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Energetic, Economic and Environmental (3E) Evaluation of Grid-Connected Wind-Powered Electric Vehicle (EV) Charging Station: Effect of Wind Turbine Type

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Abstract

The electric car charging station, which is one of the infrastructure elements used to recharge electric vehicles (EVs), has not been developed in Iran. Therefore, in the present work a hybrid wind turbine-electricity grid system is simulated to supply electricity to an EV charging station in Bandar Abbas, located in the southern coastline of Iran. Technical, economic, environmental and energy surveys using HOMER software have been conducted over 25 years using NASA's website climate data. The use of 12 different types of wind turbines (horizontal axis, vertical axis and bladeless), many of which are not available in the software database and have been added to the database by the authors of the present work, has made the present work a comprehensive study in this field. The use of three-time electricity tariffs, considering the incentive purchase price of renewable electricity, the use of up-to-date price and financial data, and the fines for pollutions of national grid electricity, have made the present work differs from previous works and the results will be very close to reality. The results showed that the Invelox wind turbine is very economical and its LCOE parameter is negative, but it cannot be used due to the high initial investment cost. The most economically viable wind turbine is the Generic 10 kW, which costs $ 0.023 per kWh of electricity generated. The most environmentally friendly wind turbine is the WES 5 Tulipo, which will reduce emissions by about 35 tons per year and has the highest amount of renewable electricity generation with 10% of the total electricity required by wind energy.

Keywords: Electric vehicle; Bandarabbas; HOMER software; CO2; Wind turbine.
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1. Introduction

Dangerous emission characteristics of greenhouse gases (GHGs) based on the road vehicles create a warning situation for urban communities [1]. With the rapid increase in GHG emissions [2] and fuel prices, gasoline vehicle is gradually being replaced by EVs [3]. Governments promote the use of EVs in every possible way, such as encouraging entrepreneurs to set up charging stations, creating government incentive policies for customers and manufacturers, and so on [3, 4]. The construction of charging stations is very important to meet the demand for EVs and the construction of charging station infrastructure for EVs is also necessary [5, 6]. However, the idea of EVs will only be sustainable if they are charged using renewable energy [7]. Demand for various types of renewable energy EV charging stations is growing in many countries [8]. Global acceptance of EVs has increased significantly in the last decade [9]. After a decade of rapid growth, by the end of 2020, there were 10 million EVs on the world's roads, and of course demand for EVs increased by 41% by 2020 (Figure 1) [10]. To further expand the global reach of EVs, public perceptions of EV acceptance must be strengthened through the widespread distribution of EV charging stations. The reason is to ensure that owners of EVs can safely travel long distances with easy access to charging facilities whenever they need to.

Electric vehicles charged at renewable energy-based charging stations offer lower GHG emissions and lower charging costs than grid-based charging stations [11, 12]. Iran has a huge potential for renewable energy sources such as solar and wind [13-16], biogas/biomass [17, 18], hydropower and so on. These renewable sources can be used to charge EVs, which can help reduce pollution.

Iran is the second-largest country in the Middle East in the center of fossil fuel reserves, and the share of solar and wind energy in its electricity sector is less than 1%, and fossil fuels account for 83% of the installed capacity of electricity [19]. According to international and domestic renewable energy experts, Iran has the potential for renewable energy sources, especially wind energy [20, 21]. Iran has 302.2 MW of wind capacity installed by the end of 2019 (Figure 2) [22]. According to the Sixth Plan for Socio-Economic and Cultural Development of Iran (2016-2020) and the Paris COP21 Agreement in 2016, Iran is committed to supplying 10% of its electricity needs from renewable energy sources [23]. The government strongly supports renewable energy incentive policies in addition to the establishment of several organizations such as SATBA (Renewable Energy and Energy Efficiency Organization) and IRREA (Iranian Renewable Energy Association). These organizations support the participation of the private sector in the operation of renewable power plants, especially wind power, which has made Iran the only center for the production of wind turbines in the Middle East [24, 25]. Iran's wind energy market is expected to grow by more than 7% in the forecast period 2020-2025 with Compound Annual Growth Rate (CAGR) due to factors such as increased demand for renewable energy, increased investment in wind farms, government policies and reduced wind energy costs [22].

Steps have been taken to expand the use of EVs in Iran, and even measures have been taken to build these cars. But it must be admitted that Iran in the field of EVs is far from the global situation and has a long way to go to expand these vehicles in front of this country. Of course, the lack of sufficient infrastructure to use this type of vehicle has also been further caused. One of these required infrastructures is an EV charging station, of which there are currently only two pilot charging stations in the country. Iran's first EV charging station was launched in May 2019 by MAPNA Group in Milad Tower, Tehran, which has an area of more than 700 m2 (Figure 3, right). The station includes a 43-kW alternating current (AC) fast charging output that can be used for all standard EVs in the world and a 50 kW direct current (DC) fast charging output that can be used for East Asian vehicles, including Mitsubishi, Kia, Nissan and others. The station also has a 4.7 kW electric vehicle slow charger that can power all standard EVs, as well as two 5.5 kW electric motorcycle chargers [26]. For the first time in Iran, on July 18, 2021, the first charging station for electric vehicles based on solar energy was unveiled by the experts of MAPNA Group in the Fardis city of Alborz province (Figure 3, left). This solar power station has a capacity of about 4 kWh and is connected to an EV charger with a discharge capacity of 3.7 kWh [27].

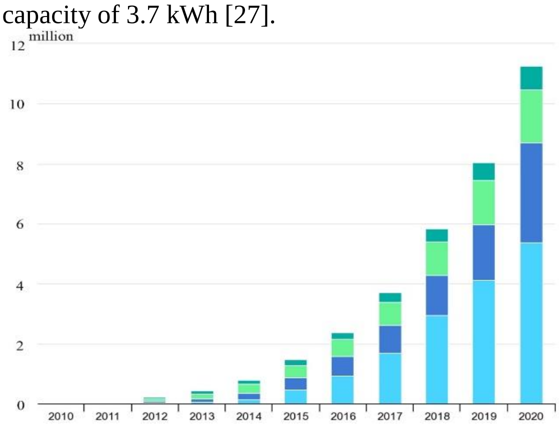


Fig. 1. Global electric vehicle stock by region, 2010-2020 [10].

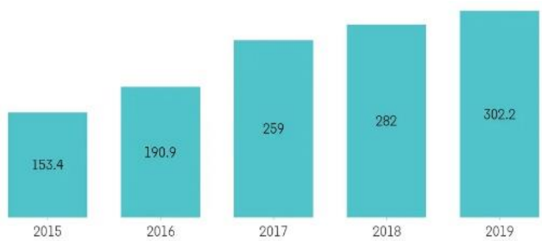


Fig. 2. Wind power installed capacity in mw, Iran, 2015-2019 [22].

Fig. 3. The first EV charging station in Iran and the first solar EV charging station in Alborz province

The following is a review of recent studies in the field of EV charging stations in the world.

In 2022, Al Wahedi and Bicer conducted a feasibility study for a new fast-charging station based on stand-alone renewable energy using HOMER software in four cities in Qatar [28]. The design includes a concentrated PV/thermal system, a 60m high wind turbine, a converter, an electrolyser, a backup bio generator, H_2 and NH_3 fuel cells. The annual electricity generated by the optimal configurations in the east, west, north and south of the country is 1003 GWh, 967 MWh, 984 MWh and 1003 GWh, respectively. The total net present cost (NPC) of optimized configurations for East, West, North and South are $ 2.53 million, $ 2.63 million, $ 2.92 million, and $ 2.53 million, respectively. The levelized cost of energy (LCOE) is also $ 0.285, $ 0.296, $ 0.329 and $ 0.285, respectively.

In 2021 [9], Ekren et al. studied the design and optimization of an EV charging station consisting of a 200-kW wind turbine and a total of 250 kW of photovoltaic panels for Izmir, Turkey. The optimization study was performed by HOMER software. 44.4% and 55.6% of the energy produced are supplied by wind energy and solar energy, respectively. The cost of electricity generated is $ 0.064 per kWh for an EV charging station.

In 2021, Kim and Hur analyzed a grid-connected EV charging station for Jeju island, Korea [29]. The proposed algorithm was based on the EV charge demand forecast using probabilistic random sampling considering the weight of the charge frequency for each season. In addition, wind power outputs were predicted using the improved ARIMAX model. The obtained results confirmed that the proposed algorithm can help to create an EV charge distribution scheme. The proposed method can effectively solve the problems of imbalance between supply and demand and power system uncertainty that may occur due to increased penetration rates of wind farms and EVs.

In 2020, Noman et al examined the possibility of using wind as a direct energy source to power EV charging stations [30]. The results showed that direct charging by wind using DC fast charging technology is more preferred due to the significant reduction in power conversion steps.

In 2017, Fathabadi surveyed a new charging station for grid-connected EVs where the coastal wind blows at an average speed of 41.6 km/h almost all year round [31]. The system consisted of a 10 kW vertical wind turbine, a one-way DC/DC converter, an MPPT and 15 two-way DC/DC converters. Based on the obtained results, it showed that the average power generation by the charging station on a sunny day in summer is equal to 8 kWh and on a cloudy day in winter is equal to 7 kWh. Experimental results from the day-to-day operation of the built-in EV charging station show that it not only provides electricity for charging EVs but also helps the local utility distribution grid. In particular, around 20:00 to 23:00, when the demand for electricity in the grid reaches its peak.

According to the above works and other studies of the authors of the present work, so far no technical-energy-economic-environmental evaluation has been done to find a suitable wind turbine for an electric vehicle charging station in Iran. Therefore, in the present work, 12 types of wind turbines (three different generations: vertical axis, horizontal axis and bladeless) were evaluated by HOMER software for Bandarabbas station. The hybrid system under consideration is the wind turbine-electricity grid and has the following advantages:

- Exchange with the national electricity network through a three-time tariff and considering the incentive price of buying wind power,
- Having the up-to-date price of equipment and other economic information,
- Considering the fines of pollutants for the national electricity grid,
- Review of important parameters such as return on investment, LCOE and etc.,
- Comparison of the results of the present work with the average world price of electricity.

2. Wind energy potential in Iran

Iran has more than 100,000 MW of potential installed capacity in the wind power sector [32], which by the end of 2021, the share of wind energy from 904.07 MW of renewable electricity generated from various renewable power plants in Iran, was equal to 310.2 MW [33] (Figure 4). However, according to a well-planned plan, it is predicted that the development of renewable energy capacity in the wind sector in Iran will be 1600 MW by 2027 [34]. Figure 5 shows the wind atlas of Iran, which indicates the very good potential of this country in the field of wind energy utilization. Figure 6 also shows the status of renewable power plants installed in Iran by the end of February 2022 [35]. According to Figures 5 and 6, the main wind farms in the country are in the northern one-third of the country, which has good wind energy potential. This indicates the need for further research in the south of the country in order to develop wind energy.

3. The place under study

The study site is the city of Bandarabbas located in southern Iran, which has coordinates of 56' 27º east and 27' 18º north and an altitude of 10m above sea level. Bandarabbas is the largest port in Iran, the capital of Hormozgan province and also one of the southern metropolises of Iran. Bandarabbas is one of the economic hubs of Iran due to its location in the strategic and economic region of the Strait of Hormuz [37]. The location of Bandarabbas on the map of Iran is shown in Figure 7.

4. Methodology

A) Software used

The software used for the present work is HOMER, which is the most used in the field of such works [38-41]. Figure 8 provides a flowchart of software performance to illustrate the various stages of simulation. The inputs are known and the economic optimization and how to find the optimal systems are presented in Figure 8 [42]. Finally, HOMER software offers the best possible configurations economically based on the input data [42]. Software results validation has been performed by many researchers around the world [43].

B) System under study

The schematic of the studied system is shown in Figure 9. It is clear from the schematic that there are three charging lines for AC fast charging vehicles, DC fast charging vehicles and AC slow charging vehicles.As it turns out, the system is connected to the national grid and can buy electricity from it or sell surplus electricity to it. Regarding wind turbines, it should be noted that 12 different types of wind turbines (horizontal axis, vertical axis,

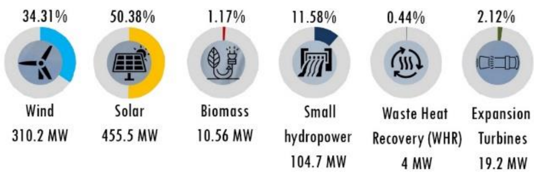


Fig. 4. Share of renewable power plants in the total renewable electricity of the country until the end of 2021 [33].

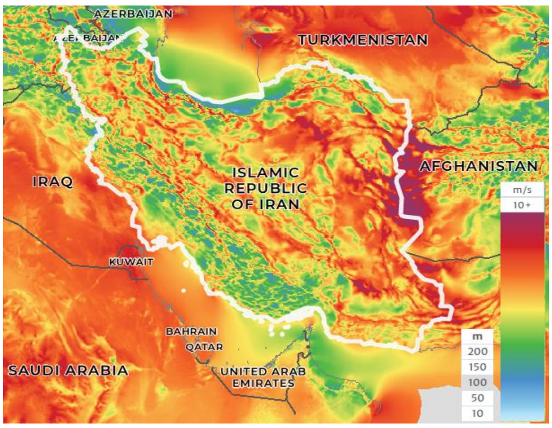


Fig. 5. Wind Atlas of Iran in terms of Mean power density [36].

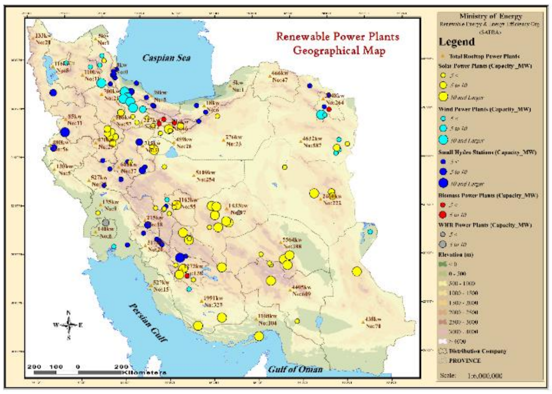


Fig. 6. Installed renewable energy power plants situation up to end of February 2022 in Iran [35].

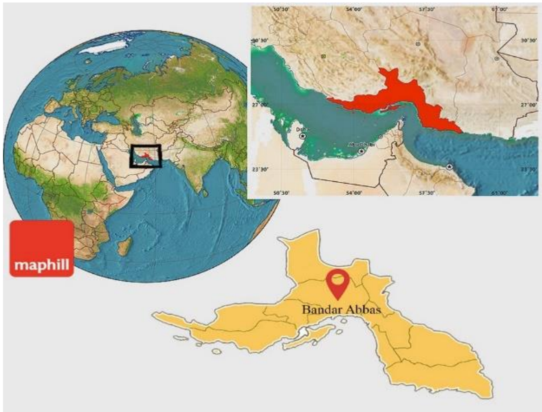


Fig. 7. Location of Bandarabbas on the world map, Iran and Hormozgan province.

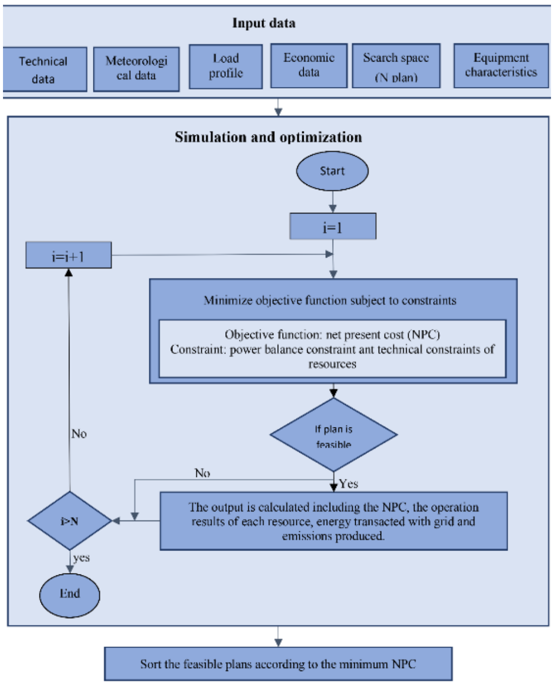


Fig. 8. Software performance flowchart [42]

bladeless) were used in the present work and their performance was compared. Some wind turbines were AC and some were DC. The names of the wind turbines used and the power output curve of each according to the wind speed are given in Table 1.

C) Governing equations

Table 2 shows the equations governing the various parts of the wind-grid hybrid system. The parameters used in Table 2 are described in the Nomenclature.

D) Required data

The study site is a wind turbine-electricity grid charging station for EVs located in Bandarabbas. Figure 10 shows the average monthly wind speed for the study site, which is an average of 20 years [54], and is obtained from the NASA website. According to the figure, the average wind speed during the year is 6,013 m/s. The annual interest rate in Iran is 18% [55] and the useful life of the project is 25 years [56]. Also, the price of electricity exchange with the electricity grid according to the times used is shown in Figure 11. Also, considering that the generation of electricity in the national grid in Iran is through the consumption of fossil fuels in power plants, the information of pollutants produced by the national grid and their penalties are given in Table 3.

Figures 12 show the amount of electric charge of the under study charging station of EVs. Figure 12a shows the daily electrical charge diagram for fast DC charging, Figure B shows the daily electrical charge diagram for fast AC charging, and Figure C shows the daily electrical charge diagram for AC slow charging.

Table 4 provides information on the price of equipment used, their size and other technical characteristics. It should be noted that this equipment has been selected based on access to the Iranian market and the limitation in the number of available equipment has been due to technical and economic issues.

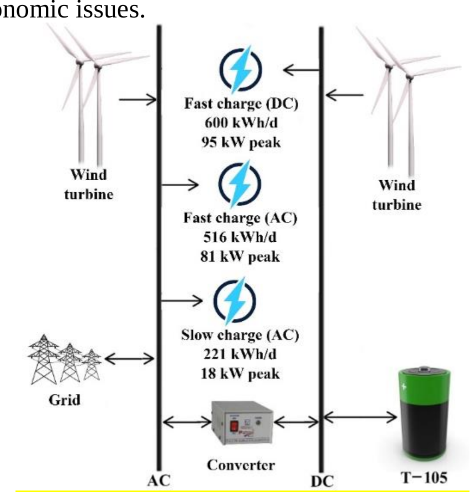


Fig. 9. Schematic of the simulated system in HOMER software

Table.1.
Power curve of wind turbines used in simulation

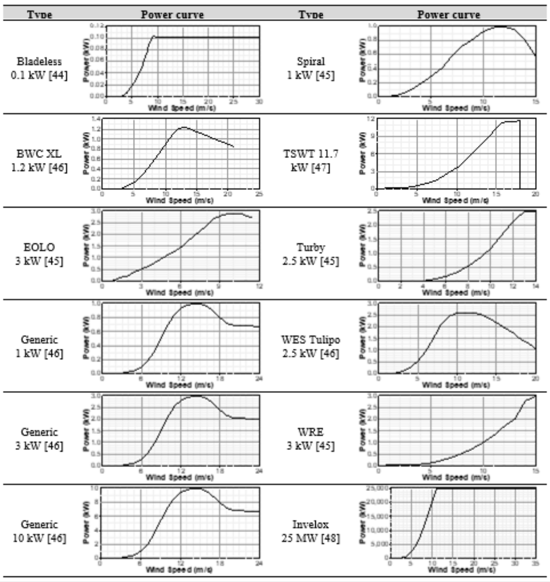


Table.2.
The governing equations of the problem

Desired parameters	Governing equation	Reference
Power of wind turbine	$P_{WTG} = \frac{\rho}{\rho_0} \times P_{WTG,STP}$	[49]
Maximum power of battery	$P_{batt,cmax} = \frac{Min\,(P_{batt,cmax,kbm}, P_{batt,cmax,mcr}, P_{batt,cmax,mcc})}{\eta_{batt,c}}$	[50]
Exchange of electricity with grid	$C_{grid,energy} = \sum_{i}^{rates} \sum_{j}^{12} \begin{cases} E_{net\ grid\ purchases,i,j} \cdot c_{power,i} & \text{if } E_{net\ grid\ purchases,i,j} \geq 0 \\ E_{net\ grid\ purchases,i,j} \cdot c_{sellback,i} & \text{if } E_{net\ grid\ purchases,i,j} < 0 \end{cases}$	[51]
Total NPC	$\text{Total NPC} = \frac{C_{ann,total}}{\frac{i\,(1+i)^N}{(1+i)^N - 1}}$	[52]
LCOE	$LCOE = \frac{C_{ann,total}}{E_{Load\ served}}$	[53]

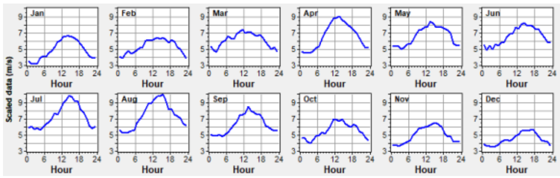


Fig. 10. Average monthly wind speed for the study site

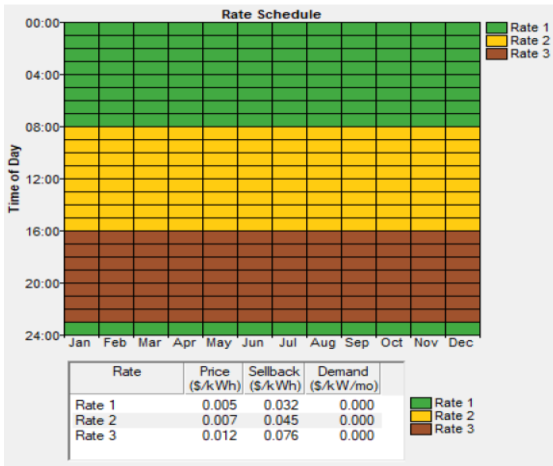


Fig. 11. Three-time electricity tariff in Iran and the hours related to each

Table.3.
Information on pollutants produced and their penalties

Item	***Properties***
Grid [57]	Carbon dioxide: 632 g/kWh, Sulfur dioxide: 2.74 g/kWh, Nitrogen oxide: 1.34 g/kWh
Emission penalty [58]	Carbon dioxide: 3.1 $/t, Sulfur dioxide: 560 $/t, Nitrogen oxides: 184 $/t

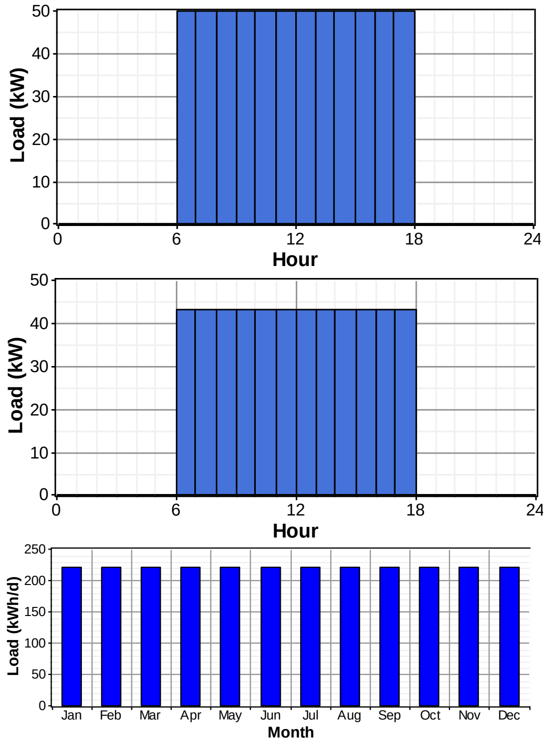


Fig. 12. Electricity profile a) DC fast charge b) AC fast charge c) AC slow charge

5. Results

The results of technical-energy-economic-environmental simulation of using 12 types of wind turbines are presented in Table 5. The results show that the lowest LCOE with $ -0.002 is related to Invelox wind turbine and the highest LCOE with $ 0.063 is related to Turby wind turbine. The reason the LCOE is negative for the Invelox wind turbine is that the amount of electricity it generates is so high that it can be profitable by selling it to the national electricity grid. It should be noted that this type of wind turbine cannot be used in Iran due to the very high initial cost of purchasing its equipment. Therefore, for usability, a 10kW Generic wind turbine with an LCOE of $ 0.023 is recommended. Due to the most expensive price of electricity in Iran (peak time) which is $ 0.012, using the national electricity grid system-wind turbine in Iran is not economical, which is due to very cheap grid electricity price in Iran. Compared to the world average commercial electricity price of $ 0.123 [61], the national electricity grid-wind turbine is very cost-effective. The point about the payback time from Table 5 is that only the Invelox and Generic 10kW wind turbines have a payback time. The payback time for Invelox and Generic 10kW wind turbines is 4.73 years and 9.7 years, respectively. It seems that the use of wind energy on a small and home scale is not cost-effective, which can be considered as suggestions for further work.

With the removal of the Invelox wind turbine due to its very high initial price, the wind turbine power output is between 11184 kWh/y (TSWT) and 55376 kWh/y (WES5 Tulipo). In terms of wind power generation percentage, TSWT and WES5 Tulipo wind turbines with 2% and 10% of total electricity generation, respectively, have produced the lowest and highest wind power percentages.

Table.4.
Equipment information of wind turbine-electricity grid hybrid system

Equipment	**Cost**			**Size (kW)**	**Other information**
	Capital ($)	**Replacement ($)**	**O&M ($/year)**		
Converter [59]	200	200	10	0-5	Lifetime: 10 y Inverter Efficiency: 90% Rectifier Efficiency: 85%
Battery Trojan T-105 [60]	174	174	5	0-25	Lifetime: 845 kWh Nominal specs: 6V, 225 Ah
Bladeless 0.1 kW DC [44]	242	242	12	12	Lifetime: 25 years Hub height: 2.75 m
BWC XL 1.2 kW DC [46]	2307	1845	10	12	Lifetime: 20 years Hub height: 25 m
EOLO 3 kW DC [45]	5269	5269	130	12	Lifetime: 20 years Hub height: 10 m
Generic 1 kW DC [46]	2000	2000	20	12	Lifetime: 20 years Hub height: 25 m
Generic 3 kW DC [46]	9000	8000	15	12	Lifetime: 20 years Hub height: 25 m
Generic 10 kW DC [46]	6118	6118	35	10	Lifetime: 19 years Hub height: 25 m
Invelox 25 MW DC [48]	18750000	18750000	502000	25000	Lifetime: 25 years Hub height: 219 m
Spiral 1 kW DC [45]	1900	1900	48	12	Lifetime: 20 years Hub height: 10 m
TSWT 11.7 kW AC [47]	35000	35000	200	11.7	Lifetime: 19 years Hub height: 6.8 m
Turby 2.5 kW DC [45]	19243	19243	480	12.5	Lifetime: 20 years Hub height: 10 m
WES 5 Tulipo 2.5 kW AC [46]	5000	4000	50	12.5	Lifetime: 15 years Hub height: 25 m
WRE 3 kW DC [45]	13635	13635	340	12	Lifetime: 20 years Hub height: 10 m

Also, the highest and lowest capacity factors with values of 50.6% and 10.9% are related to WES5 Tulipo and TSWT wind turbines, respectively.

An important point that can be seen from Table 5 is the price of each kWh of generated wind power, which, excluding the Invelox wind turbine, is between $ 0.0472 (Generic 10 kW wind turbine) and $ 1.28 (Turby wind turbine). Due to the average commercial price of electricity in the world, the use of wind turbines BWC XL.1, EOLO, Generic 10 kW, Spiral and WES5 Tulipo is recommended. Another point from Table 5 is that no battery storage is required when using the Invelox and WES5 Tulipo wind turbines. The maximum and minimum battery losses are 21 kWh/yr (TSWT wind turbine) and 1 kWh/yr (BWC XL.1 wind turbine), respectively. Regarding the inverter losses, it should be noted that because the TSWT and WES5 Tulipo wind turbines generate AC power, the inverter losses in these two turbines are zero (no DC power is generated to convert to AC). In terms of rectifier losses, the Spiral wind turbine with 34156 kWh/yr has the lowest losses. The highest losses in rectifier are related to WES5 Tulipo wind turbine with a value of 38646 kWh/yr.

In terms of electricity sales to the grid, except for the Invelox wind turbine, which cannot be purchased due to high costs, the WES5 Tulipo wind turbine with 5203 kWh/yr has the highest electricity sales to the electricity grid. The Turby wind turbine with 1636 kWh/yr has made the lowest electricity sales to the electricity grid.

In terms of emissions, the Invelox wind turbine, because of its high electricity sales to the grid, prevents the production of CO_2 emissions and its amount is negative. The WES5 Tulipo wind turbine is in the second category with the lowest level of pollutants with an emission of about 298 tons/year. The highest amount of pollutant production, which is related to the lowest amount of wind power generation with about 326 tons/year, is related to the use of TSWT wind turbine. According to the simulation results, the production of all electricity required by the national electricity grid leads to the production of about 332.8 tons of CO_2 pollutants.

The output power contours of the studied wind turbines are presented in Table 6. Based on the contours, it is clear that the highest average output power after the Invelox wind turbine, which is not economically affordable, with 6.3 kW is related to the WES Tulipo 2.5 kW wind turbine. The lowest average output power with 1.3 kW is related to TSWT 11.7 kW wind turbine.

6. Conclusion

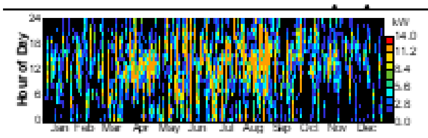
There are several ways to charge an EVs that have different costs. Governments welcome plans to charge EVs using renewable energy. Despite the good potential of wind energy in Iran, so far no feasibility study has been conducted to study a hybrid wind turbine-national electricity grid to supply electricity to a charging station for EVs. In the present work, technical-economic-energy-environmental analyzes have been performed by HOMER software for Bandarabbas. Three different generations of wind turbines (12 different wind turbines) were used for the simulations. The prices used for the equipment have been updated, penalties have been included for the pollutants of the electricity grid, and the electricity exchange has been three-time, with an incentive tariff for the purchase of renewable electricity. The main results of the present work are:

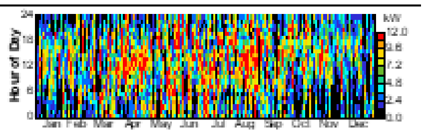
- Generic 10 kW wind turbine with LCOE equal to $ 0.023 is the most economical wind turbine.
- Only Invelox and Generic 10 kW wind turbines have a payback time of 4.73 years and 9.7 years, respectively.
- In terms of wind power generation percentage, TSWT and WES5 Tulipo wind turbines with 2% and 10% of total electricity generated, respectively, have produced the lowest and highest percentage of wind power.
- The price of each kWh of generated wind power (excluding wind Invelox turbine), is between $ 0.0472 (Generic 10 kW wind turbine) and $ 1.28 (Turby wind turbine).
- Due to the average price of commercial electricity in the world, the use of wind turbines BWC XL.1, EOLO, Generic 10kW, Spiral and WES5 Tulipo is recommended.
- Unlike other wind turbines, when using Invelox and WES5 Tulipo wind turbines, no battery storage is required.
- WES5 Tulipo wind turbine with 5203 kWh/yr has the highest electricity sales to the electricity grid.
- In the field of production of pollutants, WES5 Tulipo wind turbine with an emission of about 298 tons year is in the first category the lowest amount of pollutants and the highest amount of pollutants with about 326 tons/year is related to the use of TSWT wind turbine.

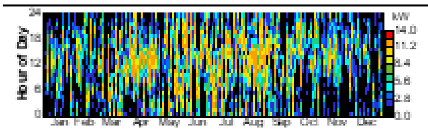
Table.5.
Simulation results of different scenarios based on wind turbine

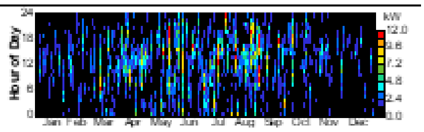
Wind turbine type	LCOE ($/kWh)	Total NPC ($)	Payback time (year)	Wind turbine production (kWh/year)	Capacity factor (%)	Wind turbine LCOE ($/kWh)	Battery Lifetime (year)	Battery Losses (kWh/y)	Inverter/Rectifier losses (kWh/y)	energy sold to grid (kWh/y)	CO_2 (kg/year)
Bladeless	0.034	91957	-	27896 (5% of total)	26.5	0.242	10	2	998/ 35478	2311	313805
BWC XL.1	0.029	78455	-	36265 (7% of total)	41.4	0.121	10	1	1396/ 34705	2868	308292
EOLO	0.029	77928	-	45786 (9% of total)	43.6	0.0976	10	6	2041/ 34168	4208	302357
Generic 1kW	0.030	80839	-	30283 (6% of total)	28.8	0.156	10	8	1110/ 35256	2075	312234
Generic 3kW	0.034	92034	-	30327 (6% of total)	28.9	0.224	10	3	1109/ 35246	2059	312199
Generic 10kW	0.023	61754	9.7	25240 (5% of total)	28.8	0.0472	10	8	924/ 35817	2098	315655
Invelox	- 0.002	-1130307	4.73	112494536 (≈100% of total)	51.4	0.0350	-	-	1227616/330	100768224	-3692120
Spiral	0.03	80257	-	43379 (8% of total)	41.3	0.112	10	5	1795/ 34156	3532	303711
TSWT	0.035	94784	-	11184 (2% of total)	10.9	0.609	10	21	0/ 38644	1668	325750
Turby	0.063	167721	-	15950 (3% of total)	14.6	0.28	10	9	557/ 36807	1636	321910
WES 5 Tulipo	0.030	82233	-	55376 (10% of total)	50.6	0.0923	-	-	0/ 38646	5203	297836
WRE	0.045	119448	-	13185 (3% of total)	12.5	0.878	10	5	470/ 37140	1746	323811

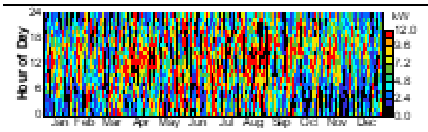
Table.6.
Output power contours of wind turbines

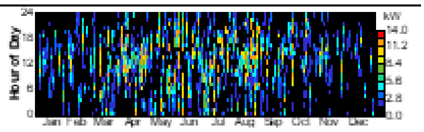

Bladeless 0.1 kW

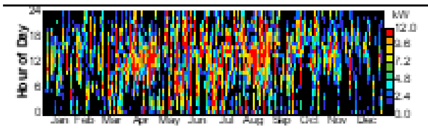

Spiral 1 kW

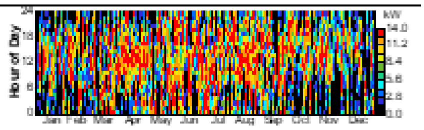

BWC XL 1.2 kW

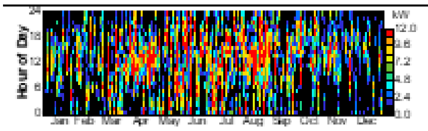

TSWT 11.7 kW

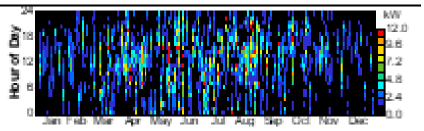

EOLO 3 kW

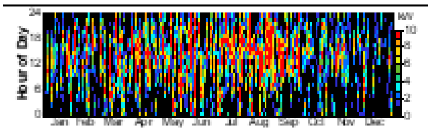

Turby 2.5 kW

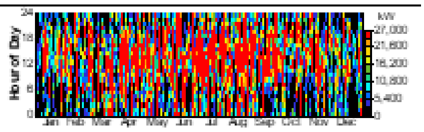

Generic 1 kW


WES Tulipo 2.5 kW


Generic 3 kW


WRE 3 kW


Generic 10 kW


Invelox 25 MW

References

[1] Alayi, R., Zishan, F., Mohkam, M., Hoseinzadeh, S., Memon, S. and Garcia, D.A., 2021. A sustainable energy distribution configuration for microgrids integrated to the national grid using back-to-back converters in a renewable power system. Electronics, 10(15), p.1826. https://doi.org/10.3390/electronics10151826.

[2] Alayi, R. and Rouhi, H., 2020. Techno-economic analysis of electrical energy generation from urban waste in Hamadan, Iran. International Journal of Design & Nature and Ecodynamics, 15(3), pp.337-341. https://doi.org/10.18280/ijdne.150307.

[3] Pal, A., Bhattacharya, A. and Chakraborty, A.K., 2021. Allocation of electric vehicle charging station considering uncertainties. Sustainable Energy, Grids and Networks, 25, p. 100422. https://doi.org/10.1016/j.segan.2020.100422

[4] Shi, R., 2013. The dynamic impacts of electric vehicle integration on the electricity distribution grid, Doctoral dissertation, University of Birmingham. http://etheses.bham.ac.uk//id/eprint/4193/1/Shi13MPhil.pdf

[5] IEA. 2020. Global EV outlook 2020. https://iea.blob.core.windows.net/assets/af46e012-18c2-44d6-becd-bad21fa844fd/Global_EV_Outlook_2020.pdf [Available: 04 April 2022].

[6] Alayi, R., Mohkam, M., Seyednouri, S.R., Ahmadi, M.H. and Sharifpur, M., 2021. Energy/economic analysis and optimization of on-grid photovoltaic system using CPSO algorithm. Sustainability, 13(22), p.12420. https://doi.org/10.3390/su132212420.

[7] Singh, A., Shaha, S.S., Sekhar, Y.R., Saboor, S. and Ghosh, A., 2021. Design and analysis of a solar-powered electric vehicle charging station for Indian cities. World Electric Vehicle Journal, 12(3), p. 132. https://doi.org/10.3390/wevj12030132

[8] Fathabadi, H., 2018. Utilizing solar and wind energy in plug-in hybrid electric vehicles. Energy conversion and management, 156, pp. 317-328. https://doi.org/10.1016/j.enconman.2017.11.015

[9] Ekren, O., Canbaz, C.H. and Güvel, Ç.B., 2021. Sizing of a solar-wind hybrid electric vehicle charging station by using HOMER software. Journal of Cleaner Production, 279, p. 123615. https://doi.org/10.1016/j.jclepro.2020.123615

[10] IEA. 2021. Global electric vehicle stock by region, 2010-2020. https://www.iea.org/data-and-statistics/charts/global-electric-vehicle-stock-by-region-2010-2020 [Available: 28 Apr 2021].

[11] Pathipati, V.K., Shafiei, A., Carli, G., Williamson, S.S., 2017. Integration of Renewable Energy Sources into the Transportation and Electricity Sectors. In Technologies and Applications for Smart Charging of Electric and Plug-in Hybrid Vehicles; Springer International Publishing: Cham, Switzerland, pp. 65–110. https://doi.org/10.1007/978-3-319-43651-7_3

[12] Ye, B., Jiang, J., Miao, L., Yang, P., Li, J. Shen, B., 2015. Feasibility study of a solar- powered electric vehicle charging station model. Energies, 8, pp. 13265-13283. https://doi.org/10.3390/en81112368

[13] Alayi, R., Khalilpoor, N., Heshmati, S., Najafi, A. and Issakhov, A., 2021. Thermal and environmental analysis solar water heater system for residential buildings. International Journal of Photoenergy, 2021. https://doi.org/10.1155/2021/6838138.

[14] Jahangiri, M., Rizi, R.A. and Shamsabadi, A.A., 2018. Feasibility study on simultaneous generation of electricity and heat using renewable energies in Zarrin Shahr, Iran. Sustainable Cities and Society, 38, pp. 647-661. https://doi.org/10.1016/j.scs.2018.01.043

[15] Jahangiri, M. and Shamsabadi, A.A., 2017. Designing a horizontal-axis wind turbine for South Khorasan province: A case study. International Journal of Precision Engineering and Manufacturing, 18(10), pp. 1463-1473. https://doi.org/10.1007/s12541-017-0174-5

[16] 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), pp. 1422-1435. https://doi.org/10.1080/15435075.2019.1671415

[17] 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), pp. 149-160. https://doi.org/10.14710/ijred.8.2.149-160

[18] Alayi, R., Sadeghzadeh, M., Shahbazi, M., Seyednouri, S.R. and Issakhov, A., 2022. Analysis of 3E (Energy-Economical-Environmental) for Biogas Production from Landfill: A Case Study. International Journal of Chemical Engineering, 2022. https://doi.org/10.1155/2022/3033701.

[19] Ghorbani, N., Aghahosseini, A. and Breyer, C., 2020. Assessment of a cost-optimal power system fully based on renewable energy for Iran by 2050–Achieving zero greenhouse gas emissions and overcoming the water crisis. Renewable Energy, 146, pp. 125-148. https://doi.org/10.1016/j.renene.2019.06.079

[20] Alayi, R., Seydnouri, S.R., Jahangeri, M. and Maarif, A., 2021. Optimization, Sensitivity Analysis, and Techno-Economic Evaluation of a Multi-Source System for an Urban Community: A Case Study. Renewable Energy Research and Application. https://dx.doi.org/10.22044/rera.2021.10752.1054.

[21] Rezaei, M., Khalilpour, K.R. and Jahangiri, M., 2020. Multi-criteria location identification for wind/solar based hydrogen generation: The case of capital cities of a developing country. International Journal of Hydrogen Energy, 45(58), pp. 33151-33168. https://doi.org/10.1016/j.ijhydene.2020.09.138

[22] Mordor Intelligence. Iran Wind Energy Market - Growth, Trends, COVID-19 Impact, and Forecasts (2021 - 2026). https://www.mordorintelligence.com/industry-reports/iran-wind-energy-market [Available: 10 July, 2021].

[23] Ministry of Energy. Renewable energy and energy efficiency organization (SATBA); http://www.satba.gov.ir [Available: 25 July, 2021].

[24] Najafi, G. and Ghobadian, B., 2011. LLK1694-wind energy resources and development in Iran. Renewable and Sustainable Energy Reviews, 15(6), pp. 2719-2728. https://doi.org/10.1016/j.rser.2011.03.002

[25] Almutairi, K., Mostafaeipour, A., Jahanshahi, E., Jooyandeh, E., Himri, Y., Jahangiri, M., Issakhov, A., Chowdhury, S., Hosseini Dehshiri, S.J., Hosseini Dehshiri, S.S. and Techato, K., 2021. Ranking locations for hydrogen production using hybrid wind-solar: a case study. Sustainability, 13(8), p.4524. https://doi.org/10.3390/su13084524

[26] MAPNA Group. 2021. MAPNA Unveils Iran's First Solar-Based EV Charging Station in Alborz https://www.mapnagroup.com/en/news/power/mapna-unveils-solar-ev-station [Available: 12 June, 2021].

[27] Financial Tribune. 2021. Alborz EV Charging Station Opens. https://financialtribune.com/articles/auto/109554/alborz-ev-charging-station-opens [Available: 19 April, 2021].

[28] Al Wahedi, A. and Bicer, Y., 2021. Techno-economic optimization of a novel stand-alone renewables-based electric vehicle charging station in Qatar. Energy, 243, p. 123008. https://doi.org/10.1016/j.energy.2021.123008

[29] Kim, G. and Hur, J., 2021. Methodology for Security Analysis of Grid-Connected Electric Vehicle Charging Station with Wind Generating Resources. IEEE Access, 9, pp. 63905-63914. https://doi.org/10.1109/ACCESS.2021.3075072

[30] Noman, F., Alkahtani, A.A., Agelidis, V., Tiong, K.S., Alkawsi, G. and Ekanayake, J., 2020. Wind-Energy-Powered Electric Vehicle Charging Stations: Resource Availability Data Analysis. Applied Sciences, 10(16), p. 5654. https://doi.org/10.3390/app10165654

[31] Fathabadi, H., 2017. Novel wind powered electric vehicle charging station with vehicle-to-grid (V2G) connection capability. Energy conversion and management, 136, pp. 229-239. https://doi.org/10.1016/j.enconman.2016.12.045

[32] Mohammadpour Penchah, M. and Malakooti, H., 2020. The eastern-Iran wind-resource assessment through a planetary boundary layer simulation (2011–2015). Wind Engineering, 44(3), pp. 253-265. https://doi.org/10.1177/0309524X19849863

[33] Renewable Energy and Energy Efficiency Organization. 2022. http://www.satba.gov.ir [Available: 20 March 2022].

[34] Zahedi, R., Zahedi, A. and Ahmadi, A., 2022. Strategic Study for Renewable Energy Policy, Optimizations and Sustainability in Iran. Sustainability, 14(4), p. 2418. https://doi.org/10.3390/su14042418

[35] Renewable power plants Geographical map, Ministry of energy, Renewable Energy and Energy Efficiency Organization (SATBA), http://www.satba.gov.ir/suna_content/media/image/2020/03/8144_orig.png [Available: 29 March 2022]

[36] Global Wind Atlas. 2022. https://globalwindatlas.info/area/Iran [Available 22 July 2022]

[37] Bandar Abbas, Wikipedia, https://en.wikipedia.org/wiki/Bandar_Abbas [Available 5 March 2022]

[38] Rezaei, M., Mostafaeipour, A. and Jahangiri, M., 2021. Economic assessment of hydrogen production from sea water using wind energy: A case study. Wind Engineering, 45(4), pp. 1002-1019. https://doi.org/10.1177/0309524X20944391

[39] Alayi, R., Jahangeri, M. and Monfared, H., 2020. Optimal location of electrical generation from urban solid waste for biomass power plants. Anthropogenic Pollution, 4(2), pp. 44-51. https://doi.org/10.22034/AP.2020.1903832.1069

[40] 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, Article ID 6679358. https://doi.org/10.1155/2021/6679358

[41] Alkawsi, G., Baashar, Y., Alkahtani, A.A., Lim, C.W., Tiong, S.K. and Khudari, M., 2021. Viability Assessment of Small-Scale On-Grid Wind Energy Generator for Households in Malaysia. Energies, 14(12), p. 3391. https://doi.org/10.3390/en14123391

[42] Ghaderian, A., Jahangiri, M. and Saghaei, H., 2020. Emergency power supply for NICU of a hospital by solar-wind-based system, a step towards sustainable development. Journal of Solar Energy Research, 5(3), pp. 506-515. https://doi.org/10.22059/JSER.2020.306423.1166

[43] Alkawsi, G., Baashar, Y., Alkahtani, A.A., Lim, C.W., Tiong, S.K. and Khudari, M., 2021. Viability Assessment of Small-Scale On-Grid Wind Energy Generator for Households in Malaysia. Energies, 14(12), p. 3391. https://doi.org/10.3390/en14123391

[44] Bridgestone Corporation. 2019. No blades! A pole-shaped wind turbine, Vortex Bladeless, generates power by shaking. Available from: https://www.bridgestone.com/bwsc/stories/article/2019/11/13-2.html [Available: January 5, 2020].

[45] Jahangiri, M., Haghani, A., Shamsabadi, A.A., Mostafaeipour, A. and Pomares, L.M., 2019. Feasibility study on the provision of electricity and hydrogen for domestic purposes in the south of Iran using grid-connected renewable energy plants. Energy Strategy Reviews, 23, pp. 23-32. https://doi.org/10.1016/j.esr.2018.12.003

[46] 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), pp. 317-338. https://doi.org/10.22059/EES.2019.37669

[47] 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 & Environment, 31(7), pp. 1230-1256. https://doi.org/10.1177/0958305X19888878

[48] Jahangiri, M., Shamsabadi, A.A., Nematollahi, O. and Mostafaeipour, A., 2020. Enviro-economic investigation of a new generation of wind turbines. International Journal of Strategic Energy & Environmental Planning, 2(3), pp. 43-59. https://www.researchgate.net/publication/341670932

[49] Pahlavan, S., Jahangiri, M., Alidadi Shamsabadi, A. and Rahimi Ariae, A., 2019. Assessment of PV-based CHP system: The effect of heat recovery factor and fuel type. Journal of Energy Management and Technology, 3(1), pp. 40-47. https://doi.org/10.22109/JEMT.2018.137207.1106

[50] 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, Tehran, Iran, pp. 1-10. https://en.civilica.com/doc/672922

[51] Vahdatpour, S., Behzadfar, S., Siampour, L., Veisi, E. and Jahangiri, M., 2017. Evaluation of off-grid hybrid renewable systems in the four climate regions of Iran. Journal of Renewable Energy and Environment, 4(1), pp. 61-70. https://doi.org/10.30501/JREE.2017.70107

[52] 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), pp. 8-22. https://doi.org/10.30501/JREE.2018.88377

[53] Kalbasi, R., Jahangiri, M. and Tahmasebi, A., 2021. Comprehensive investigation of solar-based hydrogen and electricity production in Iran. International Journal of Photoenergy, 2021, Article ID 6627491. https://doi.org/10.1155/2021/6627491

[54] 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), pp. 201-211. https://journals.ut.ac.ir/article_68643.html

[55] Jahangiri, M., Haghani, A., Heidarian, S., Mostafaeipour, A., Raiesi, H.A. and Shamsabadi, A.A., 2020. Sensitivity analysis of using solar cells in regional electricity power supply of off-grid power systems in Iran. Journal of Engineering, Design and Technology, 18 (6), pp. 1849-1866. https://doi.org/10.1108/JEDT-10-2019-0268

[56] Ebrahimi, S., Jahangiri, M., Raiesi, H.A. and Ariae, A.R., 2019. Optimal planning of on-grid hybrid microgrid for remote island using HOMER software, Kish in Iran. International Journal of Energy, 3(2), pp. 13-21. http://dx.doi.org/10.47238/ijeca.v3i2.77

[57] 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, 19

(3), pp. 698-720. https://doi.org/10.1108/JEDT-04-2020-0123

[58] Mostafaeipour, A., Sedaghat, A., Hedayatpour, M. and Jahangiri, M., 2020. Location planning for production of bioethanol fuel from agricultural residues in the south of Caspian Sea. Environmental Development, 33, p. 100500. https://doi.org/10.1016/j.envdev.2020.100500

[59] Alizadeh, K., Jahangiri, M. and Bakhtdehkordi, M., 2021. Comprehensive 3E analysis and optimization of off-grid renewable-based microgrids to meet the clinic energy demand, a case study for medical tourism. Energy Equipment and Systems, 9(3), pp. 291-305. https://doi.org/10.22059/EES.2021.246081

[60] Rahmati Dehkordi, S. and Jahangiri, M., 2021. Sensitivity Analysis for 3E Assessment of BIPV System Performance in Abadan in Southwestern Iran. Journal of Renewable Energy and Environment, 9(1), pp. 1-12. https://doi.org/10.30501/JREE.2021.262420.1173

[61] Ganjei, N., Zishan, F., Alayi, R., Samadi, H., Jahangiri, M., Kumar, R. and Mohammadian, A., 2022. Designing and Sensitivity Analysis of an Off-Grid Hybrid Wind-Solar Power Plant with Diesel Generator and Battery Backup for the Rural Area in Iran. Journal of Engineering, 2022, Article ID 4966761. https://doi.org/10.1155/2022/4966761