Journal of
Renewable Energy Research and Applications (RERA)
Vol. 3, No. 1, 2022, 21-30 *DOI: 10.22044/rera.2021.10752.1054*

Optimization, Sensitivity Analysis, and Techno-Economic Evaluation of a Multi-Source System for an Urban Community: a Case Study

Reza Alayi [1*], Seyed Reza Seyednouri [2], Mehdi Jahangiri [3], Alfian Ma'arif [4]

1. Department of Mechanical Engineering, Germi Branch, Islamic Azad University, Germi, Iran.
2. Young Researchers and Elite Club, Germi Branch, Islamic Azad University, Germi, Iran.
3. Department of Mechanical Engineering, Shahrekord Branch, Islamic Azad University, Shahrekord, Iran.
4. Department of Electrical Engineering, Universitas Ahmad Dahlan, Yogyakarta, Indonesia.

Receive Date 22 April 2021; Revised 14 May 2021; Accepted Date 16 May 2021
**Corresponding author: reza.alayi@yahoo.com (R. Alayi)*

Abstract

Given the decline of non-renewable energy sources, trying to find new technologies and ways in order to supply energy and reduce fuel consumption is one of the top priorities in the world. One of the new technologies is the fuel cell technology, which has received very little attention in Iran so far, and there is a requirement to study this technology more and more carefully, especially in combination with the renewable energy sources in order to help the energy decision-makers. In the present work, for the first time, a hybrid wind-solar-fuel cell system for residential use in Yazd, located in a hot and dry climate in Iran, is simulated using the HOMER software. The aim is to find an optimal economic system in order to supply 15 kWh of electricity per day, and to assess the impact of uncertainties, the sensitivity analysis is performed on the intensity of solar radiation and wind speed. The simulation results show that the most economical system consisting of a fuel cell is based on wind turbine and solar cell, and has a total NPC, LCOE, and LCOH of $23,674, $0.824 per kWh, and $254.4 per kilogram, respectively. Also not using the battery will lead to a 33.6% increase in the cost per kWh of electricity generated. For the wind speeds of more than 8 m/s, the results obtained show that the optimal system with a fuel cell only includes wind turbines, and therefore, increasing the solar radiation intensity has no effect on the results.

Keywords: *Hybrid system; Fuel cell; Off-grid; LCOE; LCOH.*

1. Introduction

The ever-increasing energy consumption, the rising cost and cost of fossil fuels, and the deteriorating global environment [1] have led to a rapid trend toward the fuel cell-based green power generation systems [2-5]. In the recent decades, the wind [6, 7] and solar [8, 9] energies have grown more among renewable energies, and it has been considered that the wind and solar energies are the most important renewable sources due to their high efficiency and non-emission of polluting gases [10-13]. In addition, one of the most important concerns in the remote and off-grid areas around the world is to provide the sources of electricity for these areas. Connecting these areas to the grid is costly, and in some cases, physically impossible [14-16]. Thus different modes of hybrid systems can be selected for these areas according to the characteristics of the installation area (radiation intensity, ambient temperature, wind speed, etc.) [17-20]. Different energy sources include fuel cell, photovoltaic, wind turbine, etc. [21-23], in combination, can form a hybrid energy system. Therefore, the wind-solar hybrid system is a new source of energy. Due to their cleanliness and renewability, many organizations and countries are interested in using it, and conducting research works in this area [24-26]. Table 1 shows some recent works carried out in the field of power supply by the fuel cell and using its combination with renewable energies inside and outside Iran.

Based on the results tabulated in Table 1 and other studies conducted by the authors of the present work, it can be seen that very little work has been done in the field of technical-economic analysis of the use of the fuel cell-based hybrid renewable system in Iran, in which uncertainties have not been examined. In the present work, for the first time, using the HOMER software, the off-grid wind-solar-fuel cell system to supply electricity to a residential house in a hot and dry climate in Iran (city of Yazd) was studied. The sensitivity analysis was performed on the parameters of wind speed and solar radiation, and it was investigated to find the minimum cost per kWh of electricity and hydrogen produced, and different scenarios were compared, and for the optimal economic system, the return-on-investment time was calculated. Also for the first time, the effect of battery back-up on the performance of an optimal fuel cell-based system was evaluated. It should be noted that the results of the present work can be used for other regions of the world with similar climatic conditions. Although the present work is a case study, the methodology and analysis performed can be used for other regions with different climatic conditions. Using the up-to-date prices for the equipment used, performing the sensitivity analysis and covering the issue of uncertainties as well as using the up-to-date annual interest rates for economic studies are other advantages of the present work compared to the similar previous works.

Table 1. Recent studies on fuel cell power supply in combination with renewable energies.

Reference, Year	Location	Renewable energy used	Purpose	Sensitivity analysis	Connection mode	Electricity demand (kWh/day)	LCOE ($/kWh)
[27], 2019	Egypt	PV	Reverse osmosis desalination	Yes	Off-grid	110	0.062
[28], 2020	China	Wind	Residential house	Yes	Off-grid	10	1.278
[29], 2020	Egypt	Biomass	Small tourist village	Yes	Off-grid	92.2	0.335
[30], 2020	Saudi Arabia	PV	Desalinate seawater	No	Off-grid	522	0.124
[31], 2020	Iran	PV, wind, biomass	Rural electrification	No	Off-grid and on-grid	361	0.164-0.233 (off-grid), 0.096-0.125 (on-grid)
[32], 2021	Iran	PV, wind, tidal	Remote application	No	Off-grid	20-40	0.4477-10.864
[33], 2021	Turkey	PV, wind	Electric vehicle	Yes	Off-grid	11.27	0.685
[34], 2021	Pakistan	PV, wind	Co-generation of electricity, heat, and hydrogen	Yes	Off-grid	15	0.965
Present work	Iran	PV, wind	Residential-scale power	Yes	Off-grid	15	0.824

2. Materials and Methods

In this research work, first, the wind power potential in the city of Yazd was investigated, and in the next phase of the work, after obtaining other required information such as solar energy, electric charge in the desired area, by the HOMER software, the most economical system was obtained by considering the reliability of the hybrid system. Due to the variability of wind speed and the amount of solar radiation as well as taking into account the changes in the costs of different components, the sensitivity analysis have been performed.

2.1. Specifications of studied site

The intensity of solar radiation for the years 1999-2019 was obtained from the Meteorological Organization of Yazd, and then this information was considered as the input for the HOMER software. Based on this, the average annual amount of solar radiation by this software was 5.41 kWh/m^2/d; the diagram can be seen in Figure 1.

The wind for the years 1999-2019 was collected by the Meteorological Organization of Yazd, and then this information was considered as the input for the HOMER software. Based on this, the average annual wind rate was 5.19 m/s by this software, which can be seen in Figure 2.

The required electric load for a residential unit in the city of Yazd was considered. The total power in a day was 15 kWh/d, and the peak load was 2.57 kW, which can be seen in Figure 3.

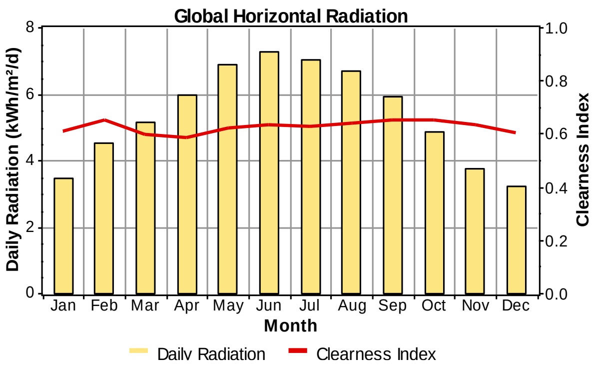

Figure 1: Monthly average solar intensity.

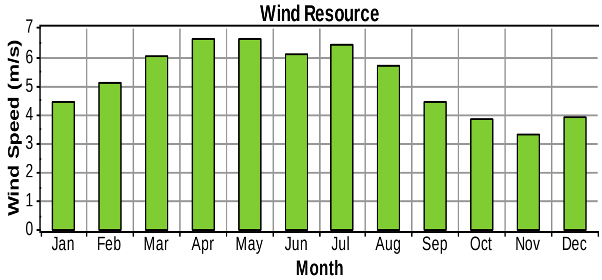

Figure 2: Monthly average wind intensity in the studied area.

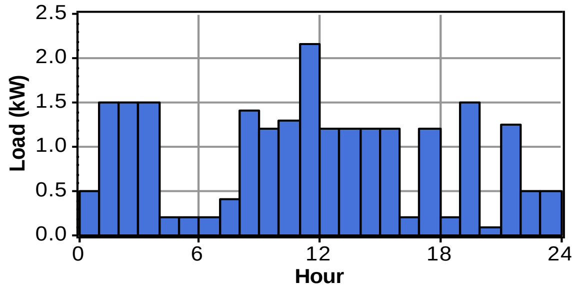

Figure 3: Electric load of the desired residential unit.

2.2. Modeling of studied system

2.2.1. Photovoltaic cells

The power generation simulation model for a photovoltaic system consists of three parts: the power model of the photovoltaic array, the model of solar radiation on the surface of the photovoltaic module, and the temperature of the photovoltaic module. Due to the low effect of the temperature of the photovoltaic module on the result of modeling, this part is ignored [35].

The performance of the photovoltaic module is greatly affected by the weather conditions, especially the solar radiation and temperature of the photovoltaic module. Four non-linear environmental parameters are temperature, radiation intensity, radiation angle, and radiation duration, which are the factors affecting the performance of the photovoltaic module. Using the scatter factor definition, the maximum output power delivered by the photovoltaic module can be written as follows [36]:

$$P_{pv} = V_{oc} \times I_{sc} \times \eta_{MPPT} \quad (1)$$

where, V_{oc} is the open-circuit voltage, I_{sc} is the short-circuiting current, and η_{MPPT} is the maximum power tracing efficiency of the photovoltaic cell since the photovoltaic systems are usually equipped with a maximum power point tracker to maximize the output power.

2.2.2. Wind turbine

The wind turbine output depends on three main factors: aerodynamic efficiency, electrical efficiency, and mechanical transmission. In order to select a wind turbine, the wind speed distribution is very important. In order to model the output power of a wind turbine, the following equation can be used. Given the wind speed (v) of a place, the power generated by a certain type of wind turbine is calculated by Eq. (2) [37]. This equation indicates that the wind turbine generator starts the output power at the cut-in wind speed (V_c). As the wind speed v increases to the rated wind speed (V_r), the output power increases linearly till the rated powerP_{wtr}. When v varies from V_r to the cut-off speed (V_f), the rated power is generated. The wind turbine will be shut down for safety reasons when $v < V_c$ or $v > V_f$.

$$P_{wt} = \begin{cases} 0, & v < V_c \ or \ v > V_f \\ P_{wtr} \times \dfrac{v - V_c}{V_r - V_c} & V_c \le v < V_r \\ P_{wtr} & V_r \le v < V_f \end{cases} \quad (2)$$

The output power of the wind turbine (Figure 4) is strongly dependent on the wind speed, so the selected wind turbine must be above the average load range and must be selected according to the minimum and maximum wind speeds of the area to be able to meet part of the required load. In this research work, a WES 5 Tulipo 2.5 kW AC wind turbine was used [38].

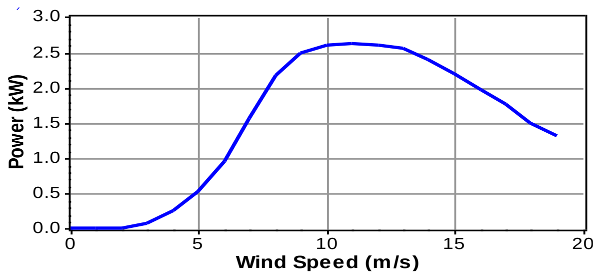

Figure 4: Power generation characteristics of wind turbine.

2.2.3. Fuel cell

In the HOMER software, the electrical efficiency of a fuel cell (η_{FC}) is defined as the output electrical energy divided by the chemical energy of the input fuel, as follows [39]:

$$\eta_{FC} = \frac{3.6 \times E_{FC}}{\mathrm{M}_{H_2} \cdot LHV_{H_2}} \quad (3)$$

In the above equation, E_{FC} is the total annual electricity production of the fuel cell (kWh per year), m_{H_2} is the total annual hydrogen consumption of the fuel cell (kg per year), and LHV_{H_2} is the lower heating value of hydrogen (megajoules per kg).

2.2.4. Battery

In the HOMER software, two independent factors, the lifetime throughput and the storage float life, may limit the battery life. HOMER calculates the battery life in years (R_{batt}) using the following equation [40]:

$$R_{batt} = \begin{cases} \dfrac{N_{batt} \times Q_{lifetime}}{Q_{thrpt}} & if\ limited\ by\ throughput \\ R_{batt,f} & if\ limited\ by\ time \\ MIM\left(\dfrac{N_{batt} \times Q_{lifetime}}{Q_{thrpt}}, R_{batt,f}\right) & if\ limited\ by\ throughputand\ time \end{cases} \quad (4)$$

In the above relation, N_{batt} is the number of batteries in the storage bank, $Q_{lifetime}$ is the lifetime throughput of single storage [kWh], Q_{thrpt} is the annual storage throughput [kWh/yr], and $R_{batt,f}$ is the storage float life [year].

2.2.5. Hydrogen tank

The hydrogen tank autonomy is the ratio of the energy capacity of the hydrogen tank to the electric load. HOMER calculates the hydrogen tank autonomy using the following equation [41]:

$$A_{htank} = \frac{Y_{htank} LHV_{H_2} (24\frac{h}{d})}{L_{prim,ave}\ (3.6\frac{Mj}{kWh})} \quad (5)$$

where Y_{htank} is the capacity of the hydrogen tank [kg], LHV_{H_2} is the energy content (lower heating value) of hydrogen [120 MJ/kg], and $L_{prim,ave}$ is the average primary load [kWh/d].

2.2.6. Electrolyzer

The efficiency of an electrolyzer is the rate of conversion of electricity to hydrogen, and is equal to the energy content of hydrogen based on the higher heating value divided by the amount of the electricity consumed.

2.2.7. Economic analysis

After simulating different system configurations, the software gives a list of configurations based on the total NPC as the output [42]:

$$TOTAL\ NPC = \frac{C_{ann,tot}}{\frac{i(1+i)^N}{(1+i)^N-1}} \quad (6)$$

In the above relation, $C_{ann,tot}$ is the total annual cost, i is the annual interest rate, and N is the useful life of the project. The HOMER software also calculates the levelized cost of energy in $/kWh from the following equation [43]:

$$LCOE = \frac{C_{ann,tot}}{R_{Prim} + R_{tot,grid,sales}} \quad (7)$$

In the above relation, R_{Prim} is the initial load in terms of KWh/year, and $R_{tot,grid,sales}$ is the total electricity sales to the network in terms of KWh/year.

2.3. Modeling of studied system

The general schematic of the hybrid system is shown in Figure 5.

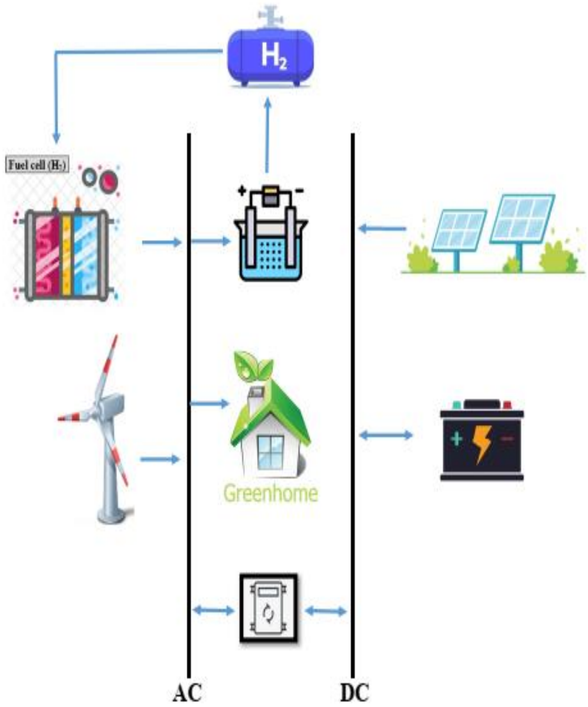

Figure 5: A general schematic representation of a combined wind and solar system with battery storage and hydrogen tank.

According to the above figure, photovoltaic panels, the wind turbines, battery storage systems, and hydrogen tanks are connected to the DC load bus due to the DC power generation. A DC/AC converter converts the total output power of these units into an AC power, and connects to the AC bus for the consumer use. By applying the above information to the software and also the cost of the tools used in the hybrid system, the software is executed, and the system optimization steps are performed.

Table 2 also provides the information on the price, lifetime, type, and size of the equipment used in the present simulation. Other useful information about the equipment used is also listed in this table. The software performance, how to solve, and different stages of simulation by the HOMER software are shown in the flowchart of Figure 6. As it can be seen, the wind and solar data as well as the required electric load are first evaluated, and a renewable energy system is proposed. The proposed system is then evaluated in terms of economics, components, power supply, and the use of renewable energy data. If this system can meet the load demand and is economically viable, the simulation for this scenario will end; otherwise, another system will be proposed and reviewed. The software then examines another scenario for another combination of renewable energy sources, and the process is repeated.

Table 2. Data of simulated hybrid power-plant.

Components	Capital ($)	Replacement ($)	O & M ($)	Lifetime	Other information
PV [44]	2000	2000	10	25 year	No Tracking, Derating factor, 80%
Battery [45]	1200	1100	50	9645 kWh	Surrette 6CS25P
Converter [46]	300	300	0	20 year	Efficiency, 95%
Wind turbine [47]	5000	4000	50	15 year	WES 5 Tulipo, Hub height, 25 m
Fuel cell [34]	3000	2500	0.02	40000 h	Max. efficiency, 50%
Hydrogen tank [34]	574	574	10	25 year	Initial tank level, 20%
Electrolyzer [34]	500	250	10	20 year	Efficiency, 85%

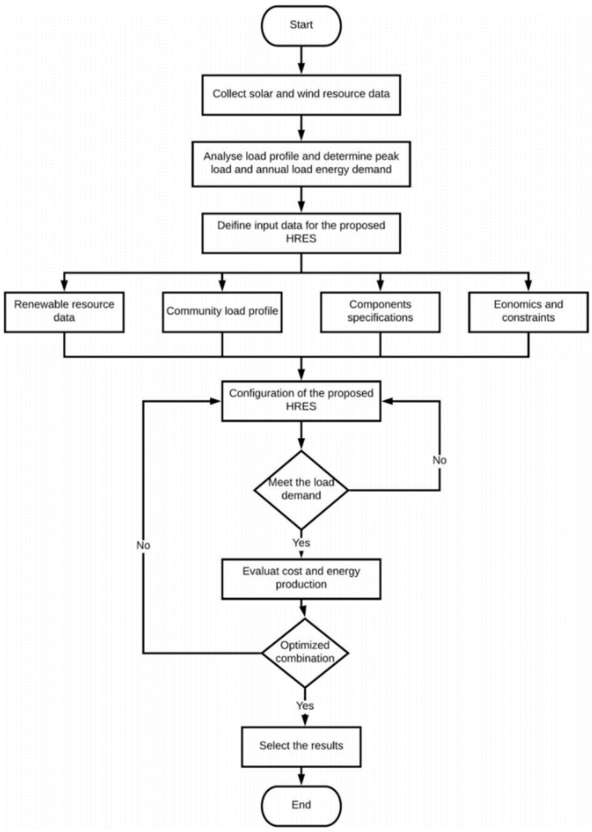

Figure 6: HOMER software performance flow chart [48].

3. Results

The simulation results of different modes are presented in Table 3. In the most optimal economic scenario based on the fuel cell (second scenario), 3 kW of solar cells, a 2.5 kW wind turbine, 2 kW fuel cell, 2 batteries, 2 kW electric converter, and 2 kW electrolyzer are used. In this scenario, the strategy used in the fuel cell is load-following, the total current net cost is $23,647, and the levelized cost of energy (COE) of generated electricity is $0.824. The number of operating hours of the fuel cell in this scenario is equal to 233 h. The significant point that can be seen from Table 3 is the difference between the second and fifth scenarios, which is related to the use of batteries in the second scenario, and not using it in the fifth scenario. Based on the results obtained, it can be seen that the role of battery storage in the systems including fuel cells, which does not use the battery, causes growth of about 33.6% in LCOE.

Figure 7 shows the average monthly electricity generation for the second scenario. From the results obtained, it is clear that the highest percentage of electricity production with 59% is related to wind energy, solar energy with 39% and fuel cell with 2% are in the next categories. According to Figure 7, the highest fuel cell usage is in November and December.

The fuel cell performance is shown in Figure 8, which according to the software results, is the result of 165 starts during the year and leads to a capacity factor of 1.27% and an annual hydrogen consumption of 15.8 kg. The electrolyzer performance is also shown in Figure 9, which has a capacity factor of 4.6% and has a performance of 1325 h during the year. According to the software results, with the annual production of 17.4 kg of hydrogen by the electrolyzer, the specific consumption of the electrolyzer is 46.4 kWh per kg and the Levelized cost of energy of hydrogen produced is equal to $254.4. This recent result indicates the immaturity of the fuel cell technology in Iran compared to the other types of renewable energy technologies.

The cheapest hydrogen produced at $31.7 per kg is in Scenario 1, which uses 3 kW of solar cells, a 2.5-kW wind turbine, six batteries, three 1-kW electric converters, and a 2-kW electrolyzer. The LCOE parameter for this scenario is $0.81. Figure

10 provides an economic comparison between the optimal system including the fuel cell (Scenario 2) and the system with the cheapest hydrogen produced during the 20 years of the useful life of the project. The results obtained show that the return on investment is 11 years for Scenario 2 compared to Scenario 1. At the end of the 20-year project's lifetime, Scenario 2 costs $8946 less than Scenario 1, which is due to the fact that the operating cost of Scenario 2 is about half the operating cost of Scenario 1. Table 4 shows the results of the sensitivity analysis for the most economical fuel cell-based system. Based on the results obtained, it can be seen that for a wind speed of 5.19 m/s, the optimal system has a fuel cell including a wind turbine and a solar cell. The results also show that with increase in the intensity of solar radiation, the need for solar cells is reduced, and also LCOE decreases. For wind speeds of more than 8 m/s, the results show that the optimal system with a fuel cell only includes wind turbines, and therefore, increasing the intensity of solar radiation has no effect on the results. LCOE and LCOH costs are reduced as the wind speeds increase from 8 m/s to 12 m/s, and since more surplus electricity is generated, more hydrogen is produced, and the amount of electricity generated by the fuel cell also increases. As a general conclusion, it can be stated that according to the results of Table 4 for the optimal economic system including the fuel cell, the effect of wind speed is much greater than the intensity of solar radiation, and for high wind speeds, the optimal economic system includes a fuel cell containing only a wind turbine.

Table 3: Simulation results with HOMER software.

Scenario	PV (kW)	WES%	FC (kW)	S6CS25P	Conv. (kW)	Elec. (kW)	H_2 Tank (kg)	Disp. Strgy.	Initial Capital ($)	Operating Cost ($/year)	Total NPC ($)	COE ($/kWh)	FC (h)
1	3	1	0	6	3	2	0	CC	20100	590	23259	0.810	0
2	3	1	2	2	2	2	2	LF	22148	285	23647	0.824	233
3	5	0	2	4	3	2	6	LF	26144	405	28313	0.986	436
4	0	2	2	4	2	2	8	LF	26922	570	30044	1.046	338
5	4	2	2	0	3	4	4	CC	29196	452	31616	1.101	2634

Table 4: Simulation results with HOMER software.

Global solar (kWh/m^2-day)	Wind speed (m/s)	PV (kW)	WES%	FC (kW)	S6CS25P	Conv. (kW)	Elec. (kW)	H_2 Tank (kg)	LCOE ($/kWh)	FC production (kWh/year)	LCOH ($/kg)
5.41	5.19	3	1	2	2	2	2	2	0.824	223	254.4
8	5.19	1	1	2	2	2	2	2	0.753	224	232.2
12	5.19	1	1	2	2	2	2	2	0.753	209	248.9
5.41	8	0	1	2	2	1	2	4	0.648	589	77.8
8	8	0	1	2	2	1	2	4	0.648	589	77.8
12	8	0	1	2	2	1	2	4	0.648	589	77.8
5.41	12	0	1	2	2	1	2	2	0.606	712	63.7
8	12	0	1	2	2	1	2	2	0.606	712	63.7
12	12	0	1	2	2	1	2	2	0.606	712	63.7

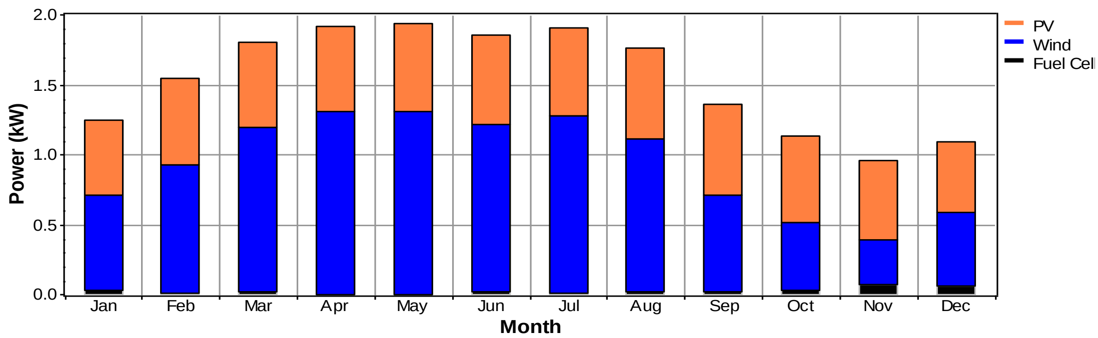

Figure 7: Average monthly electricity generation for the best economic scenario with the fuel cell.

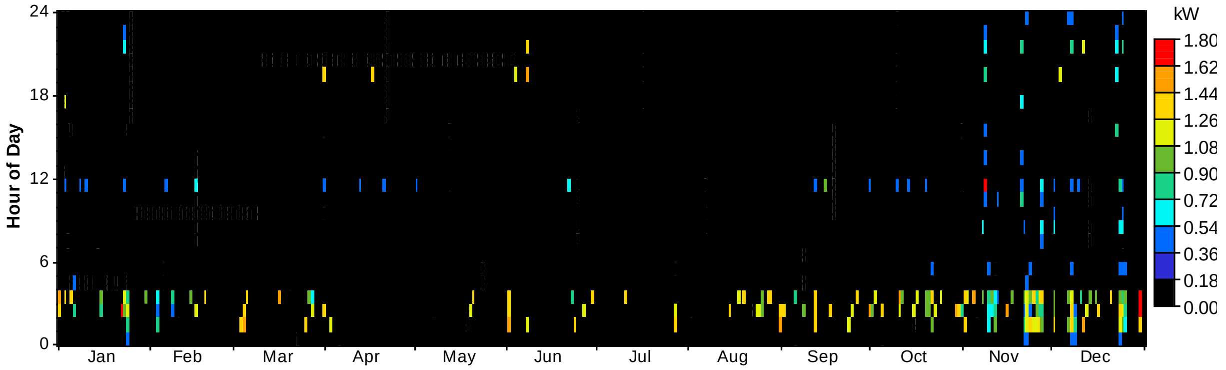

Figure 8: Fuel cell output power for the best economic scenario with the fuel cell.

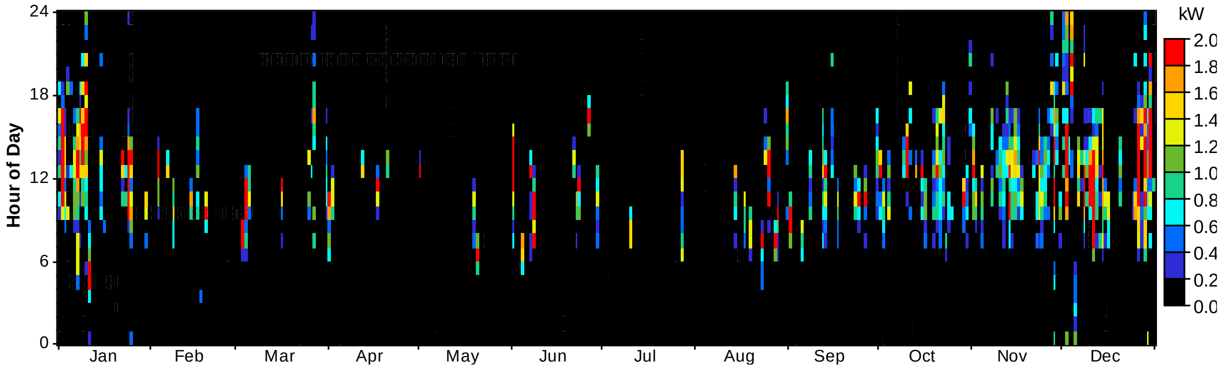

Figure 9: Power input to the electrolyzer for the best economic scenario with the fuel cell.

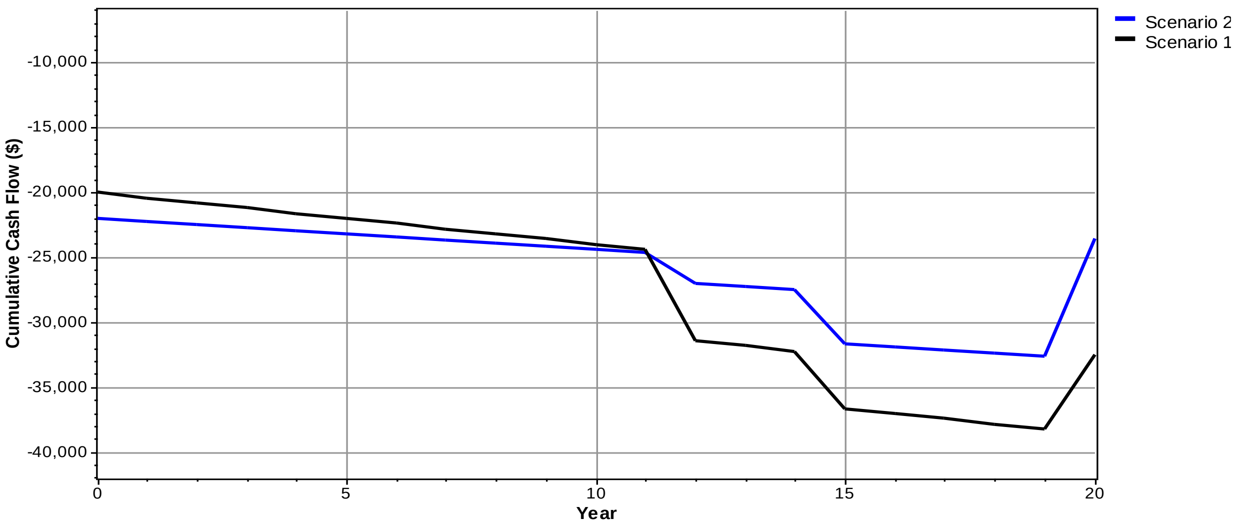

Figure 10: Economic comparison of scenarios 1 and 2.

4. Conclusions

The features such as the high efficiency of fuel cells, proper performance of these sources in anonymous load, low pollution, noiselessness, lack of moving parts, variety of the fuels used, and a wide range of capacities of these sources can be named as the main reasons to use them. On the other hand, there are no economic incentives for the private investors in order to use these resources, and due to the high construction costs, the investors will not have a suitable return on investment. Therefore, the energy researchers in different parts of the world are trying to develop these resources technically and economically, and make them available with lower construction costs and higher efficiency. Methods such as combining with wind and solar sources are such efforts. Therefore, considering the limited number of works that have been carried out in the field of technical-economic-environmental-energy potential of fuel cell energy in Iran, in the present work, a solar cell-wind turbine-fuel cell system for a hot and dry climate (city of Yazd) was conducted. The investigations were performed by the HOMER software, and an attempt was made in order to cover the uncertainty in the parameters such as the solar radiation and wind speed by performing the sensitivity analysis. The parameters under consideration are finding the optimal economic system, the total net current cost, the levelized cost of energy, the amount of hydrogen produced, and so on. The important results of the present work are as follow:

- In the systems including the fuel cells, the battery plays an important role in the costs.
- In the studied area, the wind energy potential is more than the solar energy potential, and the solar energy potential is more than the fuel cell potential.
- For the optimal system, the levelized cost of energy per kWh of electricity generated and each kg of hydrogen generated are $0.824 and $254.4, respectively.
- The return on investment for the most economical scenario including the fuel cell is 11 years compared to the scenario of the cheapest hydrogen produced.
- Based on the results of the sensitivity analysis, for the optimal economic system including the fuel cell the effect of wind speed is much greater than the intensity of solar radiation.
- Although due to various issues such as the high cost, the fuel cell cannot compete with the conventional methods of electricity generation in Iran, rapid advances in this technology show a very clear horizon for it.

5. References

[1] Assad, M.E.H., Khosravi, A., Malekan, M., Rosen, M.A., and Nazari, M.A. (2021). Energy storage. In Design and Performance Optimization of Renewable Energy Systems, Academic Press: 205-219.

[2] Alayi, R., Kasaeian, A., and Atabi, F. (2019). Thermal analysis of parabolic through concentration photovoltaic/thermal system for use in buildings. Environmental Progress and Sustainable Energy, 38(6): 13220.

[3] Kasaeian, A., Shamel, A., and Alayi, R. (2015). Simulation and economic optimization of wind turbines and photovoltaic hybrid system with storage battery and hydrogen tank (case study: the city of Yazd). Journal of Current Research in Science, 3(5): 105.

[4] Cheng, L., Zhang, F., Li, S., Mao, J., Xu, H., Ju, W., and Li, M. (2020). Solar energy potential of urban buildings in 10 cities of China. Energy, 196, 117038.

[5] Alayi, R., Sobhani, E., and Najafi, A. (2020). Analysis of environmental impacts on the characteristics of gas released from biomass. Anthropogenic Pollution Journal, 4(1): 1-14.

[6] Ehyaei, M.A. and Assad, M.E.H. (2021). Energy and exergy analyses of wind turbines. In Design and Performance Optimization of Renewable Energy Systems, Academic Press: 195-203.

[7] Abidoye, L.K., Bani-Hani, E., El Haj Assad, M., AlShabi, M., Soudan, B., and Oriaje, A.T. (2020). Effects of environmental and turbine parameters on energy gains from wind farm system: Artificial neural network simulations. Wind Engineering, 44(2): 181-195.

[8] Alayi, R., Kumar, R., Seydnouri, S.R., Ahmadi, M.H., and Issakhov, A. (2020). Energy, environment, and economic analyses of a parabolic through concentrating photovoltaic/thermal system. International Journal of Low-Carbon Technologies. ctaa086,

[9] AlShabi, M., Ghenai, C., Bettayeb, M., Ahmad, F.F., and Assad, M.E.H. (2020). Multi-group grey wolf optimizer (MG-GWO) for estimating photovoltaic solar cell model. Journal of Thermal Analysis and Calorimetry: 1-16.

[10] Wang, Q. and Wang, L. (2020). Renewable energy consumption and economic growth in OECD countries: A non-linear panel data analysis. Energy, 207: 118200.

[11] Alayi, R. and Jahanbin, F. (2020). Generation Management Analysis of a Stand-alone Photovoltaic System with Battery. Renewable Energy Research and Application, 1(2), 205-209.

[12] Wojuola, R.N. and Alant, B.P. (2019). Sustainable development and energy education in Nigeria. Renewable Energy, 139: 1366-1374.

[13] Alayi, R., Ahmadi, M.H., Visei, A.R., Sharma, S., and Najafi, A. (2020). Technical and environmental analysis of photovoltaic and solar water heater cogeneration system: a case study of Saveh City. International Journal of Low-Carbon Technologies. ctaa077,

[14] Alayi, R. and Rouhi, H. (2020). Techno-economic analysis of electrical energy generation from urban waste in Hamadan, Iran. International Journal of Design and Nature and Ecodynamics, 15(3): 337-341.

[15] Pahlavan, S., Jahangiri, M., Alidadi Shamsabadi, A., and Khechekhouche, A. (2018). Feasibility Study of Solar Water Heaters in Algeria, a Review. Journal of Solar Energy Research, 3(2): 135-146.

[16] Alayi, R., Kasaeian, A., and Atabi, F. (2020). Optical modeling and optimization of parabolic through concentration photovoltaic/thermal system. Environmental Progress and Sustainable Energy, 39(2): e13303.

[17] Alayi, R., Khan, M.R.B., and Mohmammadi, M.S.G. (2020). Feasibility study of grid-connected PV system for peak demand reduction of a residential building in Tehran, Iran. Mathematical Modelling of Engineering Problems, 7(4), pp. 563-567.

[18] Mustafayev, R.I., Hasanova, L.H., and Musaev, M.M. (2018). Using regulated electrical machines in small hydropower plants operating in a power network. Russian Electrical Engineering, 89(5): 322-327.

[19] Maatallah, T., Ghodhbane, N., and Nasrallah, S.B. (2016). Assessment of viability for hybrid energy system (PV/wind/diesel) with storage in the northernmost city in Africa, Bizerte, Tunisia. Renewable and Sustainable Energy Reviews, 59: 1639-1652.

[20] Vasel, A., Iakovidis, F. (2017). The effect of wind direction on the performance of solar PV plants. Energy Conversion and Management, 153: 455-461.

[21] Yu, H., Zhang, C., Deng, Z., Bian, H., Sun, C., and Jia, C. (2018). Economic optimization for configuration and sizing of micro-integrated energy systems. Journal of Modern Power Systems and Clean Energy, 6(2): 330-341.

[22] Alayi, R. and Velayti, J. (2021). Modeling/Optimization and Effect of Environmental Variables on Energy Production Based on PV/Wind Turbine Hybrid System. Jurnal Ilmiah Teknik Elektro Komputer dan Informatika (JITEKI), 7(1), 101-107.

[23] Alayi, R., Jahangeri, M., and Monfared, H. (2020). Optimal location of electrical generation from urban solid waste for biomass power plants. Anthropogenic Pollution Journal, 4(2), 44-51.

[24] Al-Masri, H.M. and Ehsani, M. (2015). Feasibility investigation of a hybrid on-grid wind photovoltaic retrofitting system. IEEE Transactions on Industry applications, 52(3): 1979-1988.

[25] Al-Janahi, S.A., Ellabban, O., and Al-Ghamdi, S.G. (2020). Techno economic feasibility study of grid-connected building-integrated photovoltaic system for clean electrification: A case study of Doha metro. Energy Reports, 6: 407-414.

[26] Al-Sharafi, A., Sahin, A.Z., Ayar, T., and Yilbas, B.S. (2017). Techno-economic analysis and optimization of solar and wind energy systems for power generation and hydrogen production in Saudi Arabia. Renewable and Sustainable Energy Reviews, 69: 33-49.

[27] Rezk, H., Sayed, E.T., Al-Dhaifallah, M., Obaid, M., Abou Hashema, M., Abdelkareem, M.A., and Olabi, A.G. (2019). Fuel cell as an effective energy storage in reverse osmosis desalination plant powered by photovoltaic system. Energy, 175: 423-433.

[28] Li, C. (2021). Technical and economic potential evaluation of an off-grid hybrid wind-fuel cell-battery energy system in Xining, China. International Journal of Green Energy, 18(3): 258-270.

[29] Samy, M.M., Elkhouly, H.I., and Barakat, S. (2020). Multi-objective optimization of hybrid renewable energy system based on biomass and fuel cells. International Journal of Energy Research, 2020: 1-17.

[30] Rezk, H., Alghassab, M., and Ziedan, H.A. (2020). An optimal sizing of stand-alone hybrid PV-fuel cell-battery to desalinate seawater at Saudi NEOM city. Processes, 8(4): 382.

[31] Rad, M.A.V., Ghasempour, R., Rahdan, P., Mousavi, S., and Arastounia, M. (2020). Techno-economic analysis of a hybrid power system based on the cost-effective hydrogen production method for rural electrification, a case study in Iran. Energy, 190: 116421.

[32] Naderipour, A., Abdul-Malek, Z., Nowdeh, S.A., Kamyab, H., Ramtin, A.R., Shahrokhi, S., and Klemeš, J.J. (2021). Comparative evaluation of hybrid photovoltaic, wind, tidal, and fuel cell clean system design for different regions with remote application considering cost. Journal of Cleaner Production, 283: 124207.

[33] Turkdogan, S. (2021). Design and optimization of a solely renewable-based hybrid energy system for residential electrical load and fuel cell electric vehicle. Engineering Science and Technology, an International Journal, 24(2): 397-404.

[34] Jahangiri, M., Mostafaeipour, A., Rahman Habib, H.U., Saghaei, H., and Waqar, A. (2021). Effect of Emission Penalty and Annual Interest Rate on Cogeneration of Electricity, Heat, and Hydrogen in Karachi: 3E Assessment and Sensitivity Analysis. Journal of Engineering, 2021: 6679358.

[35] Alayi, R., Kasaeian, A., Najafi, A., and Jamali, E. (2020), "Optimization and evaluation of a wind, solar, and fuel cell hybrid system in supplying electricity to a remote district in national grid", International Journal of Energy Sector Management, Vol. 14, No. 2, pp. 408-418.

[36] Jahangiri, M., Khosravi, A., Raiesi, H.A., and Mostafaeipour, A. (2017). Analysis of standalone PV-based hybrid systems for power generation in rural area. In International Conference on Fundamental Research in Electrical Engineering (ICEEC-2017), Tehran, Iran: 1-0.

[37] Mostafaeipour, A., Rezaei, M., Jahangiri, M., and Qolipour, M. (2020). Feasibility analysis of a new tree-shaped wind turbine for urban application: A case study. Energy and Environment, 31(7): 1230-1256.

[38] Abdali, T., Pahlavan, S., Jahangiri, M., Alidadi Shamsabadi, A., and Sayadi, F. (2019). Techno-Econo-Environmental study on the use of domestic-scale wind turbines in Iran. Energy Equipment and Systems, 7(4): 317-338.

[39] Pahlavan, S., Jahangiri, M., Alidadi Shamsabadi, A., and Rahimi Ariae, A. (2019). Assessment of PV-based CHP system: Effect of heat recovery factor and fuel type. Journal of Energy Management and Technology: 3(1), 40-47.

[40] Jahangiri, M., Nematollahi, O., Haghani, A., Raiesi, H.A., and Alidadi Shamsabadi, A. (2019). An optimization of energy cost of clean hybrid solar-wind power plants in Iran. International Journal of Green Energy, 16(15): 1422-1435.

[41] Jahangiri, M., Haghani, A., Heidarian, S., Alidadi Shamsabadi, A., and Pomares, L.M. (2018). Electrification of a tourist village using hybrid renewable energy systems, Sarakhiyeh in Iran. Journal of Solar Energy Research, 3(3): 201-211.

[42] Jahangiri, M., Shamsabadi, A.A., Riahi, R., Raeiszadeh, F., and Dehkordi, P.F. (2020). Levelized Cost of Electricity for Wind-Solar Power Systems in Japan, a Review. Journal of Power Technologies, 100(3): 188-210.

[43] Jahangiri, M., Soulouknga, M.H., Bardei, F.K., Shamsabadi, A.A., Akinlabi, E.T., Sichilalu, S.M., and Mostafaeipour, A. (2019). Techno-econo-environmental optimal operation of grid-wind-solar electricity generation with hydrogen storage system for domestic scale, a case study in Chad. International Journal of Hydrogen Energy, 44(54): 28613-28628.

[44] Kalbasi, R., Jahangiri, M., Nariman, A., and Yari, M. (2019). Optimal Design and Parametric Assessment of Grid-Connected Solar Power Plants in Iran, a Review. Journal of Solar Energy Research, 4(2): 142-162.

[45] Moein, M., Pahlavan, S., Jahangiri, M., and Alidadi Shamsabadi, A. (2018). Finding the minimum distance from the national electricity grid for the cost-effective use of diesel generator-based hybrid renewable systems in Iran. Journal of Renewable Energy and Environment, 5(1): 8-22.

[46] Mostafaeipour, A., Jahangiri, M., Haghani, A., Dehshiri, S.J.H., Dehshiri, S.S.H., Sedaghat, A., and Techato, K. (2020). Statistical evaluation of using the new generation of wind turbines in South Africa. Energy Reports, 6: 2816-2827.

[47] Ariae, A.R., Jahangiri, M., Fakhr, M.H., and Shamsabadi, A.A. (2019). Simulation of Biogas Utilization Effect on the Economic Efficiency and Greenhouse Gas Emission: A Case Study in Isfahan, Iran. International Journal of Renewable Energy Development, 8(2): 149-160.

[48] Mostafaeipour, A., Qolipour, M., Rezaei, M., Jahangiri, M., Goli, A., and Sedaghat, A. (2020). A novel integrated approach for ranking solar energy location planning: A case study. Journal of Engineering, Design and Technology, Ahead-of-print.