Deployment of a stand-alone hybrid renewable energy system in coastal areas as a sustainable energy source

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Abstract

Since the non-renewable energy sources merely are not able to fulfill the demand for electricity increasing steadily; therefore, solar and wind can be considered as environmentally friendly and omnipresent renewable energy sources for generating electrical energy. In this study, the techno-economic evaluation for two hybrid renewable energy systems is carried out to achieve this target for Bandar Dayyer. In this regard, using the Homer software, the total amount of electricity production by these systems are equal to 470176 kW, of which, 22409 kW is provided by and PV-Generic system and 447767 kW by PV-diesel-Generic system. According to the results of this analysis, it should be mentioned that this area has an appropriate potential of wind speed and solar radiation; which means that it can be suitable for investment on the renewable energy site for electrical production.

K**eywords:** Renewable energy system; HOMER software; Solar energy; Wind energy.

Introduction

Adequate provision of energy has always been a crucial issue and is deemed as one of the best measures for estimating the economic growth and development of a country. In recent decades, increasing CO_2 emission into the atmosphere is considered as one of the main reasons for global warming with adverse environmental effects such as sea level rise, floods, droughts, etc. Reduction of fossil fuels consumption by energy efficiency, carbon capture, and storage, conversion of CO_2 to different products, application of renewable energies and reforestation are effective mitigation options [1-3]. On the other hand, regarding the increasing population of the world, the rate of energy consumption increased and it causes further use of fossil fuels [4]. Concerning these realities, employing more sustainable energy sources such as renewable energy can be considered as an appropriate solution for overcoming these problems and achieving sustainable development [5-7]. Renewable energy sources are clean, free and have many environmental and economic advantages than other conventional energy sources [8-12]. Without doubt among clean energies, solar and wind energy are the best and well-known sources of energy and according to the released statistics has a growing influential impact on energy services [13]. Moreover, solar and wind energy has an appropriate potential for supplying a remarkable part of the required energy in the world. Also, the recent breakthroughs in solar and wind energy technology and its related fields, has increased the efficiency of different equipment used in this industry [14]. In recent years, many works in this regard have been carried out in different countries which some of them, can be mentioned. Jahangiri et al.[15] investigated renewable energy power plants in Afghanistan. In this research, the potential of solar and wind energy was investigated for this country. A study regarding a photovoltaic thermal system for electricity production and low-grade heat was carried out in Iran [16]. Sen and Bhattacharyya [17] proposed a hybrid technology using homer software for electricity production in India. They investigated wind turbines, small-scale hydropower systems, solar photovoltaic, and bio-diesel generators for supplying electrical energy for remote villages. Ma et al. [18] proposed a solution for energy saving in a remote Island in Hong Kong for supporting the microgrid hybrid solar-wind system. A mathematical pattern showed using renewable systems based on PHS technology (Pumped hydro storage) could supply energy for remote regions completely. Ntanos et al. [19] investigated the relationship between energy consumption deriving from renewable energy sources with countries growth (belong to 25 European countries) and their labor forces. Amrollahi et al. [20] analyzied and modeled a stand-alone micro-grid for remote . In this study, the ability of demand response programming about of component size optimization of a micro-grid investigated by them. In this study also wind and solar energy were considered as main resources in order to energy supply for these regions. Tao Ma et al. [21] examined the expansion of energy storage of hybrid battery for remote regions by renewable energy systems. They investigated theoretical analysis and numerical simulation using related software for these systems and in order to enhance the performance of the HESS systems, were presented an electric inductor. Aktas et al. [22] investigated smart energy management using renewable energy and based on an algorithm. In this study, moreover real various operation experiential and tests for HESS systems, effective strategies according to SEMA (Smart energy management algorithm) and in order to support of the HESS (Hybrid energy storage system) systems has been suggested. Bölük et al. [23] considered the renewable energies with an ARDL (Applying the autoregressive distributed lag) approach in Turkey. In this research, the growth of renewable energy in this country and the effect on the environment were investigated. Razmjoo et al. [24] examined energy sustainability indicators for urban areas. In this study, the most important indicators related to energy were considered for improving the urban energy situation. Goel et al. [25] examined renewable energy systems such as PV, PEV (Plug-in electric vehicle) and HRES (Hybrid renewable energy system). Different hybrid energy systems including in off-grid and in grid linked PV systems that has two or more energy resources in order to energy production for rural electrification has been investigated in this article. Jung et al. [26] presented optimal planning and design of hybrid renewable energy for microgrids systems. They showed that the use of these technical and economic analyses could be beneficial for microgrid applications. Razmjoo et al. [27] performed wind and solar energy potential assessment for Zanjan city in Iran. The main goal of this research was implementing a renewable energy power station in this area for supplying energy.

In this paper, wind speed and solar radiation potentials are considered in order to investigate the feasibility of implementing a renewable energy power station for Bandar Dayyer of Iran. Using Homer software, economic analysis and electrical energy production for Bandar Dayyer by renewable energy is investigated for the first time. Although, due to the humid subtropical climate in the coastal areas in comparison with dry zones, some amount of generated energy will be lost. However, using these hybrid energy systems can produce a remarkable amount of energy for this area that this measure has positive environmental effects and enhancing the possibility of more access to energy for inhabitants in the future.

Energy sustainability importance

Energy supply is not a usual challenge and is extremely involved with security and political issues. On the other hand, access to energy for all is essential [28]. In addition, energy is an important sustainable development issue and can have an effect on social, economic and the environment development of any country [29]. Thus, ensuring the access to affordable, reliable, sustainable and modern energy should be considered by governments for people. With regard to this reality that fossil fuels are not sustainable energy sources and hurt the environment, having a sustainable energy plan for supplying energy needs, without risk, is necessary for the future [30]. A balanced energy plan is less vulnerable. Furthermore, achieving sustainable development without sustainable energy development is meaningless. In this regard, a sustainable energy plan, for the protection of the environment and prevention of probable issues for the future, should be applied in the practical plan of any nation. Actually, the highest target of energy sustainability, is energy security and energy balance for different countries. Energy sustainability has many advantages such as creating energy opportunity, energy security, energy affordability, and energy reliability [31].

Fig. 1 presents the energy sustainability based on the demand and supply by 2050. As it is seen, year-by-year, the role of renewable energy will be increased as a reliable source of energy.

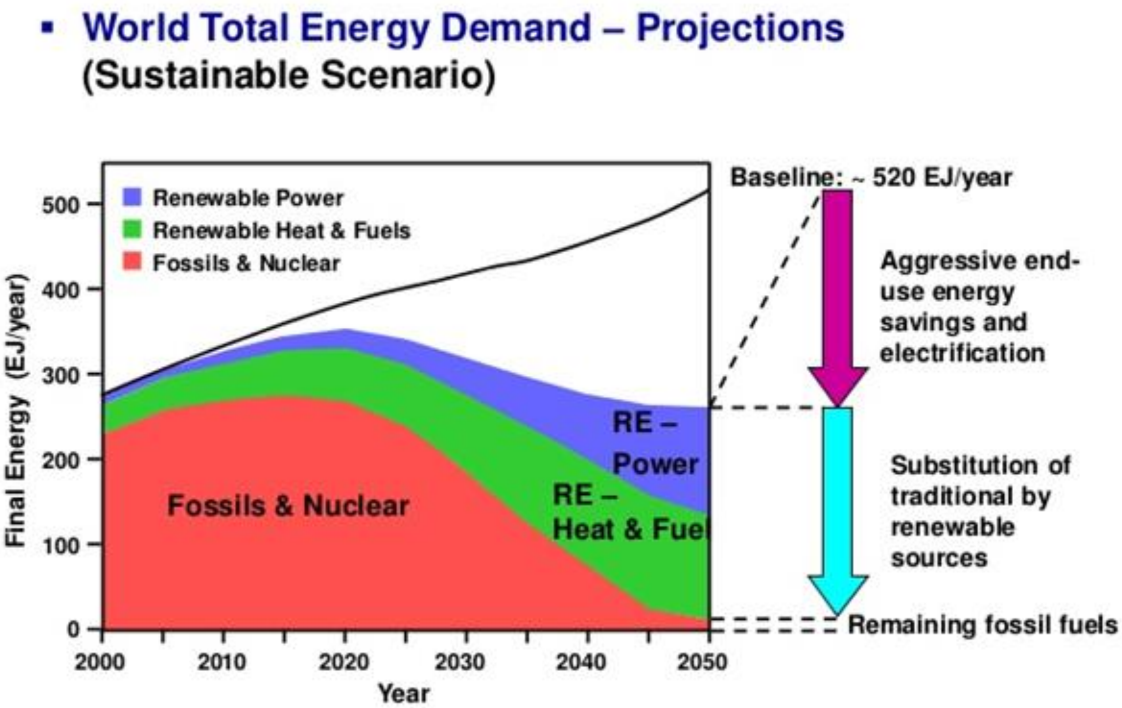


Fig. 1. Energy sustainability based on the demand and supply by 2050 [32]

Fig. 2 shows the Iran's Wind Atlas. In this Atlas, the regions which are marked with brown red, including the northern cities and several cities in the Sistan-Baluchestan province in the south, have the most desirable wind data. There are also other points with very good wind potentials, which are scattered in the central regions of the country.

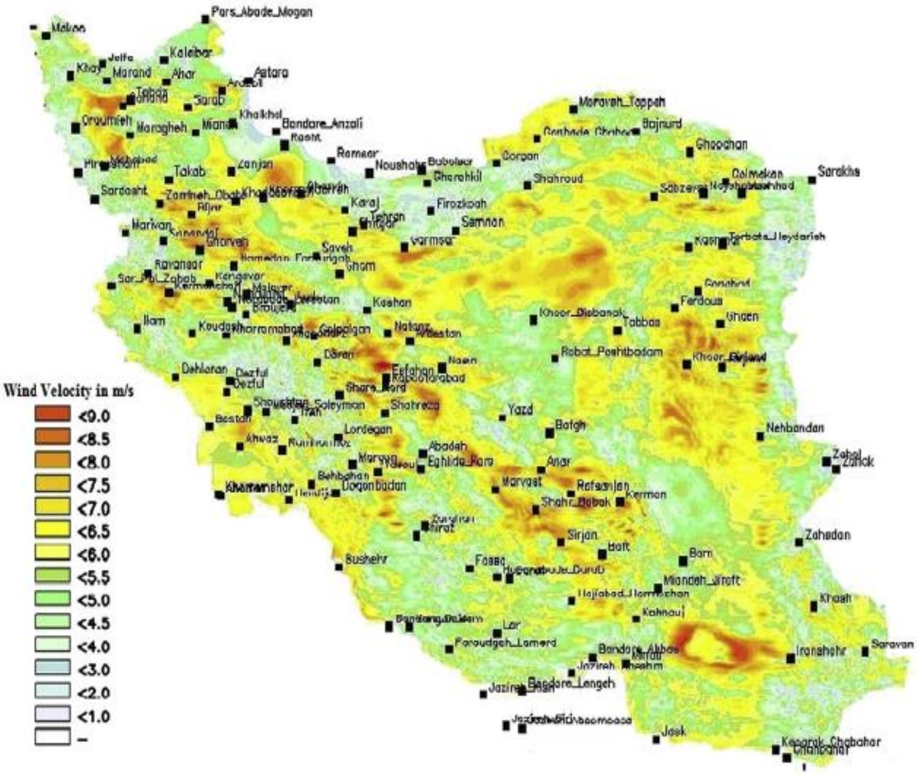


Fig 2. The Iran's Wind Atlas

The Iran's solar radiation atlas is shown in Fig. 3. In this Atlas, Iran is classified into a number of regions based on their solar radiation potential. In this figure, the provinces which receive the highest amount of radiation (Fars, Yazd, and Kerman), are within the middle black frame.

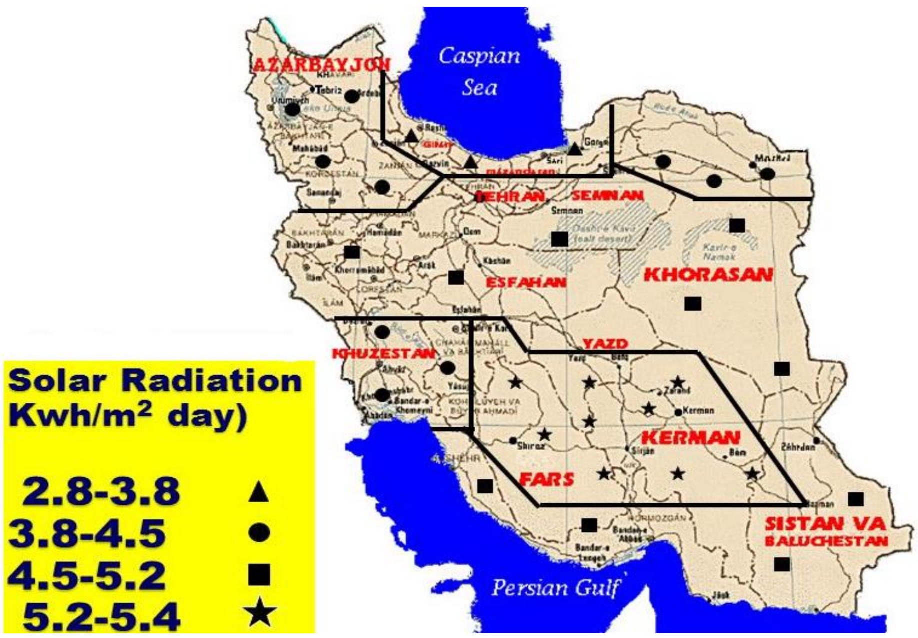


Fig 3. Iran’s areas receiving high levels of solar radiation

Site Location

Bandar Dayyer is a known port in the south of Iran, located in Bushehr province. This city is located at the coordinates of 27°50′24″N and 51°56′16″E and an altitude of 12 meters above sea level. At the 2011 census, its population was 24,083. In the south, winters are mild and the summers are very hot, having average daily temperatures in July exceeding 100.4°F. Summer heat in areas abutting the Persian Gulf is accompanied by high humidity [33]. There are three cities near Bandar Dayyer as Kangan, Asaluyeh, and Jam. The distance from Dayyer to the center of Bushehr province is almost *180* kilometers. Fig. 4 shows the studied area on the Iran map in this research.

Fig 4. The studied area on the Iran map

Table 1 shows the average wind speed (m/s) and daily radiation (kWh/m^2.d) for Bandar Dayyer. As it is presented, the highest wind speed is occurred in March with 3.902 m/s, and the lowest wind speed is occurred in August with 2.343 m/s. In addition, the lowest daily radiation is allocated to December with 3.42 kWh/m^2.d, while the highest daily radiation corresponds to June with 7.95 kWh/m^2.d.

Table1. The average wind speed and daily radiation

Month	Wind speed (m/s)	Daily radiation (kWh/m2.d)
Jan	3.778	3.72
Feb	3.711	4.73
Mar	3.902	5.44
Apr	2.987	6.77
May	3.7	7.61
Jun	3.413	7.95
July	2.718	7.85
Aug	2.343	7.34
Sep	2.493	6.7
Oct	2.542	5.77
Nov	3.098	4.31
Dec	3.403	3.42

According to Table 1, Fig. 5 shows the average wind speed and daily radiation for Bandar Dayyer.

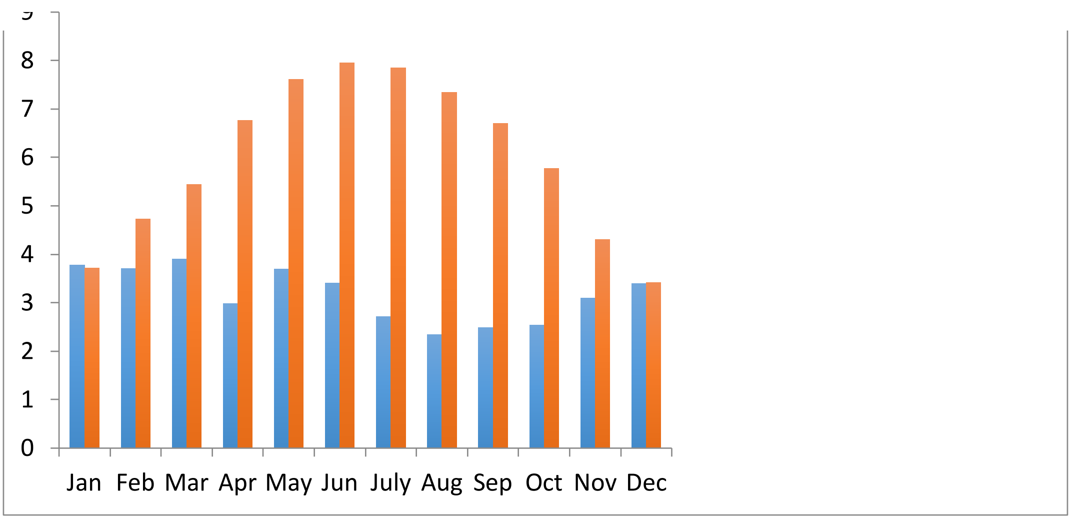


Fig 5. The average wind speed and daily radiation for Bandar Dayyer.

Table 2 shows the specification of the wind turbine. This wind turbine has 10 kW rated power with 15 kW maximum power. The detail of the turbine is specified in Table 2.

Table 2. Specifications of the wind turbine with 10 kW rated power

Parameter	Value
Rated Rotated speed	200 r/min
Blade diameter	8.0 m
Weight of the tower top	600 kg
Rated speed	10 m/s
Rated power	10 kW
Max power	15 kW
Startup wind speed	3 m/s
Work speed	3-30 m/s
Security wind speed	50 m/s
High of tower	12 m
Weight of the tower top	60 kg
Tower Steel tube model	φ219 mm
Capacity and quantity of battery	12V200AH18 pcs
Design lifetime	20 years

Table 3 shows the specification of the diesel generator with 100 kW. This diesel generator has 100 kW capacity with the rated voltage of 400/230V. The detail of the diesel generator is specified in Table 3.

Table 3. Specification of the diesel generator with 100 kW capacity

Parameter	Value
Rated Power	5kW~3500kW
Rated Voltage	400/230V
Speed	1500 r/min
Option	Automatic Transfer Switch
Generator Type	Open, Silent, Trailer, ATS
Alternator	AC 3 phase
Transport Package	Wooden, Pallet or Customized
Rated current	20A-7000A
Prime power	125 kW
Standby power	137.5 kW
Frequency	50 HZ/60 HZ
Voltage	400V/230V
Fuel consumption at 100 % load	238g/kWh

Design lifetime	20 years

Table 4 shows the specification of the Generic flat plate PV. The capacity of this Generic flat plate is 10 kW with the work time of 24 HRS/DAY. The detail of this solar panel is specified in Table 4.

Table 4. Specification of the flat plate PV with 10 kW capacity

Parameter	**Value**
Rated Capacity	10 kW
Work Time (h)	24 HRS/DAY
Battery Type	Lithium
Output Frequency	50/60hz
Specification	Normal
System type	On-Off-Grid Solar System
Est. Time (Days)	10
Controller Type	PWM or MPPT
USING	Home, Factory, Commercial
Battery	free maintenance Gel battery
Output Voltage (V)	380V, 220V, 110V

Also, Fig. 6 shows the real meteorological station of Bandar Dayyer. As it can be seen in this figure, the meteorological equipment belongs to the studied area.

Fig 6. The meteorological station of Bandar Dayyer

Methodology

Different software programs are used to calculate the wind speed and solar radiation, one of those is the Homer software, which is used by many researchers in the world [34]. In this study, by using Homer software, the wind speed and solar radiation data for Bandar Dayyer are gathered and measured for implementing a hybrid power station in this area. After this step, the simulated results and the amount of electricity production for these systems are investigated. At the end, a comparison investigation between these systems and others is presented in the framework of a table.

The Homer software benefits

Homer is an optimization and simulation software for renewable energy. This software is able to present a model for the renewable electricity and micro-power optimization for evaluating the designs of both off-grid and grid-connected power systems. In addition, this software can analyze the economy of hybrid renewable energy systems. Indeed, the Homer software models a power system's physical behavior and its life-cycle cost, so that it is able to estimate the total cost of installing and operating of the considered systems. Homer software has three main tasks: simulation, optimization, and sensitivity analysis. For the simulation step, this software models the performance of a specific micro-power system for determining its technical feasibility and life-cycle cost. For the optimization step, Homer is able to analyze and select the feasible system for implementation in the studied areas. For the sensitivity analyses, this software simulates each configuration and discovers the effects which change the factors.

Results and Discussion

By using the Homer software, technical analysis for this study is performed. Homer software is applied for the techno-economic feasibility of the wind-solar-generator hybrid system. Initially, the related data of wind speed and solar radiation for the studied area were extracted via Iran's weather forecasting website; then, the data were entered to the software and analyzed.

Load demand

Fig. 7 shows a schematic of the PV-Wind-Diesel-Converter-Battery system. The load demand for this unit is 11.25 kWh/d and the peak load is estimated at 0.89 kW, which is obvious in Fig. 7.

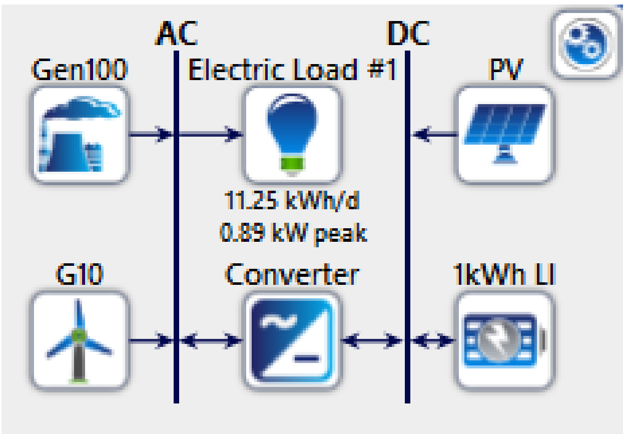


Fig 7. A schematic of the PV-Wind-Diesel-Converter-Battery unit

Technical analysis

In this study, two separated units were considered and analyzed for producing electrical energy. In this regard, firstly, the input data were entered to Homer software; then, with regard to the output data, the analyses were carried out.

Electrical production analysis

Since producing electrical energy by fossil fuels could lead to environmental issues, the importance of electricity production for residential areas by renewable energy is extremely essential for each country. In this regard, Table 5 shows the electrical production by each main component for PV-Generic system. The total amount of electrical production by this system is 22409 kW, of which, most of the production belongs to the generic flat plate PV with 18862 kW. Moreover, this system is capable of producing 17983 kW excess electricity, which does not have any fuel emission.

Table 5. Electrical production by each main component for PV-Generic system

Generic flat plate PV	Generic 100	Generic 10	Total Production	Fuel consumption (L)	Excess electricity
18862 kW	0	3545 kW	22409 kW	0	17983 kW

To complete this table, Fig. 8 shows the monthly average electric production for the PV-Generic. As it is shown in this figure, among different months, May has the highest amount of electrical production, while December has the lowest amount of electrical production.

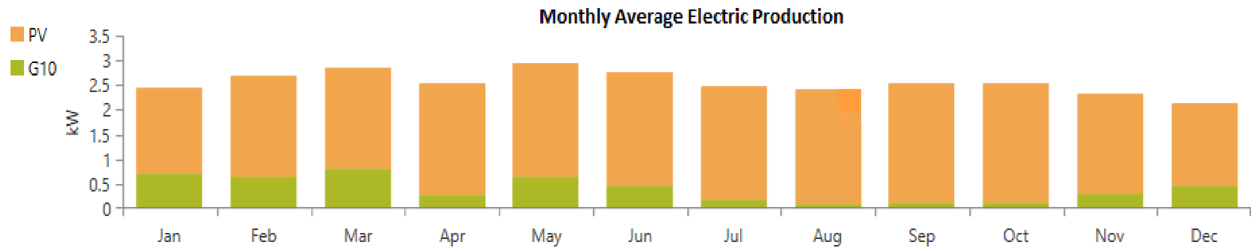


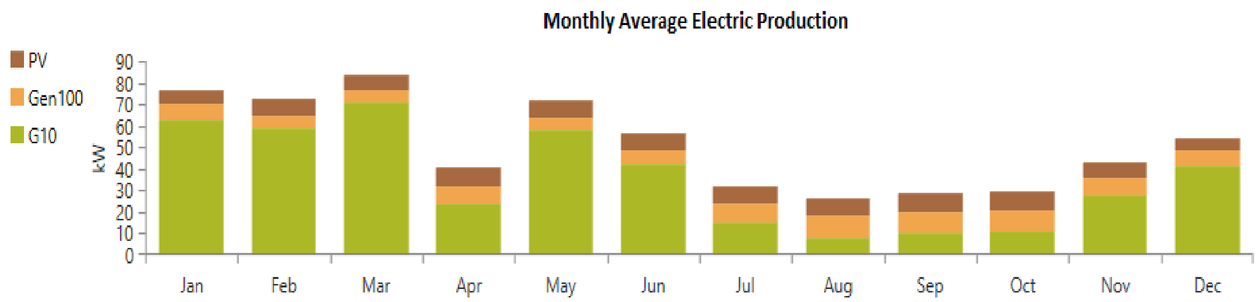
Fig 8. Monthly average electricity production for the PV- Generic system.

In addition, Table 6 shows the electrical production for PV-diesel-Generic system by each main component. With this regard, the total amount of electrical production is 447,767 kW that most amount electrical production of it is producing by generic 10 kW and with amount value of 315,481 kW. In addition, this system is able to produce 443,629 kW excess electricity.

Table 6. The electrical production for PV-diesel-Generic system by each main component.

Generic flat plate PV	Generic 100	Generic 10	Total Production	Fuel consumption (L)	Excess electricity
67536 kW	64750 kW	315481 kW	447767 kW	23634	443629 kW

Moreover, Fig. 9 shows the monthly average electrical production by the PV-diesel-Generic. According to the figure, March and August have the highest and lowest amount of electrical production, respectively.



Figs 9. Monthly average electric production by PV-Generator 100 kW-Generator 10 kW.

Battery analyses for PV-Wind-Diesel-Converter-Battery system

The importance of battery for energy storage has been caused that selection of this section was done with high accurate by designers of Hybrid systems. Table 7 shows the specifications of the utilized battery for the hybrid unit. As it could be seen, the battery receives 1,744 kWh/yr and energy out is 1,571 kWh/yr, actually the battery only losses 175 kWh/yr that it shows the battery has high percent to save energy.

Table 7. Specifications of the utilized battery for the hybrid unit

Energy In (kWh/yr)	1744
Energy Out (kWh/yr)	1571
Storage Wear Cost ($kWh)	0.0126
Nominal Capacity (kWh)	25
Lifetime Throughput (kWh)	24857
Storage Depletion (kWh)	2
Losses (kWh)	175
String Size	1
Bus Voltage (V)	6
Expected Life (Year)	15

Fig. 10 shows the state of charge for the battery. The oscillating's in this figure demonstrates that this battery does not have 100% performance, which means in some times the wind turbine and PV are not able to produce and receive energy completely and this system will be forced to use the generator.

Fig 10. State of charge for the utilized battery

Converter analyses for the hybrid system

The converter is an essential part of each hybrid component. Table 8 demonstrates the total specification of the used converter for the PV-Wind-Converter-Battery System. As it could be seen, this converter has 2,847 amount of energy in and 2,705 amount of energy out with 142 kWh/yr losses.

Table 8. Specification of the utilized converter

Specification	Inverter	Rectifier
Hours of Operation (hrs/yr)	7044	327
Energy In (kWh/yr)	2847	126
Energy Out (kWh/yr)	2705	120
Losses (kWh/yr)	142	6.32
Capacity (kW)	1.17	1.17
Mean Output (kW)	0.309	0.0137

Economic evaluation

Careful and accurate technical-economic evaluation of solar and wind potentials is considered as the most important step in the construction of wind or solar power system because these evaluations are the pre-requirements of a successful source utilization plan. Parameters required for such evaluations can be obtained by the following formulas.

Net present cost can be calculated by the following equation [35]:

$$NPC = \frac{Ctann}{CRF(i,Tp)} \quad (1)$$

NPC in the above formula is the net present cost (in dollars), $Ctann$ is the total annualized cost, *CRF* is the capital recovery factor, *i* is the real annual interest rate (in percentage) and T_p is the period of the project.

Capital recovery factor can be calculated by the following formula:

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

In the above formula, *CRF* is the capital recovery factor, *i* the nominal interest rate and *n* is the number of years. In the Homer software, the energy cost balance can be obtained from the following equation [35]:

$$COE = \frac{Ctann}{\text{Eis+Egrid}} \qquad (3)$$

In the above formula, COE is the levelized cost of energy, $Ctann$ is the total annualized cost; Eis is the electrical energy that the micro grid system actually serves, and Egrid is the amount of electricity sold to the grid by micro grid.

Table 9 shows the output economic analyses for two considered systems. As it is shown in the table, the total NPC for the PV-Diesel-Wind-Converter system is approximately more eight times of PV-Wind-Converter-Battery system, and so on the costs of PV-Diesel-Wind-Converter system is more.

Table 9. The output economic analyses for two considered systems

System	Total NPC	Levelized COE	Operating Cost	Present Worth	Annual Worth
PV-Wind-Converter-Battery	$23148.84	$0.44	$260.59	$17316	1339 ($/yr)
PV-Diesel-Wind-Converter	$186969.00	$3.52	$12623.38	$181136	14012 ($/yr)

Table 10 demonstrates the cost summary for the PV-Wind- Battery-Converter. The highest cost value in this system belongs to the generic 10 kW with $15,000, and the lowest cost value is for the converter with a value of $280. In addition, the total cost value for this system is $23,148.84.

Table 10. Cost summery for PV-Wind- Battery-Converter System

Component	Capital $	Replacement $	Q&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic 10 kW	15000	3825.69	646.38	0	2156.02	17316.04
Generic 1kW Li - Lon	1000	381.85	129.28	0	71.87	1439.25
Generic flat plate PV	3500	0	387.83	0	0	3887.83
Converter	280	118.8	129.28	0	22.36	505.71
System	19780	4326.33	1292.75	0	2250.25	23148.84

Also, table 11 indicates the cost summary analysis for the PV-Wind-Diesel-Converter. The lowest cost value was estimated for the converter with $280, while the highest cost value was for the generic 10 kW with a value of $15,000. In addition, the total cost value for this system was $186,968.99.

Table 11. Cost summary for the PV-Wind-Diesel-Converter system

Component	Capital ($)	Replacement ($)	Q&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic 10 kW	15000	3825.69	646.38	0	2156.02	17316.04
Generic 100 kW	5000	7481.70	669.65	152762.85	654.79	165259.40
Generic flat plate PV	3500	0	387.83	0	0	3887.83
Converter	280	118.8	129.28	0	22.36	505.71
System	23780	11426.19	1833.12	152762.85	2833.17	186968.99

Validation

A comparison of the results of the present simulation with the published literature with similar electrical power demand is presented here. Since the main goal of the hybrid systems is energy production, thus different types of the hybrid units could be used and coupled for this target. Table 12 shows a comparison of the results of the study with other similar cases. As it is shown, various types of hybrid systems with different amount of energy production are presented in Table 12.

Table 12. A comparison of results of the study with other similar electric power demand situation

System	**Total electrical production**	**High producer section and amount of electric production**	**Authors**
PV-Wind-Generator	49835 kW	Wind turbine 25230 kW	Qolipour et al. [36]
PV-Wind	2575 kW	PV 2079 kW	Hiendro et al. [37]
PV-Wind-Generator	447767 kW	Wind turbine generic 10 315481 kW	Present study (case 1)

PV-Generator	37948 kW	Diesel generator 5kW 25379 kW	Shaahid et al. [38]
Wind-Generator	2641666 kWh	Wind turbine 1807624 kWh	Himri et al. [39]
PV-Wind	22409 kW	Wind turbine generic 10 3545 kW	Present study (case 2)
PV-Generator	31722 kW	PV 26567 kW	Ismail et al. [40]
PV-Wind-Fuel cell	2 126 048 kW	Wind turbine 1461955 kW	Kalinci et al. [41]
PV-Wind-Generator	229617054 kW	Generator 156680000 kW	Ahmad et al. [42]

Conclusion

Achieving energy sustainability using renewable energy has many advantages such as reducing fossil fuels and reliable energy supply for deprived areas, especially in the developing countries. The main goal of this study is a techno-economic analysis using Homer software for two different hybrid systems. With regard to this reality that the average wind speed in Bandar Dayyer is 3.174 m/s, and the average solar radiation is 5.96 h/d, PV array, wind turbine, generator, converter and battery are chosen as the main sections for energy production. The electrical production analysis for two considered systems shows that the total amount of electricity production for PV-Generic system is 22409 kW, and for the PV-Generator 100 kW-Generator 10 kW systems is 447,767 kW with the total amount of 470176 kW electricity production for two systems. In addition, the economic analysis shows that the net present cost for the PV-Generic system is $23148.84, and for the PV-Generator 100 kW-Generator 10 kW systems is $186969.00. In addition, the capital cost for two systems was obtained as $ 15000 with the replacement cost of $ 3825.69. In general, it should be mentioned that Bandar dayyer has a suitable potential for energy production, and investment on this area would have economic justification in the near future.

Nomenclature

ARDL	Applying the autoregressive distributed lag
COE	Levelized cost of energy
CRF	Capital recovery factor
Ctann	Total annualized cost
GDP	Gross Domestic Product
Eis	Electrical energy of the micro-grid system
Egrid	Amount of electricity sold to the grid by micro-grid
i	Real annual interest rate
HESS	Hybrid energy storage system
HRES	Hybrid renewable energy system
n	Number of years
NPC	Net present cost
PHS	Pumped hydro storage
PV	Photovoltaic
SEMA	Smart energy management algorithm
Tp	Period of the project

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