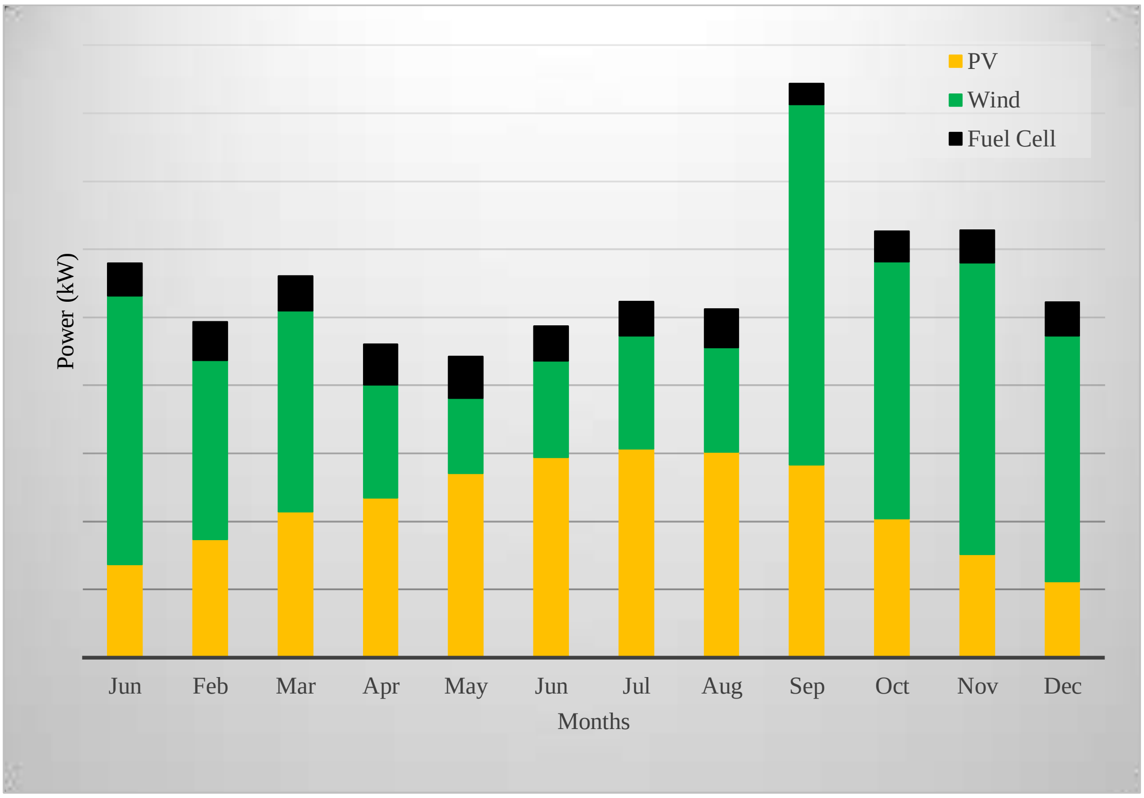

Fig 6. Monthly average electricity production by sources

In addition, the capacity shortage of the optimal system is only %0.1 produced by hybrid power systems always exists and it can be used for different purposes including improving the system reliability [25,26]. Excess energy of the hybrid system is about %1.02. The monthly hydrogen production of the 50kW electrolyzer can be seen from the Fig 7. According to the Fig 7, hydrogen is mostly produced in the months of March, February and April with 5.5 kg/d, 4.46 kg/d and 4.2 kg/d, respectively. Meanwhile, the amount of yearly hydrogen production is 621 kg.

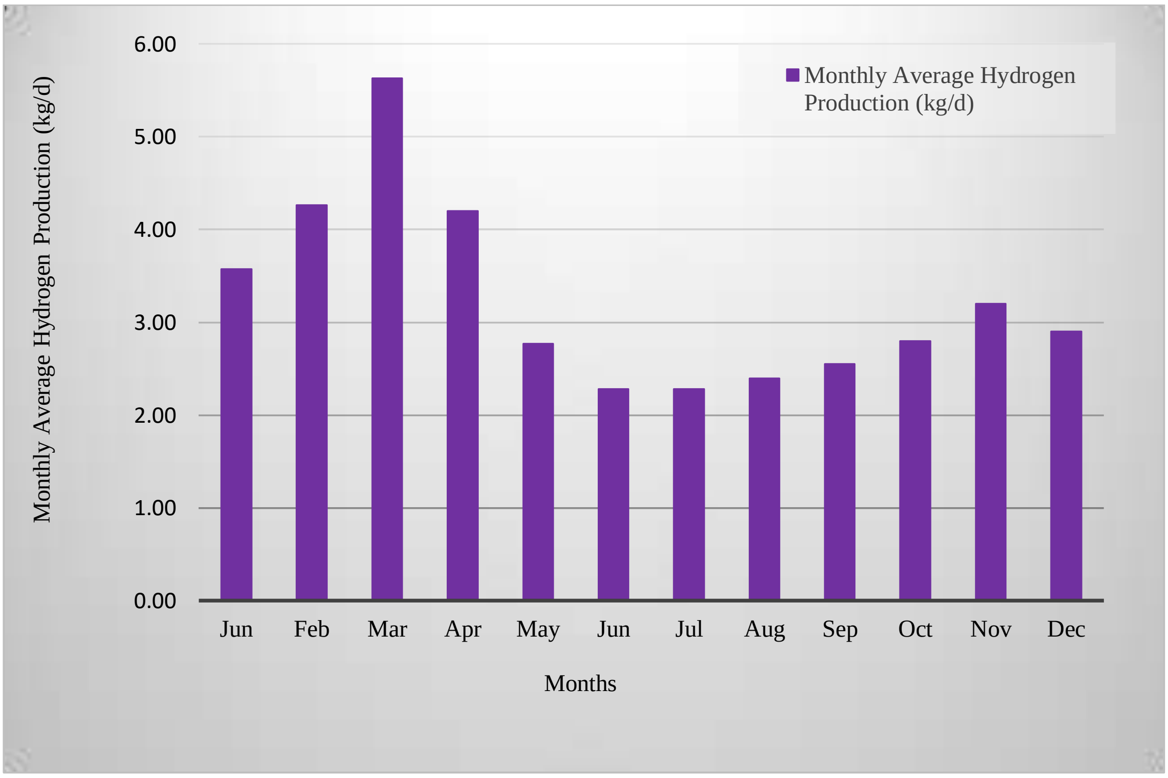

Fig 7 The monthly hydrogen production of the 50kW electrolyzer

Furthermore, renewable fraction in the hybrid power system with optimal configuration is 100. Therefore, electricity generated through this hybrid system is completely clear and no harmful emission gases in this hybrid system are generated and there is no contribution of the HRES to the pollution of environment. Moreover, the emission rates of CO_2, SO_2 and NO_x are exactly zero, that is, there are no dangerous gas emissions to atmosphere caused by the standalone PV/Wind/Fuel Cell/Electrolyzer hybrid systems. Emission values of the standalone PV/Wind/Fuel Cell/Electrolyzer hybrid systems is seen in Table 1.

Table 1. Emission values of the standalone PV/Wind/Fuel Cell/Electrolyzer hybrid systems

Pollutant	**Emissions (kg/year)**
Carbon dioxide	5.44
Carbon monoxide	3.46
Unburned hydrocarbons	0.383
Particulate matter	0.261
Sulfur dioxide	0
Nitrogen oxides	30.9

7. Sensitivity analysis of HRES

Sensitivity analysis aids in assessing the effects of changes or uncertainty in the variables over which a designer has no control such as average solar irradiation and average wind speed. A sensitivity analysis basically reveals how sensitive the outputs are to change in the inputs. In this study, while doing the sensitivity analysis for the HRES, two different sensitivity variables such as average solar global irradiance and average wind speed are taken into consideration. In the sensitivity analysis, the sensitivity variables are considered to be in a proper range which can cover the probable changes in the model inputs in future:

- Average wind speed values vary between 3m/s and 8m/s, that is, five different values are specified.
- Average solar global irradiance values vary in the range of 3 – 8 kWh/m^2/d, with an increment of 1 kWh/m^2/d, that is, five different average solar global irradiance values are specified.
- The total number of sensitivity cases is 36, which is calculated by multiplying of wind speed (6) and solar global irradiance (6) multipliers.
- It is easily understood from Fig 8 that increasing the evaluation range of wind speed and solar radiation value for the sensitivity analysis (they do not only contain the current value of these two sensitivity variables), the Wind/PV/Fuel Cell/Electrolyzer hybrid renewable power generating system among all the systems are more efficiently applicable because it occupies the bigger green area in this Fig. It is followed by Wind/Fuel Cell /Electrolyzer hybrid renewable power generating system marked with blue. Rest of them is PV/Fuel Cell/Electrolyzer hybrid system with marked red.
- Analyzing Fig 8 more detail, while both the solar radiation value is between 3kWh/m^2/day and 5kWh/m^2/day and also the wind speed is lower than 7m/s, the optimum hybrid system is the Wind/PV/Fuel Cell/Electrolyzer renewable hybrid system and it is shown in this Fig as a yellow area.
- Under the conditions that are described like the followings: Both wind speed are between 7m/s and 8m/s and also solar radiation value is upper the value of 3kWh/m^2/day, the region is completely blue, that is, the Wind/Fuel Cell/Electrolyzer hybrid renewable power generating system is the most suitable system.

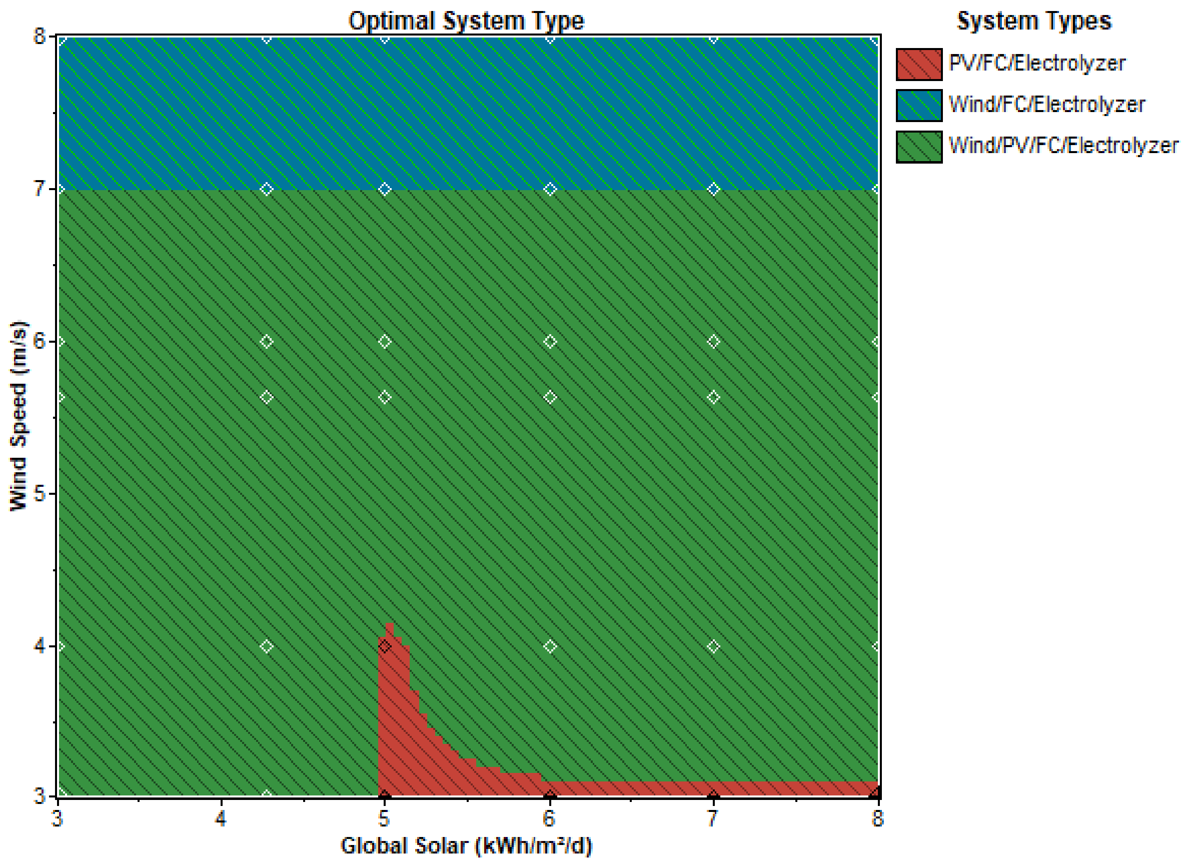

Fig 8. Situation of the standalone HRES for all possible wind speed and solar irradiation values

- In all the line equations in the analysis results of the Fig 8 indicating all the probable PV/Wind/Fuel Cell/Electrolyzer hybrid power generating systems according to the wind speed and solar irradiation values, the variables y and x represent wind speed and solar irradiation, respectively.
- Mathematical modeling of the sensitivity analysis in standalone HRES is demonstrated in Table 2. Specific wind speed and solar radiation values are given in Table 2. It is obtained some linear equations for corresponding to these values to determine the optimal hybrid system configuration among the three different hybrid systems (PV/Wind/Fuel Cell/Electrolyzer, PV/Fuel Cell/Electrolyzer and Wind/Fuel Cell/Electrolyzer).

Table 2. Mathematical modeling of the sensitivity analysis in standalone HRES

Wind speed (m/s)	Solar Radiation	Equation	Color of the area	Type of HRES
$3 \le w_s \le 7$	$3 \le s_r \le 5$	$y = 2x - 3$	Green	Wind/PV/Fuel Cell/Electrolyzer HRES
$3 \le w_s \le 4.1$	$4.9 \le s_r \le 5$	$y = 11x - 50.9$		
$3.1 \le w_s \le 7$	$6 \le s_r \le 8$	$y = 0.05x + 2.7$		
$4.1 \le w_s \le 7$	$5 \le s_r \le 5.5$	$y = 7.8x + 1$		
$4.2 \le w_s \le 7$	$5.5 \le s_r \le 6.5$	$y = 1.4x - 26.6$		
$7 \le w_s \le 8$	$3 \le s_r \le 8$	$y = 0.2x + 6,40$	Blue	Wind/Fuel Cell/Electrolyzer HRES
$3 \le w_s \le 3.1$	$6 \le s_r \le 8$	$y = 0.05x + 2.7$	Red	PV/Fuel Cell/Electrolyzer HRES
$3.1 \le w_s \le 3.3$	$5.5 \le s_r \le 6.0$	$y = 0.4x + 0,9$		
$3 \le w_s \le 3.5$	$4.9 \le s_r \le 5.5$	$y = 0.83x - 1.08$		
$3 \le w_s \le 4.2$	$4.9 \le s_r \le 5.2$	$y = 4x - 16.6$		

8. Conclusions:

All possible standalone and grid connected HRES that can be applied in the Central Library of Istanbul Esenyurt University are investigated in this study. Considering the results obtained in the simulations performed using the HOMER software, for Wind/PV/ Fuel Cell/Electrolyzer HRES the following important outputs can be highlighted.

- Renewable fraction in the hybrid power system with optimal configuration is 100. Therefore, electricity generated through this hybrid system is completely clear and no harmful emission gases in this hybrid system are generated and there is no contribution of the hybrid system to the pollution of environment.
- The optimal system configuration with the lowest total NPC contains 40kW Wind turbine, 20kW Fuel Cell, 25kW PV array, 25kW power converter, 50kW Electrolyzer and 100kg hydrogen tank.
- Total NPC of the optimal HRES configuration is estimated to be $809,442 and COE is about $2.040/kWh.
- Share of the Fuel Cell in the total cost is the highest with 33% followed by PV array with 27%, wind turbine with 23%, and others (hydrogen tank, converter and electrolyzer) with 17%.
- Total electricity generation of the hybrid power system is 97,514.000kWh; shares of wind turbine, PV array, and Fuel Cell in the total cost are almost 46%, 35% and 19%, respectively.

The sensitivity analysis was realized to investigate how the economic parameters of the interested HRES show a change in the case of the strongly probable small or large change in the sensitivity variables in future (solar irradiance value and wind speed). A summary of the results obtained in the sensitivity analysis is given below;

- It can be seen from the results of the sensitivity analysis that the Wind/PV/ Fuel Cell/Electrolyzer HRES renewable hybrid power system among all the systems are more efficiently applicable and this hybrid power system is more suitable for the majority of all possible combinations of wind speed and solar irradiance values.
- Fig 8 including the sensitivity analysis results shows the most suitable HRES under the various conditions.

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