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A renewable energy solution for stand-alone power generation: A case study of KhshU Site-Iran

Mojtaba Haratian [a,*], Pouya Tabibi [a], Meisam Sadeghi [a], Babak Vaseghi [b], Amin Poustdouz [a]

[a] Department of Mechanical Engineering, Khomeinishar Branch, Islamic Azad University, Khomeinishar /Isfahan, Iran
[b] Research Director, Motor Power Tech, Canada

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ABSTRACT

In order to offer cost-effective options to supersede fossil fuel resources, we developed a research methodology based on techno-economic feasibility analysis. The purpose of this paper is to find off-grid renewable energy solutions, including solar panel, wind turbine and batteries as possible options for zero-emission stand-alone power generation in KhshU Site, a renewable energy laboratory in Iran. The HOMER software, which determines the most cost effective system for a given load by considering incident solar radiation, wind speed, electrical demand profile, and equipment characteristics, was employed. The results revealed that the most economical configuration among different renewable energy systems (RES's) was the PV-battery, which has a total net present cost (NPC) of 8173 US$ and a cost of energy (COE) of 0.546 $/kWh, followed by the hybrid PV/wind/battery. Sensitivity analysis demonstrated that raising discount rates could increase the cost of energy while net present cost of the entire system would be reduced in any inflation rate. The analysis also showed that the wind speed variation between 3 and 6 m/s didn't have a considerable effect on NPC and COE.

1. Introduction

Considering cleanliness as producing no burden on the environment in terms of waste emissions, resource extractions, or other environmental disruptions, It cannot be indicated that all renewable energy sources are intrinsically clean; however, comparing with increased controls on conventional energy systems, applying these sources results in a cleaner energy system, which is also more sustainable [1].

Technology development in solar and wind energy has encouraged countries to turn to one of these energies regarding their geographical conditions, especially for electricity production [2]. To augment the reliability, complementary features of wind and solar sources are blended by hybrid wind/PV power systems with the aid of a storage device. Even in such a case, in extended cloudy days and non-windy ones, the need for a battery bank capacity should be met in order to provide power to the electrical load demand. Therefore, the importance of hybrid power system is highlighted by the optimum fitting of system parts [3]. There have been numerous studies related to the evaluation and optimization of hybrid renewable power generation systems in different areas of the word.

In 1998, Kellogg developed the earliest model of optimal sizing methodology for hybrid systems, using an iterative method [4]. This approach has been followed by a large number of other studies in order to size the hybrid systems via mathematical methods. They have considered the minimum levelized cost of energy by using iterative methods [5–7].

In addition to mathematical model developed by different researchers, various pieces of software have been developed by different companies, using the same techniques. A review was conducted by Sinha and Chandel to investigate different features of optimization software such as HOMER, Hybrid2, RETScreen, iHOGA, INSEL, etc. [8]. Being found as the most frequently used tool among the nineteen software tools, Homer (Hybrid Optimization Model for Electric Renewable) was developed by National Renewable Energy Laboratory (NREL) of the USA.

Optimal planning in HOMER is based on the technical feasibility assessment of a system, considering the minimum total net present cost (NPC) of the system and the levelized cost of energy (COE). The

* Corresponding author.
E-mail address: haratian@iaukhsh.ac.ir (M. Haratian).

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Nomenclature

C_T	Total annualized cost of system ($/year)
CRF	Capital recovery factor
C	Cost ($)
COE	Levelized Cost of Energy ($/kWh)
C_{OM}	Operation and maintenance (O&M) cost ($)
C_R	Replacement cost ($)
C_S	Salvage value ($)
NPC	Net Present Cost ($)
N	System life time (year)
I	Interest rate (%)
N	Lifetime of project (year)
Trem	Remaining lifetime of equipment (year)
Tcom	Lifetime of component (year)
E	Electrical energy (kWh)
V	Wind speed (m/s)
Subscripts	
PV	Photovoltaic
W.T	Wind turbine
NREL	National Renewable Energy Laboratory
HOMER	Hybrid Optimization Model for Electric Renewable
RES	Renewable Energy System
O&M	Operating and maintenance

application of HOMER, as a common piece of software all over the word, particularly in developing countries [9], has been reviewed in the literature.

Chong Li et al. conducted a techno-economic feasibility study in which they analyzed an autonomous hybrid wind/photovoltaic (PV)/battery power system in terms of the renewable energy sources and load data research. The study was carried out in a household in Urumqi, China, using HOMER simulation software. The ambient temperature, the various load, and PV module tilt angles were taken into account in this simulation [10]. They performed a sensitivity analysis, then found it had a better performance than the wind energy for their proposed model. They also found that Net Present Cost (NPC) of their model increased while the primary load increased. Finally, they found that the generation of PV module using hybrid system including tracking system performed better than optimized PV module tilt angle.

To find out the best hybrid technology combination for electricity generation, a piece of research was designed by Rohit Sen et al. The research used HOMER software to find optimal plan to meet the electrical needs in an off-grid remote village in Parlari, Chhattisgarh, India. Having considered four renewable resources, small-scale hydropower, solar photovoltaic systems, wind turbines, and bio-diesel generators, the results showed that hybrid configuration of renewable energy resources, compared to grid extension, can be cost-effective, sustainable, techno-economically viable, and environmentally sensible [11].

Considering net present cost, initial capital cost, and cost of energy as economic indicators, a techno-economic feasibility analysis was conducted in three off-grid villages in Colombia, where had unique climatic characteristics. HOMER software was used to apply photovoltaic (PV) panels, wind turbines, and diesel generators in a standalone hybrid power generation system for rural electrification. The results indicated that an important obstacle was the need for a larger investment, which could hinder application of these systems in the considered communities. However, in long-term, the most preferable designs were renewable and hybrid configurations in an environmental point of view and were economically convenient as well [12].

To meet the electrical power generation need for an average house of 150 $m^{2,}$ situated in Ineck region of Ankara, Turkey, a combination of photovoltaic solar panels, a small scale wind turbine, an electrolyzer, and a proton exchange membrane fuel cell hybrid system was proposed because of the intermittent nature of one renewable energy resource for satisfying the electrical energy need of even a single house. The upshot showed the potential of the hybrid system to meet the electrical need of the house all year round, except November. The proposed system produces an amount of energy that exceeds the demand in many months and this extra amount can be applied in order to support the cooling and heating systems of the house [13].

Shezan et al. [14] investigated the performance of an off-grid PV (photovoltaic)-wind-diesel-battery hybrid energy system which was going to be used in KLIA Sepang Station of Malaysia. The results of an in-depth simulation by HOMER regarding the manufacturing cost and efficiency for the suggested optimized hybrid energy system revealed less COE and NPC, compared to those of the conventional power plants, of about $ 1.88/kWh and $ 288,194.00 respectively. What stands out from the comparison between the designed hybrid system and conventional power plants is the reduction of CO_2 and other greenhouse gas emissions by 16 tons and 25% per annum, which makes it a considerable environmentally friendly energy system to the earth.

During the last decade of the 20th century, Iran as one of the leading countries in oil production, experienced some great changes, also followed the trend of utilizing renewable resources in the fourth development program. However, Iran's trend did not seem to converge well with its global counterparts mainly because of Iran's tight dependency on the fossil fuel consumption [15].

Regarding geographical conditions Iran, with an area of approximately 1600,000 km^2, benefits from 300 annual clear sunny days, which results in an average 2200 kWh solar radiation per square meter. Iran's ministry of energy is carrying out 11 projects to reach the maximum solar energy capacity of the country. The solar energy potential in Iran is 9 million MWh energy produced from only 1% of the total area, applying 10% system efficiency for solar energy harness. As a case in point, the total photovoltaic power installed in 2010 was 67 MW at the end of a 6 year period, started in 2004, with 14,020 MW ([16]. What stands out from the researches in this country is that the estimated mean capacity factor of wind parks, built in 45 existing sites in 26 regions, is 33%, with a significant wind potential of approximately 6500 MW applying wind turbines of 60,000 MW [17].

To evaluate renewable energy generation potential in different cities of Iran, a lot of studies have been carried out. The studies consist of assessment and feasibility study of wind energy potential in cities such as Semnan [18], Aligodarz [19], Zahedan [20,21], North and South Khorasan [22], Shahrbabak [23], Kerman [24], Ardebil [2]. Research also includes the assessment of wind and solar energy potential in Salafchegan, Kish and Chabahar [25]. There have been many research works related to renewables in Iran which shows that implementing renewables are economically feasible in the country [26–30,2,20,21]. Many researches have been performed to show the importance of renewable energies across the world [31,32]. There have been recent research in Iran to produce hydrogen from renewable energy which is a unique work in this regards [33]. Zarezade and Mostafaeipour [34] identified factors which affect using of solar energy for city of Yazd in central part of Iran [35]. have recently evaluated passive systems as one of renewables for buildings. Their study indicated that using the passive would yield to enormous saving.

Recently, an in-depth study has been carried out in four specific sites, as candidates for research centers, in Iran with high potential for wind and solar energy. The outcomes obtained from a computer program reveal that the hybrid systems, including wind turbine and photovoltaic with battery support, are less expensive than other systems. In addition, photovoltaic is more cost-effective than wind turbine in the majority of Iranian regions. Fuel cell has a high initial cost and low replacement life; therefore, it has not been used in the optimal systems [36].

The major aim of optimal planning in the literature is to achieve the optimal renewable energy system configuration, considering the minimum NPC ($/kWh) and COE ($/kWh), as well as to meet the restrictions. According to the previous studies, component cost, wind speed, solar radiation, primary load, and fuel price are the most uncertain variables.

In this paper, a renewable energy solution for a stand-alone power generation in Khomeinishar University site (KhshU), a renewable energy laboratory located in the middle of Iran, is provided to fulfill the required electrical load demand of the considered place. Considering its features and widespread use, the HOMER software has been used to determine the most cost-effective system for a specified load based on techno-economical parameters. The alternative options include fully renewable-based energy solutions such as solar panel, wind, and batteries.

In this study, the following goals, which can be the distinguishing points with other studies, have been pursued:

1. It is a case study for a location in central part of Iran, in which it is the first research for this area. Also, the study is one of the first studies carried out in renewable energy sites in Khomeinishahr University with the goal of designing an efficient system for providing the electricity for the office buildings.
2. Efforts have been made to generalize the results of the study to other parts of Iran regarding the selected range of sensitive parameters related to the geographical location like solar radiation and wind speed.
3. Due to the fact that Iran's economic situations had a lot of fluctuations in recent years, the study tried to offer, based on economic forecasts, a clear prospect of the effects of economic parameters on the cost of energy (COE) and Net Present Cost (NPC).
4. A comparison of COE in Iran and other parts of the world, focusing on developing countries, has been drawn in order to clarify the final costs of renewable electricity, comparing with other parts of the world.

2. Data treatment

2.1. Location

KhshU site and its main office are situated in Khomeinishahr (32 _ 37′ N, 51 _40′ E), Isfahan province, Iran, as shown in Fig. 1. Because it is located in the central part of Iran, it has, according to Iran's solar and wind energy map, a great potential for applying solar energy with an average amount of 4.5–5.2 kWh/m^2/day [39]. The average wind speed is 3–4 m/s which may indicate that the wind energy in this area might not be as efficient as the solar energy. Now, because most renewable energy sites and research centers are located in regions with enormous solar and wind potential, KhSU site can be introduced as a renewable energy laboratory that can help supply energy in this area to show the capability of renewable energy resource in the central part of Iran.

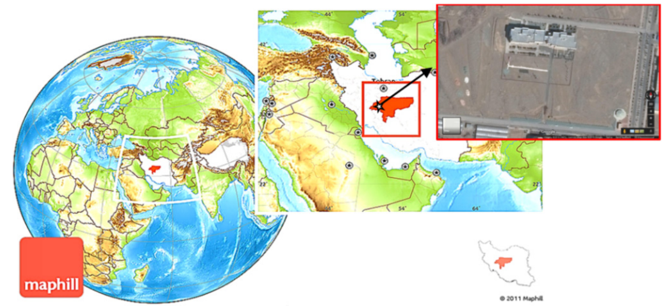

Fig. 1. Geographical condition of KhSU site, Isfahan province (Edited from " [37]" and " [38]").

2.2. Energy resource

The Central Meteorology Station has provided the hourly global radiation and wind speed data to be used in KhshU site. To design the synthesized 8760 hourly values of a year, HOMER applied Graham algorithm (NREL, 2005). It also used the latitude and longitude information of the selected site to set the clearness index, which is a fraction gained as the result of sending solar radiation to the atmosphere in order to strike the Earth. thus, it can measure the clearness of the atmosphere with a dimensionless number, Kt, that varies between 0 and 1, subject to different weather conditions, being low and high in cloudy and sunny conditions respectively [40]. The average annual solar radiation for this region is 5.38 kWh/m^2/day, according to the solar radiation profile shown in Fig. 2.

Weibull, autocorrelation factor, diurnal pattern strength, and the time of peak wind speed are four parameters making synthetic wind speed data generator more different to use than the solar data [41] The first parameter is Weibull value, set to 2 in this study, which is the yearly distribution of wind speed. The second parameter is autocorrelation factor, set to 0.78, in which low and high values represent the hourly fluctuation of wind speed in a more random fashion and the reliability of the wind speed in 1 h on its previous hour value. The third factor is the diurnal pattern strength, which indicates the dependency of wind speed on the time of the day. This value is set to 0.30 in this study. The last parameter is the hour of peak wind speed, which is the windiest time of the day throughout the year. This value has been taken 20:00. In Fig. 3, The yearly average wind speed for the location, which is measured 10 m above the earth surface with 3 h intervals, the wind speed variation over a day (diurnal pattern strength), and the randomness in wind speed (autocorrelation factor) are 2.97 m/s, 0.032, and 0.97 respectively. It can also be seen that the wind speed varies from 1.3 m/s to 3.9 m/s. The long term seasonal wind speed is higher in the period from February to June.

2.3. Load estimation

In this study, it is assumed that the selected RES is capable of providing the required electrical load of KhshU site and the main office. The load is a primary type, i.e., it must be produced immediately. The main source of energy to power the lighting, a PC, and a projector is electricity. On the weekend, the only source of load is field lighting because the head office is closed and its load value is zero. During all the seasons, the office is open except some short

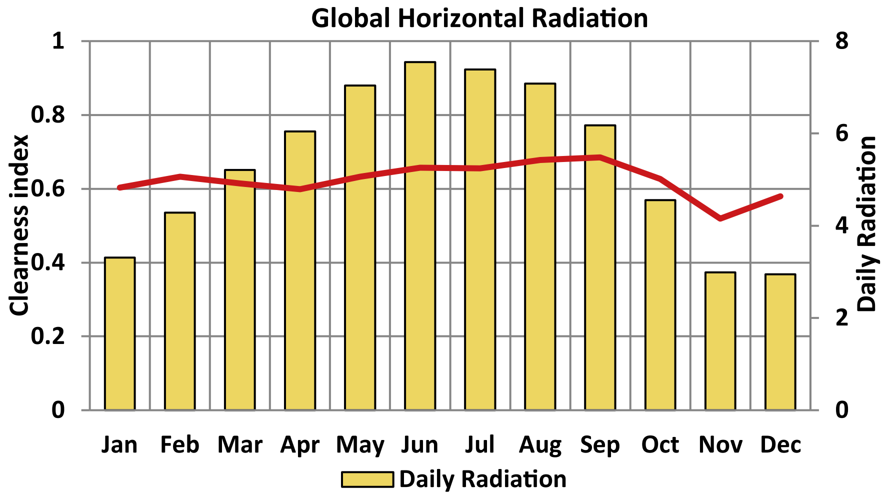

Fig. 2. Monthly average solar Global Horizontal Irradiance (GHI) data.

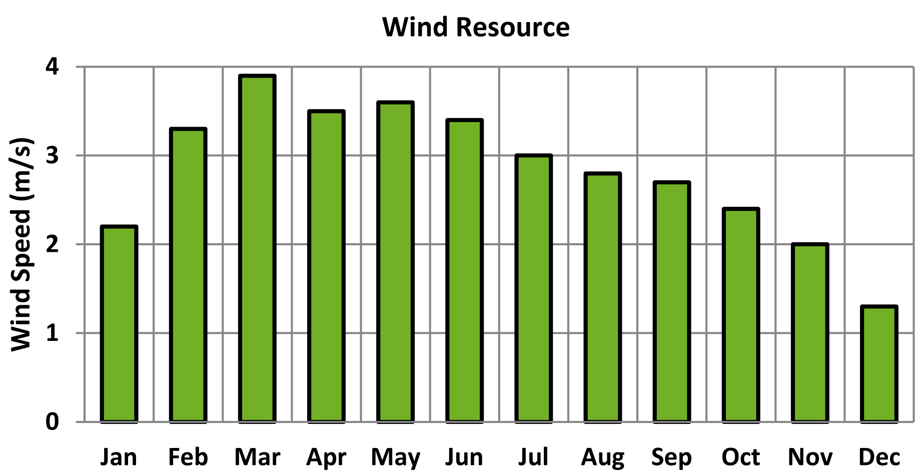

Fig. 3. Monthly average wind speed data.

Table 1
Load pattern in a typical year for weekdays.

No	Load Type	Power (watt)	Qty	Working time (h/d)	Used (d/week)	Energy demand/day (Wh)
1	Lighting (office)	10	27	6	5	1620
2	PC computer	300	1	6	5	1800
3	Projector	28	1	1	5	28
4	Lighting (site)	50	1	9	7	450
		388				3898 (daily average)

negligible holidays. Table 1 shows the typical load pattern in which the peak primary load demand is assumed to be 388 W and the total daily consumption is around 3 kWh.

In order to synthesize electrical load for the whole year (8760 total hours), the hourly load for a day in a typical year is generated by Homer in Fig. 4. Load profile is variable in different days and hours in a real condition which is because of seasonal changes in electricity consumption.

3. Renewable energy system components

The study of RES includes PV panels, wind turbines, batteries, and converters. HOMER takes into account the number of units, capital costs, replacement and O&M costs, and operating hours to simulate the system.

3.1. Solar photovoltaic

The cost of PV module and the life time of the modules have been considered 2000 $/kW and 20 years respectively. Solar PV simulation parameters are shown in Table 2, in which horizontal axis tracking systems as well as monthly adjustments are considered. This study takes into account the SANYO HIP200BA19 photovoltaic module.

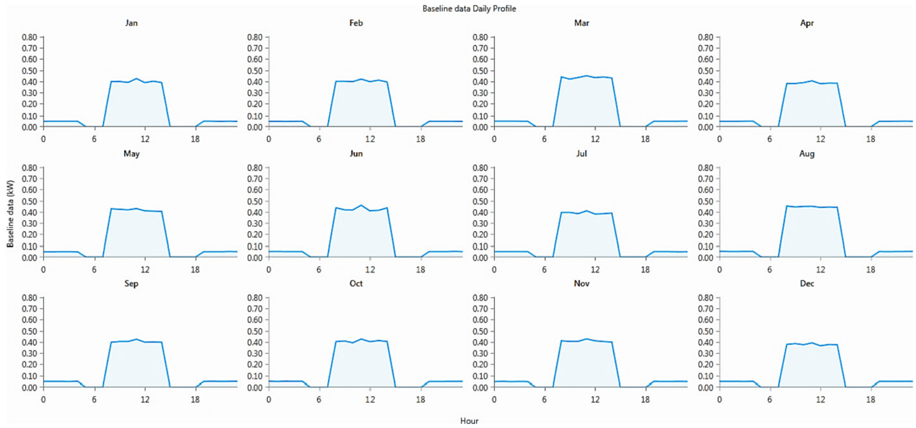

Fig. 4. Monthly average load demand profile at hourly sequence for a specific residence.

Table 2
Solar PV array technical parameters and cost assumptions.

Parameter	Unit	Value
Nominal Max. Power	W	200
Capital cost	$/kW	2000
Replacement cost	$/kW	2000
Operation and maintenance cost	$/kW/yr	10
Lifetime	Years	20
Efficiency	%	17.2%

3.2. *Wind turbine*

A HUMMER wind turbine of 500 W has been used for the analysis and its technical and economic parameters are shown in Table 3.

3.3. *Battery*

The specifications of the Discover 12VRE-3000TF-L storage batteries, which are used in the renewable energy system, are shown in Table 4.

Table 3
Technical and economic parameters of wind turbine.

Parameter	Unit	Value
Rated power	kW	0.5
Starting wind speed	m/s	3
Rated wind speed	m/s	7
Cut-off wind speed	m/s	20
Capital cost	$/kW	1350
Replacement cost	$/kW	1000
Operation and maintenance cost	$/yr	15
Lifetime	Years	20

Table 4
Technical parameters and cost assumptions for battery.

Parameter	Unit	Value
Nominal voltage	Volt	12
Nominal capacity	Ah	245 (3 kW)
Maximum charge current	A	57
Round-trip efficiency	Percent	85%
Capital cost	$	390
Replacement cost	$	390
Operation and maintenance cost	$/yr	0
life time throughput	kWh	3550

3.4. *Converter*

To convert DC (solar panel output) to AC voltage, HUMMER three in one controller box, used as a converter (inverter), is utilized in this project with 1000, 1500 and 2000 W rated power. This combines the tasks of battery charger, inverter, and controller with an extra terminal of solar panel on the back. It also uses diversion lights for dumping load. The technical and economic parameters of the converter are demonstrated in Table 5.

4. Modeling and optimization

4.1. *System modeling using HOMER*

In this study, a techno-economic analysis is conducted with the aid of HOMER software, which is an effective tool to make well-designed and well-planned RES, developed by National Renewable Energy Laboratory (NREL). HOMER requires six types of data-meteorological data, load profile, equipment characteristics, economic and technical data-to stimulate and optimize its components through the techno-economic analysis [9]. Different technologies, namely PV, wind, hydro, fuel cells, and boilers, are taken into account and the design options for both off-grid and grid-connected power systems for distant, stand-alone, and diesel generator applications are assessed in HOMER. An hourly time-step simulation utilizing inputs such as distinct technology options, component costs, and resource availability helps HOMER to model different system layouts. Then, HOMER checks the technical feasibility of a layout and predicts the total cost of a system during its life time as well [12].

4.2. *Economic modeling*

Economic modeling in HOMER is based on minimizing the total net present cost (NPC) and levelized cost of energy (COE). These

Table 5
Technical parameters and cost assumptions for converter.

Parameter	Unit	Value
Capital cost	$/kW	470
Replacement cost	$/kW	470
Operation and maintenance cost	$/kW/yr	10
Lifetime	Years	15
Inverter Efficiency	Percent	90%
Rectifier Efficiency	Percent	85%

two major economic factors rely on the system's total cost, calculated on yearly basis. This cost is the annual cost of the components, which consists of annualized capital cost, operation and maintenance (O&M) cost, replacement cost, and annual operation and maintenance (O&M) cost system minus any miscellaneous expenses such as CO_2 emissions [12,42]. NPC is a mathematical concept while COE is kind of arbitrary [12]. Hence, NPC is considered more reliable as an economic parameter and is calculated using the following equation.

$$NPC = \frac{C_T}{CRF(i,n)} \tag{1}$$

where C_T is the total annualized cost ($/year), i is the annual real interest rate (%), n is the lifetime of the project, CRF is the capital recovery factor, which is calculated using the following equation.

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

The average cost of effective electrical energy production per kWh (E_T), which is called the levelized cost of energy (COE), is determined as follows [12].

$$COE = \frac{C_T}{E_T} \tag{3}$$

The remaining value of the part of the power system at the final point of the project is shown by the salvage value. This value is assumed to face a reduction, which indicates a direct proportionality to the remaining life and is based on the replacement cost rather than initial capital cost [12]. The value for each component is shown by:

$$S = C_{rep}\frac{R_{rem}}{R_{comp}} \tag{4}$$

where C_{rep}, R_{comp}, and R_{rem} are the replacement cost ($), the remaining cost of the component, and the component lifetime (year) respectively. The summation of the annual operation and maintenance (O&M) costs and annualized replacement cost minus the annualized salvage value define total operating cost (TOC), which is calculated as follows:

$$TOC = \sum_{i=1}^{n} C_{OM,j} + \sum_{i=1}^{n} C_{R,i} - \sum_{i=1}^{n} C_{S,i} \tag{5}$$

where $C_{OM,j}$ is the cost of annual operation and maintenance (O&M) and $C_{R,i}$ is the annualized replacement cost for the ith component of the system with n devices. The $C_{S,i}$ is the salvage value of the ith component.

5. Results and discussion

5.1. Optimization results

As mentioned above, Homer Software is applied to arranging the optimized layout of the hybrid wind solar system based on various important variables such as electrical load, energy resource, cost, and size of each component as well as economic parameters like rate of interest. During its optimization procedure, Homer assesses each system using the search space and ranks them in terms of the total net present cost. For the present study, the search space variables are the PV array capacity (0, 0.4, 0.8 … 2.4 kW), the number of 500 W Hummer wind turbines (0, 1, 2), the number of batteries (0, 2, 4, 6, 8), and the size of the converter (1, 1.5, 2 kW).

Interest rate, as an economic input parameter, is presumed to be 6.5% (" [43]; "; " Statistical Centre of Iran") and the project lifetime is assumed to be 25 years. Resolving each sensitivity case, HOMER simulates each system in the search space and ranks, based on NPC, all feasible systems.

The results are demonstrated in either an overall form with top-ranked system layouts based on their net present costs or a categorized form, in which the possible low cost system layout is regarded for each possible system type. Referring to categorized rankings, Table 6 shows the most cost-effective system layout consisting of PV array, battery, and converter, without any wind resource, with a total net present cost (NPC) of $8173 and a cost of energy (COE) of 0.546 $/kWh.

The second most cost-effective layout is found to be the PV-wind turbine-battery-converter setup as the best hybrid solution with the NPC of $9267 and COE of $0.620.

Levelized cost of energy (COE) is considered to be an appropriate indicator to evaluate the optimal plan, especially compared with fossil-fuel power plant. Table 7 illustrates the COE of different renewable energy system plans discussed in previous studies. Iran and Egypt had the lowest price of renewable energy production compared to other regions. It can be seen that the levelized cost of renewable energy production in Malaysia is far higher than the other regions; it is less than the COE of a conventional plant in this country [14]. By contrast, the levelized tariff of electricity in Iran is about half of the COE of the current research plan due to the easy access to a vast variety of fossil-fuel resources.

Regarding the system components for both optimum models, the cost summary is shown in Fig. 5. An inflow, being an income from electricity sales or the salvage value of the equipment at the end of the project life time, is shown by a positive value whereas an outflow or expenditure for fuel, equipment replacements or operation and maintenance (O&M) is stated by a negative value. Table 8 includes the breakup of capital, replacement, O&M, fuel, and salvage costs.

Table 7
COE of the optimal plan in different regions.

Region	Province/City/village	COE ($/kWh)	Ref.
Malaysia	KLIA, Selangor	1.88	[14]
China	Urumqi	1.05	[10]
Colombia	Unguia	0.44	[12]
India	Parlari, Chhattisgarh	0.42	[11].
Ethiopia	Six site	0.38	[44]
Egypt	New Borg El Arab	0.19	[45]
Iran	Tehran	0.78	[46]
Iran	KhshU site - Isfahan	0.55	Current research
Iran	Moaleman	0.54	[36]
Iran	Ardebil	0.25	[2]

Table 6
Optimum model according to the best cases of simulation.

System Architecture	PV (kW) (HIP200BA19)	Wind(No.) H500W	Battery (No.) 12VRE-3000TF-L	Conv.(kW) (HC1000W)	NPC ($)	COE ($/kWh)
PV/Battery	2.0	–	4	1.0	8173	0.546
PV/Wind/Battery	1.2	1	6	1.0	9267	0.620

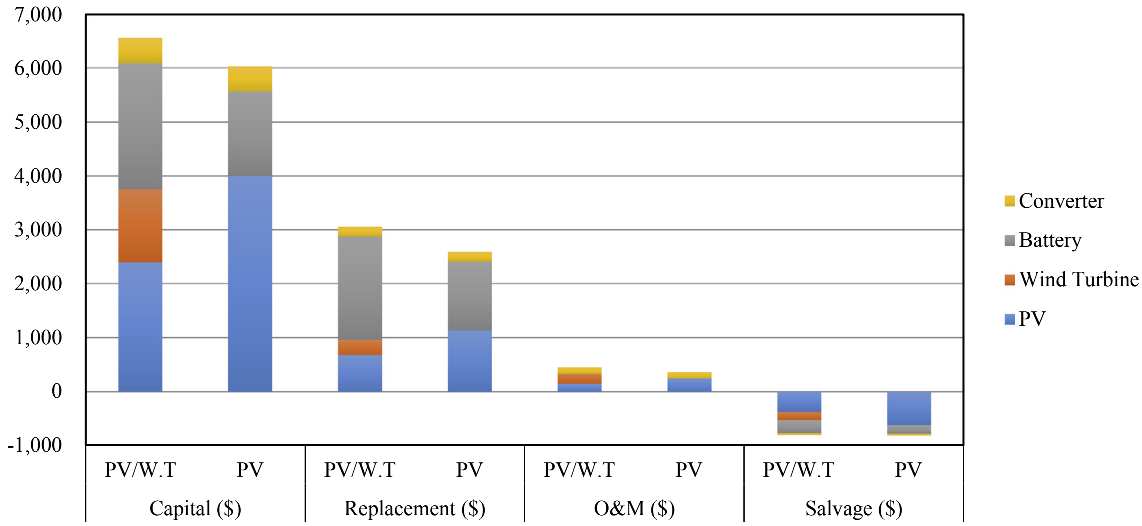

Fig. 5. Cost summary based on the selected components.

Table 8
Cost analysis for PV/Wind & PV systems.

Component	Capital		O&M		Replacement		Fuel		Total	
Unit	($)		($)		($)		($)		($)	
Architecture	PV/Wind	PV	PV/Wind	PV	PV/Wind	PV	PV/Wind	PV	PV/Wind	PV
PV	2400	4000	681	1136	146	244	(373)	(622)	2855	4758
Wind turbine	1350	0	284	0	183	0	(155)	0	1661	0
Battery	2340	1560	1911	1274	0	0	(242)	(162)	4009	2672
Converter	470	470	183	183	122	122	(32)	(32)	743	743
Total	6560	6030	3059	2593	451	366	(802)	(816)	9268	8173

Homer prognosticates the actual cash flows in each year of the project life time. Fig. 6 represents the yearly nominal cash flows for both systems. Figs. 7–8 depict the average amount of electricity produced monthly from the optimized hybrid wind/PV/battery and PV/battery power systems. Table 9 shows the significance of the PV array in electricity production.

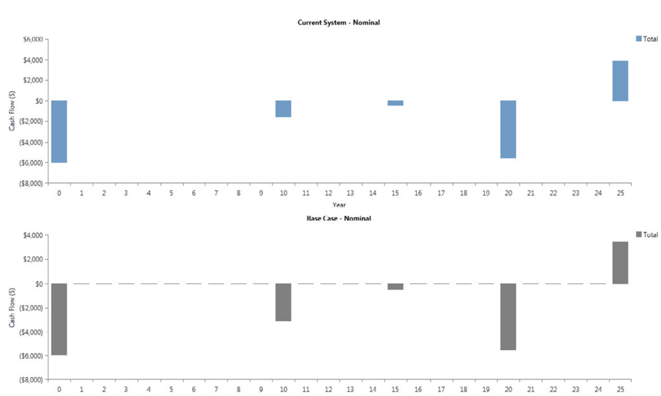

Fig. 6. Comparison between PV (Base Case) and PV/W.T (Current System) life cycle cash flow.

The average amounts of electricity produced monthly from the optimized wind/PV/battery and PV/battery systems are compared in Table 9.

5.2. Sensitivity analysis

In order to explore the effect of uncertainty or changes in the model inputs such as resource availability and economic conditions, HOMER performs sensitivity analysis, in which multiple optimizations under a range of input assumptions are carried out [40]. The sensitivity analysis is done after the completion of the simulation and optimization stages and sorting the feasible plans based on the minimum NPC. The stages are repeated for each uncertain parameter and the new feasible and best plans could be acquired [9].

For the case of Iran, sensitivity variables can be categorized in two major groups, including economic parameters, such as inflation rate, and resource-based parameters, such as wind speed.

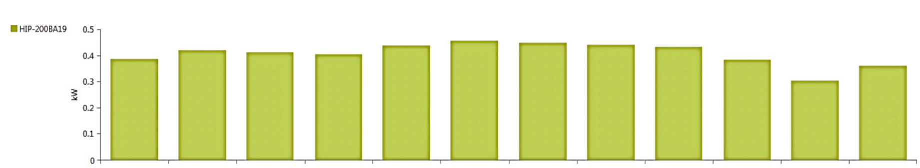

Fig. 7. Monthly average electric production from PV.

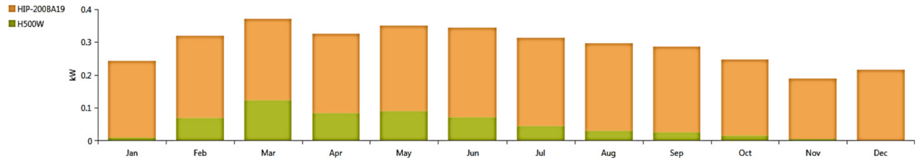

Fig. 8. Monthly average electric production from PV/wind.

Table 9
Comparison of average electrical production for two systems per year.

Components	Proportion ((%		Production value (kWh/yr)	
	PV/battery	PV/wind/battery	PV/battery	PV/wind/battery
PV	100	84	3566	2139
W.T	0	16	0	413
Total	100	100	3566	2553

5.2.1. *Economy-based analysis*

Interest rate, which is inflation subtracted from bank lending rate measured by the GDP deflator (The Global Economy), can be considered as the subject in a sensitivity analysis. A vital economic development in Iran is the reduction of interest rate [51], as it is regulated by the government [47]. For that indicator, The International Monetary Fund provides data for Iran from 2004 to 2014, as shown in Fig. 9 [52].

The minimum, maximum, and average values for Iran during that period were −17.37, −4.43 and 9.04% respectively, of which the minimum and the maximum values were observed in 2013 and 2009 [48]. Recent observations showed an approximate value of 6.5% by the end of April 2016 (Central Bank of the Islamic Republic of Iran, 2016; [49]. In a 3 year period, between June 2013 and June 2016, the inflation rate decreased on a monthly basis, bottoming out at 6.8 at the end of the period. As a result, the annual inflation rate experienced a downward trend, beginning in October 2013, and registered the most psychologically striking level of a single digit since November 2010, in June 2016 [51]. The real interest rate on term deposits rose considerably to an exceptional level in the history because of the recent rapid decrease in inflation rate and nominal failure of discount rates to follow suit (Middle East Bank Headquarters, 2016). According to Trading Economics econometric models, the nominal discount rate and the inflation rate are going to trend around 13.90 and 5.5% in Iran in 2020 [50], respectively. If nominal discount rate and inflation rate get new values of 13.9 and 5.5 respectively, then total net present cost will decrease to 4%, and its value will be $7847 (in comparison with efficient systems in Table 6) and the cost of energy will increase by 9% ($ 0.675/kwh). Economical sensitivity variables can be wrapped up in Table 10 based on the mentioned data.

The nominal discount rate and the inflation rate affect the energy cost and the total net present cost as demonstrated in Fig. 10. What stands out is that energy cost rises as discount rates increase from 8% to 18% whereas net present cost of the whole system falls in any inflation rate. Also, a rise in inflation rate from 5% to 11% can cause a decline in energy cost, but the total net present will increase. According to Fig. 10, the CEO and NPC can have various values between 0.27 and 0.76 and between $7000 and $12000 respectively (see Fig. 11).

5.2.2. *Resource-based analysis*

Due to the effect of site place characteristics such as buildings, trees, or steep mountain tops, the local wind speed may be a little different from the meteorology station data. Hence, a sensitivity analysis can be useful to study the effect of wind speed variation on the optimal plan. It is expected that output power of wind turbine will rise by increasing wind speed at a constant solar irradiance. The figure below shows the effect of wind scaled average on both the COE and Total NPC.

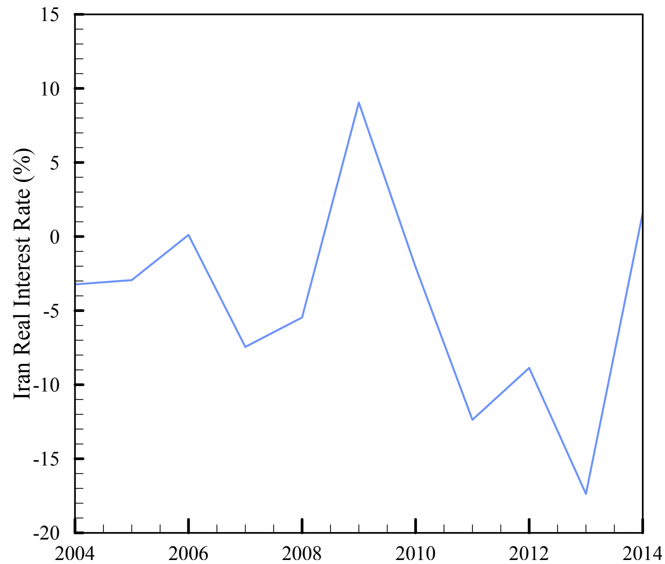

Fig. 9. Iran real interest between 2004 and 2014.

Table 10
Economical sensitivity parameters.

Nominal Discount (%)	Inflation Rate (%)
18 (current value)	10.8 (current value)
16	9
14	8
12	7
10	6
8	5

The average wind speed in Isfahan province is about 3–4 m/s [39]. However, it is not an accurate value. The analysis revealed that in this range, the NPC and COE are not sensible to wind speed variation. As can be seen from the graph, from 3 m/s to 6 m/s, both COE and NPC remained fairly static. Between 6 m/s and 7 m/s, there was a considerable decrease in both items, which were followed by constant values to 9 m/s. It can be expected that an increase in wind average speed causes an increase in wind turbine efficiency and subsequently a decrease in capacity requirements for the PV system. Due to low wind speed average in central parts of Iran, the effect of wind speed variation between 3 and 6 m/s doesn't have a considerable effect on COE and NPC.

Simultaneous effects of wind speed variation and solar radiation potential, as two important uncertainty factors in our sensitivity analysis of the optimal system, are shown in Fig. 12. The diagram can be used to determine the optimal system in other regions of Iran, with different amounts of wind speed and solar radiation.

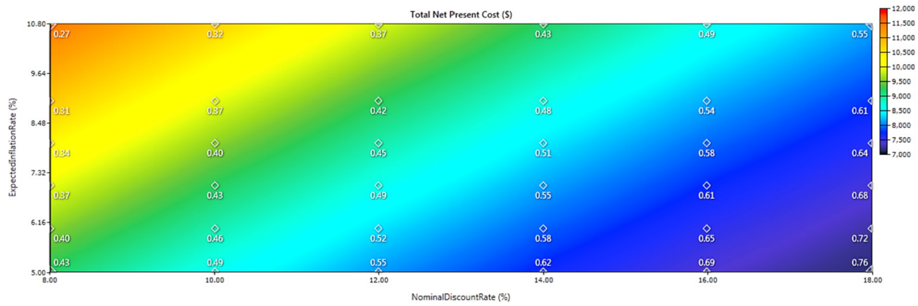

Fig. 10. Effect of nominal discount rate and inflation rate on COE and NPC.

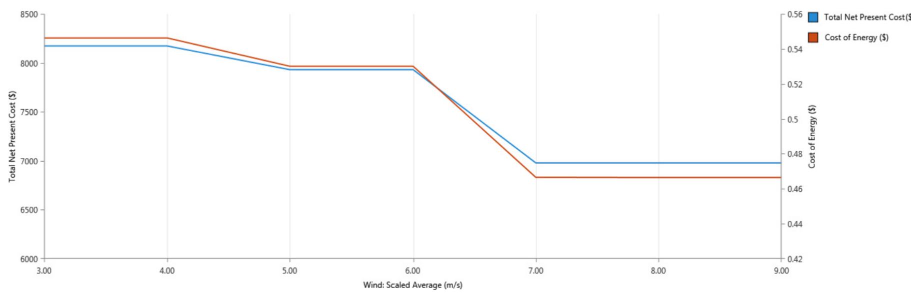

Fig. 11. The effect of wind scaled average on CEO and total NPC.

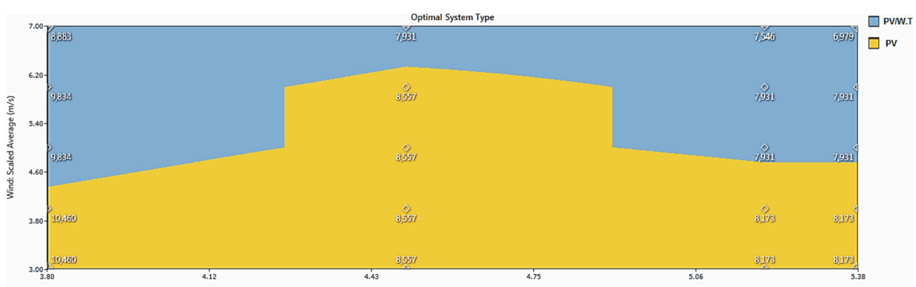

Fig. 12. Effect of energy resources on optimal system configuration.

6. Conclusion

Renewable energy solution, an effective tool to reduce the environmental impact of fossil fuels, is needed to be developed in order to achieve sustainability. In this regard, a feasibility study of renewable-based power generation by means of mathematical modeling or computer simulation can be beneficial to design a reliable and economic system. In this study, an off-grid renewable energy solution was followed to supply power to a given load in KhshU Site in Iran, using the HOMER Pro. Solar panel, wind, and batteries are three possible fully renewable-based energy solutions. The average daily electricity consumption, over an annual cycle, was 3 kWh/d and the peak electrical demand was 388 W.

The first and the most economical solution was found to be the PV—battery setup, with PV arrays of 1.2 kW and 6 unit batteries each of which contained 3 kW of sized power with a total NPC of $ 8173 and a COE of 0.546 $/kWh respectively. To fulfill the electrical demand in a reliable manner, the second optimal solution, which was a wind/PV/battery system with PV arrays of 1.6 kW, one wind turbine of 0.5 kW, and 4 unit batteries each containing 3 kW, is proposed. However, it can increase the total NPC and COE by 10% and 20% respectively, compared with PV-battery setup. Sensitivity analysis revealed that raising discount rates could increase the energy cost while the net present cost of the entire system reduced in any inflation rate. Adversely, increasing inflation rate decreased cost of the energy; however, the total net present cost increased. The analysis showed that the wind speed variation between 3 m/s to 6 m/s didn't have a considerable effect on NPC and COE. Following results were obtained for this research work:

- For the central part of Iran, photovoltaic electricity generating systems are more cost effective and are preferable to wind systems. Table 6 illustrates that COE and NPC for a photovoltaic system are less than the figures for a hybrid solar wind system.
- Comparing to other parts of the world, especially developing countries, COE is less in Iran; but in other parts of the world, like Malaysia, fossil electricity tariff is lower than renewables, regarding the easier accessibility of Iran to fossil sources, and this issue challenges the survival of renewable systems in Iran.
- Furthermore, the effect of Iran's economic fluctuations in recent years on COE and NPC is another issue studied in this article. In fact, the fluctuating trend of economic parameters (Fig. 9) can affect COE and NPC directly. So, doing the sensitive analysis (Table 10) the effects of the parameters are shown (Fig. 10). The results, based on the economic forecasts, show that the COE of renewable electricity can reduce until 2020 due to the

improvement in economic situations. However, the results show that the NPC of systems will increase.

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