ISSN: 2251-9246
EISSN: 2345-6221

pp. 135:142

Capacity Assessment of Large-Scale Wind Hydrogen Production in Very Hot and Humid Region of Iran: A Case Study

Maryam Khalili Geshnigani [1, 2]

[1] Department of Mechanical Engineering, Shahrekord Branch, Islamic Azad University, Shahrekord, Iran, m.khalili@iaushk.ac.ir
[2] Energy Research Center, Shahrekord Branch, Islamic Azad University, Shahrekord, Iran

Abstract

In recent years, hydrogen production from renewable energy has been attracting the attention of investors and politicians in the world. Although green hydrogen is still in its early stages in Iran, it has a high potential for development. Considering the importance of the above-mentioned facts and Iran's very good wind potential, the present study was the first attempt to investigate hydrogen production from wind energy in the hot and humid climate zone of Iran. The investigated stations were 5 cities of Khuzestan province and 4 large scale wind turbines were selected to be evaluated. A numerical analysis on wind data and the best fit of the Weibull function for the stations were done. Based on the coefficients k and c of the Weibull function, the amount of hydrogen produced by electrolysis was calculated. The results of the study showed that the EWT 900-52 wind turbine produced the most wind electricity, an annual 4645.85 megawatt hours of wind electricity equivalent to 68.3 tons of hydrogen, in all the investigated stations. Moreover, the suitable station was found to be Dezful, which can produce 20.36, 16.45, 11.93 and 9.44 tons of hydrogen when using wind turbines EWT 52-900, AWE 54-900, AWE 52-750 and Hewind 43-600 respectively.

Keywords: Renewable Energy; Hydrogen Production; Wind Energy; HOMER; Khuzestan.Article history: Received 2023-01-24; Revised 2023-02-13; Accepted 2023-02-19.

https://doi.org/10.30495/ijsee.2023.1978540.1249

1. Introduction

In the process of defining energy supply policies in Iran, it seems necessary to consider plans for safe, sustainable and eco-friendly energy supply [1, 2]. Among the various options, hydrogen energy systems are one of the most effective solutions attracting a lot of attention in the world in recent years as an efficient and clean energy source [3-6]. Iran is a developing country with growing oil, gas, petrochemical and nuclear industries. Therefore, reaching a stable source of hydrogen is considered to be an essential goal [7].

The total hydrogen produced in the world until 2018 is approximately 50 million tons, and China is the largest producer of hydrogen with an annual production of 12.5 million tons. Approximately 88% of the total hydrogen produced in the world is related to petrochemical industries, and less than 10% of the produced hydrogen is sold commercially [8].

As shown in Figure 1, among different types of renewable energy sources, wind energy possesses the highest growth rate having increased from 1.09% in 2000 to 19.03% in 2018 [9]. Until 2018, the total installed wind energy capacity in the world was equal to 591 GW and 5.5% of the electric energy in the world was provided by wind power plants [10].

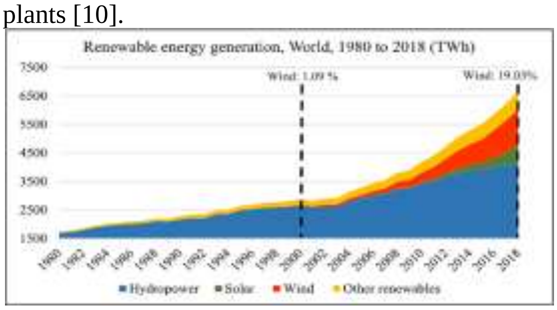

Fig. 1. Changes in energy production from renewable sources during the years 1980 to 2018 [9].

In table 1, some of the recent studies conducted in the field of wind hydrogen production in Iran are mentioned. Analysing the conducted studies, it was found that in some of these studies, only the use of hydrogen as an energy storage has been mentioned [11-13]. In many other studies, the wind power density in the area under study has been calculated using functions and statistical methods [14-17].

Table.1.
A review of previous studies and comparison with the present study

Ref.	***Year***	***Study Area***	***Energy resources***	***Method/ Software***	***Topic Focused on***	***Difference with current work***
Present work	2023	Khuzestan	WT	Best Weibull distribution curve-fit	Assessment of wind potential for hydrogen production in large scale	-
[18]	2021	Abadan	WT/PV/ Biomass/Fuel cell	HOMER	Tri-generation of heat, electricity and hydrogen	- Do not use several types of wind turbines - Not doing the best curve-fitting - The main focus was not on the hydrogen production
[19]	2021	Fars	WT/PV	MCDM techniques	Ranking location for hydrogen production	- Different climatic zone - The main focus was on the ranking of station. - Not doing the best curve-fitting - Do not use several types of wind turbines - Different methodology
[20]	2020	East Azerbaijan	WT	Data Envelopment Analysis (DEA)	Finding the best location for wind farm	- Different climatic zone - The main focus was on the ranking of station. - Not doing the best curve-fitting - Do not use several types of wind turbines - Different methodology
[21]	2020	Iranian coastal cities	WT	Mathematical analysis	Evaluation of hydrogen production from seawater with wind turbine	- Different climatic zone - Different methodology - Not doing the best curve-fitting
[11]	2019	Bandar Abbas, Shiraz, Tabriz, Tehran, and Yazd cities	WT/ PV/ DG	HOMER	Techno-economic feasibility to satisfy electric, heat and hydrogen load	- Different climatic zone - Different methodology - Constant hydrogen load - Do not use several types of wind turbines - Not doing the best curve-fitting
[12]	2019	Bandar Abbas city	Grid & WT/Grid & WT/PV/Grid	HOMER	Techno-economic feasibility study for electricity and hydrogen production	- Different methodology - Constant hydrogen load - Hydrogen production using a reformer - Not doing the best curve-fitting
[22]	2019	Firuzkuh	WT/Grid	DEMATEL & DEA/HOMER	Techno-economic feasibility study for electricity and hydrogen production	- Different climatic zone - Hydrogen production using a reformer - Constant hydrogen daily load - Not doing the best curve-fitting
[23]	2018	31 provinces of Iran	WT	Weibull distribution & GIS maps	Evaluation of wind potential for hydrogen production by using seven commercial WT	- The main focus was on the high altitudes. - The main focus was on comparing different models for estimating Weibull parameters. - Not doing the best curve-fitting
[24]	2018	Iranian coastal province	WT	Weibull distribution & MCDM techniques/RETScreen	Evaluation of wind potentials for hydrogen production from desalinated sea water	- Different climatic zone - The main focus was on desalinated water. - Not doing the best curve-fitting
[13]	2017	Hendijan/ Khuzestan	WT/PV/DG/Grid	HOMER	Techno-economic feasibility study for electricity and hydrogen production	- Different methodology - Constant hydrogen load - Do not use several types of wind turbines - Not doing the best curve-fitting
[16]	2017	Ilam, Kordestan, and Kermanshah provinces	Grid & WT/Grid & WT/PV/Grid	Weibull distribution & MCDM techniques	Suitability of stations for wind and solar hydrogen production	- Different climatic zone - The main focus was on the ranking of station. - Not doing the best curve-fitting
[17]	2017	Fars	WT	Weibull distribution & MCDM techniques	Ranking the stations for construction of a wind farm for hydrogen production	- Different climatic zone - The main focus was on the ranking of station. - Not doing the best curve-fitting
[15]	2016	Fars	WT	Weibull distribution	Feasibility study on the wind energy and hydrogen production	- Different climatic zone - The main focus was on wind energy. - Not doing the best curve-fitting
[14]	2016	Sistan-Baluchestan	WT	Weibull distribution	Feasibility study on the wind energy and hydrogen production	- The main focus was on wind energy. - Not doing the best curve-fitting

Extensive studies have been conducted on hydrogen production using wind turbines. Nevertheless, by reviewing the related literature, it was found out that no detailed evaluation focusing on the potential of wind hydrogen production in hot and humid regions in Iran has been conducted before. Also doing of the best curve-fitting, the non-constant of the produced hydrogen load, and the use of the constants of the Weibull function for the production of wind hydrogen, have not been done in previous studies or have been done very rarely. Therefore, in this study, 5 stations in the province of Khuzestan located in Iran were evaluated in order to find the best location for wind hydrogen production in this province. The 20-year average wind speed data and 4 common wind turbines in the market were used for investigation and analysis. The author hopes that the results of the present study will serve as a road map to help decision makers in the field of energy and especially renewable hydrogen in Iran.

2. The system under study

Approximately 96% of the hydrogen produced in the world is currently supplied through fossil fuels. However, in order to use the potential of hydrogen as a clean energy carrier, it is necessary to use renewable energies in hydrogen production [25, 26]. On the other hand, although various technologies have been proposed for hydrogen production, the most common method used is water electrolysis [27]. In order to produce hydrogen based on water electrolysis using renewable sources, it is possible to use different solar [6, 25, 26, 28-34], wind [14, 22, 35-38] or a combination of different renewable sources depending on the availability and geographical conditions [27, 39-43]. The schematic of the investigated system is presented in Figure 2.

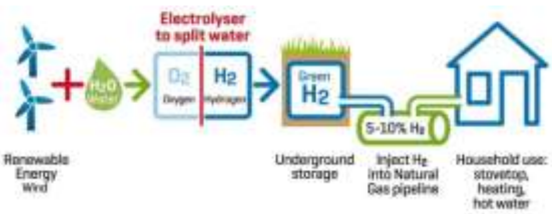

Fig. 2. Schematic of the system investigated in the present study

3. The area under study

As Figure 3 demonstrates, Khuzestan is a province in the southwest of Iran. It is the fifth most populated province of Iran having a hot and humid climate and an area of 64,057 km^2. Considering that the present study is limited to the hot and humid region and the fact that the stations have been selected for investigation whose wind speed data is available on the NASA website, 5 stations in Khuzestan province have been selected for investigation. The stations investigated in the present study are Abadan, Ahvaz, Bandar-e Mahshahr, Dezful and Masjed-e Soleyman. The wind speed data of the investigated stations, which is a 20-year average, was extracted from the NASA website. Geographical and demographic coordinates of the investigated stations are presented in Table 2.

Table.2.
Geographical and demographic coordinates of the investigated stations

Station	***Lon***	***lat***	***Height (m)***	***Population 2016***
Abadan	48.3	30.4	6	231476
Ahvaz	48.7	31.3	22	1185000
Mahshahr	49.2	30.7	46	162797
Dezful	48.5	32.4	503	264709
MJ-Soleyman	49.3	32.0	406	100497

Fig. 3. The area under study.

4. Methodology

The performance of wind turbines depends on wind speed, wind turbine installation height, turbulence intensity, etc. [44, 45]. There are several methods to estimate the wind profile. In this study, the power law method is used, the equation of which is as follows [20]:

$$\frac{u_{hub}}{u_{anem}} = \left(\frac{z_{hub}}{z_{anem}}\right)^{\frac{1}{7}} \quad (1)$$

In the above equation, u_{hub} is the wind speed at the height of the turbine hub, u_{anem} is the wind speed at the vibration of the anemometer, z_{hub} is the installation height of the turbine hub, and z_{anem} is the installation height of the anemometer.

The Weibull function, having a good correspondence with the measured wind data [46] and often used to determine the wind regime, is obtained by the following equation [21]:

$$f(u)=\frac{k}{c}.(\frac{u}{c})^{k-1}.e^{-(\frac{u}{c})^{k}} \quad (2)$$

In the above equation, u is the wind speed (m/s), k is the Weibull shape factor (dimensionless) and c is the Weibull scale parameter (m/s). The coefficient c indicates the windiness of the area and the value k is a parameter that indicates the extent of a wind distribution. In the present study, parameters k and c were calculated by the Justus method [47]:

$$k=(\frac{\sigma_u}{\overline{U}})^{-1.086} \quad (3)$$

$$\frac{c}{\overline{U}}=\frac{k^{2.6674}}{0.184+0.816\,k^{2.73855}} \quad (4)$$

In the above equations, σ_u is the standard deviation parameter and $\overline{U}$ is the annual average of wind speed. The standard deviation is obtained from the following equation [47]:

$$\sigma_u=\overline{U}\sqrt{\frac{\Gamma(1+\frac{2}{k})}{\Gamma^2(1+\frac{1}{k})}-1} \quad (5)$$

The maximum likelihood method presented by Smulders and Stevens [48] was used in the present study to fit the Weibull distribution on the wind speed data,

The capacity factor (CF), defined as the ratio of the output power to the rated power, is calculated by equation 6 using the parameters k and c of the Weibull function for each station at the desired height [49, 50].

$$CF=\frac{P_{out}}{P_{rated}}=\frac{e^{-\left(\frac{V_{cut-in}}{c}\right)^k}-e^{-\left(\frac{V_{rated}}{c}\right)^k}}{\left(\frac{V_{rated}}{c}\right)^k-\left(\frac{V_{cut-in}}{c}\right)^k}-e^{-\left(\frac{V_{cut-out}}{c}\right)^k} \quad (6)$$

In the above equation, V_{cut-in} is the cut-in speed, $V_{cut-out}$ is the cut-out speed, and V_{rated} is the rated speed of the wind turbine. The electric power produced by the wind turbine can be calculated using equation 7 for the time interval T (8760 h) [51].

$$E_{out}=CF\times P_{rated}\times T \quad (7)$$

Finally, hydrogen production by wind turbine is calculated through equation 8 [51].

$$M_{H_2}=\frac{E_{out}}{11.13\times Ec_{el}}\times\eta_{conv.} \quad (8)$$

where $\eta_{conv.}$ is the efficiency of the converter (90%) and Ec_{el} is the energy consumption of the electrolyser (5.5 kWh/N.m^3). Each kilogram of hydrogen is considered equal to 11.13 N.m^3 [52].

5. Input data

The wind speeds of the 5 investigated stations in Khuzestan province are presented in Table 3. The wind speed data used in the present work are 20-year averages extracted from the NASA site and measured for a height of 10 m above the ground [53]. Moreover, the technical data of the wind turbines used in the study is presented in Table 4. Based on the previous studies of other researchers and the availability of 4 wind turbines under investigation in the Iranian market, these wind turbines have been selected for investigation. According to the dimensions and sizes of wind turbines used, the opinion of experts in the field of wind energy, previous studies, and considering the fact that with the increase in the height of the installation of the wind turbine, the price of the supporting structure increases exponentially, the height of 40 m was chosen for the investigations.

Table.3.
Wind speed of studied stations @ 10m

Station	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*AV*
Abadan	2.1	2.8	3	3.3	3.4	4.5	4.4	3.6	3.3	2.2	2.2	2.1	3.1
Ahvaz	2	2.2	2.4	2.7	2.8	3.5	3.6	3	2.4	1.8	1.9	1.9	2.5
Mahshahr	3.6	3.8	3.8	3.7	4.4	4.6	4.4	4.1	4	3.6	3.6	3.7	3.9
Dezful	3.6	3.8	4	4.3	4.7	4.9	4.6	4.5	4.5	4.2	3.8	3.7	4.2
MJ-Soleyman	3.5	3.6	3.6	3.8	4.3	4.4	4.2	4	4	3.8	3.6	3.6	3.9

Table.4.
Wind turbines technical data @ 40m

Model	*Rated power (kW)*	*Cut-in speed (m/s)*	*Rated speed (m/s)*	*Cut-off speed (m/s)*	*Diameter of rotor (m)*
HW 43-600	600	3.5	14.5	25	43
AWE 52-750	750	3	14.5	25	52
EWT 900-52	900	3	13	25	51.5
AWE 54-900	900	2	13	25	54

6. Results

The results of performing the best fit to calculate the parameters k and c of the Weibull function at the height of 40 meters of wind turbine installation for the investigated stations are presented in figure 4. Considering the fact that coefficient c refers to the windiness of the investigated area, it can be concluded from the results that Dezful is the windiest station in Khuzestan province and Ahvaz is the weakest one. Moreover, since the coefficient k indicates the extent of a wind distribution, it can be concluded from the results that the widest range of wind speed (variability of winds in a wide range of speed) belongs to Dezful station with k=1.96 and the smallest wind speed range (narrow wind speed distribution) belongs to Abadan and Ahvaz stations with k=1.99.

Another point that can be seen in Figure 4 is the prevailing wind speed for the investigated stations. Based on the results for Abadan, Ahvaz, Bandar-e Mahshahr, Dezful, and Masjed-e Soleyman stations, the prevailing wind value is 3, 2.5, 4.5, 5, and 4 m/s, respectively. The prevailing wind percentage for these stations is 11, 14, 8, 15, and 8% respectively. According to the results of the survey of prevailing wind and percentage of the prevailing wind, it is clear that Dezful station is the windiest station because it has both the highest amount of prevailing wind and the highest percentage of the prevailing wind. Table 5 demonstrates the amount of wind power produced for all the 4 wind turbines and all the 5 cities. Based on the results, the highest and lowest wind power production are about 1384.8 MWh per year (Dezful station and EWT 52-900 wind turbine) and about 117.3 MWh per year (Ahvaz station and Hewind 43-600 wind turbine). Moreover, for all the surveyed cities, the wind turbines EWT 52-900, AWE 54-900, AWE 52-750 and Hewind 43-600 annually generate approximately 4645.85 MWh (the average of each station is 929.2 MWh), approximately 3645.4 MWh (The average of each station is 729.1 MWh), approximately 2638.5 MWh (the average of each station is 527.7 MWh) and approximately 2028.1 MWh (the average of each station is 405.6 MWh) of wind power respectively.

In Table 5, the amounts of wind hydrogen produced based on the k and c coefficients of the best fit performed on the Weibull function of the wind speed data in all the 5 investigated stations are presented. The efficiency of the converter is considered to be equal to 90% and the energy consumption of the electrolyser equal to 5.5 kWh/N.m3. It can be concluded from the results that the highest amount of annual wind hydrogen production is 68.3 tons when using EWT 52-900 wind turbine in all the investigated stations. The lowest amount of hydrogen produced, which is related to the application of the Hewind 43-600 wind turbine in all the investigated stations, is 29.8 tons per year. Among the investigated wind stations and turbines, the highest and the lowest wind hydrogen production are related to Dezful (EWT 52-900 wind turbine with a rate of 20.36 tons per year) and Ahvaz (Hewind 600-43 wind turbine with a rate of 1.73 tons per year) respectively. The average annual hydrogen production capacity for each station when using wind turbines EWT 52-900, AWE 54-900, AWE 52-750 and Hewind 43-600 is 13.7 tons, 10.7 tons, 7.8 tons and 6 tons, respectively.

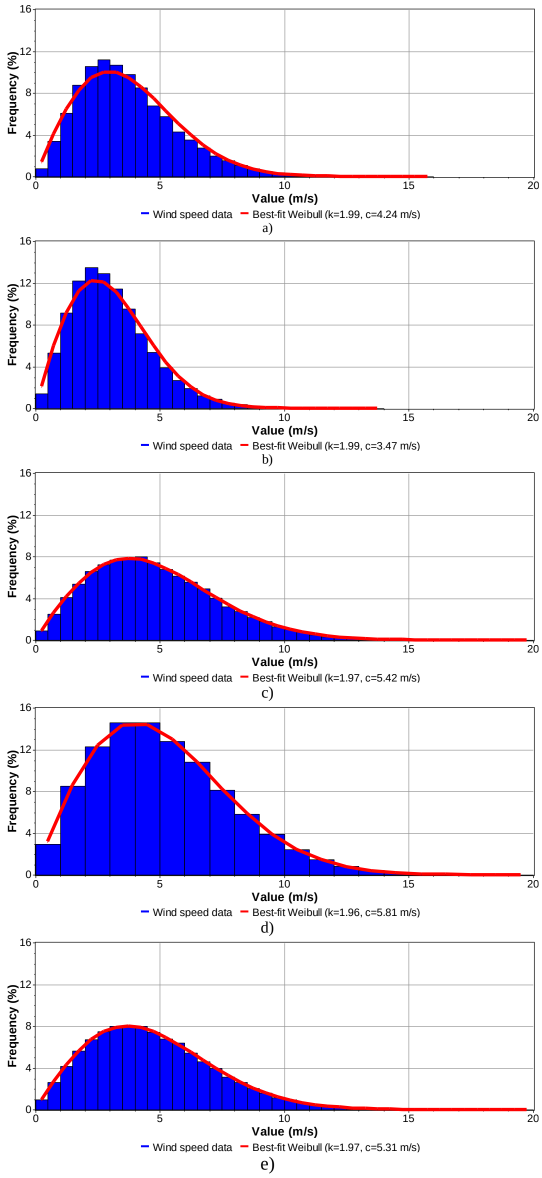

Fig. 4. Weibull function for studied stations, a) Abadan b) Ahvaz c) Mahshahr d) Dezful e) MJ-Soleyman

Table.5.
Numerical analysis results of wind electricity and wind hydrogen production

Station	E_{out} (MWh/year)				M_{H_2} (ton/year)			
	Hewind 43-600	AWE 52-750	EWT 900-52	AWE 54-900	Hewind 43-600	AWE 52-750	EWT 900-52	AWE 54-900
Abadan	244.3	335.3	621.2	464.5	3.59	4.93	9.13	6.83
Ahvaz	117.3	175.9	351.3	243.7	1.73	2.59	5.17	3.58
Mahshahr	527.1	675.3	1171.9	933.1	7.75	9.93	17.23	13.72
Dezful	641.8	811.6	1384.8	1119.1	9.44	11.93	20.36	16.45
MJ-Soleyman	497.6	640.4	1116.5	885.1	7.32	9.42	16.42	13.01

7. Conclusion

The key to success in the cycle of renewable energy is considered to be renewable hydrogen, and only a few countries do not have projects in this field. As the conducted studies indicate, Iran does not have a share in the green hydrogen market. Therefore, it is necessary to conduct preliminary investigations in different climate zones of Iran. Through analyzing previous studies, it was found out that no study has been done in the field of wind hydrogen production on a large scale in hot and humid climate zone (Khuzestan province). Therefore, the present study, was the first one to investigate the potential of wind power generation and the use of electrolysis method to produce hydrogen in the cities of Abadan, Ahvaz, Bandar-e Mahshahr, Dezful and Masjed-e Soleyman using wind turbines EWT 52-900, AWE 54-900, AWE 52-750 and Hewind 43-600. Doing the best fit of the Weibull curve and finding the most accurate k and c values make the results of the present study superior to the previous studies in terms of corresponding with reality. The important results of the present study are:

- Wind turbines EWT-900-52 and Hewind 43-600 produced the most and least wind power, respectively.
- Dezful and Ahvaz stations are the most suitable and the most unsuitable stations in the field of wind power generation respectively.
- The highest and lowest wind power production values are 1384.8 MWh/year (Dezful station) and 117.3 MWh/year (Ahvaz station) , respectively.
- The highest and lowest hydrogen produced for all the stations under investigation is 68.3 tons and 29.8 tons per year, respectively.
- The highest and lowest hydrogen produced in Dezful station is 20.36 tons and 9.44 tons per year, respectively.

References

[1] Jahangiri, M., Raeiszadeh, F., Alayi, R., Najafi, A. and Tahmasebi, A., 2022. Development of Rural Tourism in Iran Using PV-Based System: Finding the Best Economic Configuration. Journal of Renewable Energy and Environment, 2022, pp. 1-9.

[2] Jahangiri, M., Yousefi, Y., Pishkar, I., Hosseini Dehshiri, S.J., Hosseini Dehshiri, S.S. and Fatemi Vanani, S.M., 2023. Techno–Econo–Enviro Energy Analysis, Ranking and Optimization of Various Building-Integrated Photovoltaic (BIPV) Types in Different Climatic Regions of Iran. Energies, 16(1), p. 546.

[3] Mostafaeipour, A., Jahangiri, M., Saghaei, H., Raiesi Goojani, A., Chowdhury, M. and Techato, K., 2022. Impact of Different Solar Trackers on Hydrogen Production: A Case Study in Iran. International Journal of Photoenergy, 2022, p. 3186287.

[4] T. Demirdelen, F. Ekinci, B. D. Mert, İ. Karasu, and M. Tümay, "Green touch for hydrogen production via alkaline electrolysis: The semi-flexible PV panels mounted wind turbine design, production and performance analysis," International Journal of Hydrogen Energy, 2020.

[5] Jahangiri, M., Rezaei, M., Mostafaeipour, A., Goojani, A.R., Saghaei, H., Dehshiri, S.J.H. and Dehshiri, S.S.H., 2022. Prioritization of solar electricity and hydrogen co-production stations considering PV losses and different types of solar trackers: A TOPSIS approach. Renewable Energy, 186, pp. 889-903.

[6] Rezaei, M., Jahangiri, M. and Razmjoo, A., 2021. Utilization of Rooftop Solar Units to Generate Electricity and Hydrogen: A Technoeconomic Analysis. International Journal of Photoenergy, 2021, p. 8858082.

[7] M.-E. Ramazankhani, A. Mostafaeipour, H. Hosseininasab, and M.-B. Fakhrzad, "Feasibility of geothermal power assisted hydrogen production in Iran," International Journal of Hydrogen Energy, vol. 41, pp. 18351-18369, 2016.

[8] W. J. Nuttall and A. T. Bakenne, Fossil Fuel Hydrogen: Technical, Economic and Environmental Potential: Springer, 2019.

[9] Renewable Energy, OURWORLDINDATA, 2018. https://ourworldindata.org/renewable-energy.

[10] Renewables 2019 Global Status Report, REN 21, 2019. https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf.

[11] M. R. Akhtari and M. Baneshi, "Techno-economic assessment and optimization of a hybrid renewable co-supply of electricity, heat and hydrogen system to enhance performance by recovering excess electricity for a large energy consumer," Energy Conversion and Management, vol. 188, pp. 131-141, 2019.

[12] M. Jahangiri, A. Haghani, A. A. Shamsabadi, A. Mostafaeipour, and L. M. Pomares, "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, vol. 23, pp. 23-32, 2019.

[13] M. Qolipour, A. Mostafaeipour, and O. M. Tousi, "Techno-economic feasibility of a photovoltaic-wind power plant construction for electric and hydrogen production: A case study," Renewable and sustainable energy reviews, vol. 78, pp. 113-123, 2017.

[14] O. Alavi, A. Mostafaeipour, and M. Qolipour, "Analysis of hydrogen production from wind energy in the southeast of Iran," international journal of hydrogen energy, vol. 41, pp. 15158-15171, 2016.

[15] A. Mostafaeipour, M. Khayyami, A. Sedaghat, K. Mohammadi, S. Shamshirband, M.-A. Sehati, et al., "Evaluating the wind energy potential for hydrogen production: a case study," International Journal of Hydrogen Energy, vol. 41, pp. 6200-6210, 2016.

[16] A. Mostafaeipour and E. Jooyandeh, "Prioritizing the locations for hydrogen production using a hybrid wind-solar system: A case study," Advances in Energy Research, vol. 5, p. 107, 2017.

[17] M. Rezaei-Shouroki, A. Mostafaeipour, and M. Qolipour, "Prioritizing of wind farm locations for hydrogen production: A case study," International Journal of Hydrogen Energy, vol. 42, pp. 9500-9510, 2017.

[18] Jahangiri, M., Karimi Shahmarvandi, F. and Alayi, R., 2021. Renewable energy-based systems on a residential scale in southern coastal areas of Iran: trigeneration of heat, power, and hydrogen. Journal of Renewable Energy and Environment, 8(4), pp. 67-76.

[19] 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.

[20] Mostafaeipour, A., Sadeghi, S., Jahangiri, M., Nematollahi, O. and Sabbagh, A.R., 2019. Investigation of accurate

location planning for wind farm establishment: a case study. Journal of Engineering, Design and Technology, 18 (4), pp. 821-845.

[21] 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.

[22] A. Mostafaeipour, M. Qolipour, and H. Goudarzi, "Feasibility of using wind turbines for renewable hydrogen production in Firuzkuh, Iran," Frontiers in Energy, vol. 13, pp. 494-505, 2019.

[23] Z. N. Ashrafi, M. Ghasemian, M. I. Shahrestani, E. Khodabandeh, and A. Sedaghat, "Evaluation of hydrogen production from harvesting wind energy at high altitudes in Iran by three extrapolating Weibull methods," International Journal of Hydrogen Energy, vol. 43, pp. 3110-3132, 2018.

[24] M. Rezaei, A. Mostafaeipour, M. Qolipour, and H.-R. Arabnia, "Hydrogen production using wind energy from sea water: A case study on Southern and Northern coasts of Iran," Energy & Environment, vol. 29, pp. 333-357, 2018.

[25] M. Jafari, D. Armaghan, S. S. Mahmoudi, and A. Chitsaz, "Thermoeconomic analysis of a standalone solar hydrogen system with hybrid energy storage," International Journal of Hydrogen Energy, vol. 44, pp. 19614-19627, 2019.

[26] H. Arellano-Garcia, M. R. Ife, M. Sanduk, and D. Sebastia-Saez, "Hydrogen Production via Load-Matched Coupled Solar-Proton Exchange Membrane Electrolysis Using Aqueous Methanol," Chemical Engineering & Technology, vol. 42, pp. 2340-2347, 2019.

[27] M. Gokcek and C. Kale, "Techno-economical evaluation of a hydrogen refuelling station powered by wind-pv hybrid power system: a case study for izmir-cesme," International Journal of Hydrogen Energy, vol. 43, pp. 10615-10625, 2018.

[28] E. Troncoso, N. Lapena-Rey, and O. Valero, "Off-grid test results of a solar-powered hydrogen refuelling station for fuel cell powered Unmanned Aerial Vehicles," International journal of hydrogen energy, vol. 39, pp. 11267-11278, 2014.

[29] G. Dispenza, F. Sergi, G. Napoli, N. Randazzo, S. Di Novo, S. Micari, et al., "Development of a solar powered hydrogen fueling station in smart cities applications," International Journal of Hydrogen Energy, vol. 42, pp. 27884-27893, 2017.

[30] R. Carbone, C. Marino, A. Nucara, M. F. Panzera, and M. Pietrafesa, "Electric Load Influence on Performances of a Composite Plant for Hydrogen Production from RES and its Conversion in Electricity," Sustainability, vol. 11, p. 6362, 2019.

[31] Y. Han, G. Zhang, Q. Li, Z. You, W. Chen, and H. Liu, "Hierarchical energy management for PV/hydrogen/battery island DC microgrid," International Journal of Hydrogen Energy, vol. 44, pp. 5507-5516, 2019.

[32] H. Rezk, E. T. Sayed, M. Al-Dhaifallah, M. Obaid, A. H. M. El-Sayed, M. A. Abdelkareem, et al., "Fuel cell as an effective energy storage in reverse osmosis desalination plant powered by photovoltaic system," Energy, vol. 175, pp. 423-433, 2019.

[33] F. Dawood, G. Shafiullah, and M. Anda, "Stand-alone microgrid with 100% renewable energy: A case study with hybrid solar PV-battery-hydrogen," Sustainability, vol. 12, p. 2047, 2020.

[34] C. Marino, A. Nucara, M. Panzera, M. Pietrafesa, and V. Varano, "Energetic and economic analysis of a stand alone photovoltaic system with hydrogen storage," Renewable Energy, vol. 142, pp. 316-329, 2019.

[35] S. H. Siyal, D. Mentis, and M. Howells, "Economic analysis of standalone wind-powered hydrogen refueling stations for road transport at selected sites in Sweden," International Journal of Hydrogen Energy, vol. 40, pp. 9855-9865, 2015.

[36] S. Nistor, S. Dave, Z. Fan, and M. Sooriyabandara, "Technical and economic analysis of hydrogen refuelling," Applied Energy, vol. 167, pp. 211-220, 2016.

[37] F. Grüger, L. Dylewski, M. Robinius, and D. Stolten, "Carsharing with fuel cell vehicles: Sizing hydrogen refueling stations based on refueling behavior," Applied energy, vol. 228, pp. 1540-1549, 2018.

[38] T. Ayodele and J. Munda, "Potential and economic viability of green hydrogen production by water electrolysis using wind energy resources in South Africa," International Journal of Hydrogen Energy, vol. 44, pp. 17669-17687, 2019.

[39] M. Jahangiri, M. H. Soulouknga, F. K. Bardei, A. A. Shamsabadi, E. T. Akinlabi, S. M. Sichilalu, et al., "Techno-econo-environmental optimal operation of grid-wind-solar electricity generation with hydrogen storage system for domestic scale, case study in Chad," International Journal of Hydrogen Energy, vol. 44, pp. 28613-28628, 2019.

[40] M. Gökçek and C. Kale, "Optimal design of a hydrogen refuelling station (HRFS) powered by hybrid power system," Energy Conversion and Management, vol. 161, pp. 215-224, 2018.

[41] S. Kharel and B. Shabani, "Hydrogen as a long-term large-scale energy storage solution to support renewables," Energies, vol. 11, p. 2825, 2018.

[42] O. Nematollahi, P. Alamdari, M. Jahangiri, A. Sedaghat, and A. A. Alemrajabi, "A techno-economical assessment of solar/wind resources and hydrogen production: A case study with GIS maps," Energy, vol. 175, pp. 914-930, 2019.

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

[44] Dehkordi, M.H.R., Isfahani, A.H.M., Rasti, E., Nosouhi, R., Akbari, M. and Jahangiri, M., 2022. Energy-Economic-Environmental assessment of solar-wind-biomass systems for finding the best areas in Iran: A case study using GIS maps. Sustainable Energy Technologies and Assessments, 53, p. 102652.

[45] Mostafaeipour, A., Sadeghi, S., Jahangiri, M., Nematollahi, O. and Sabbagh, A.R., 2019. Investigation of accurate location planning for wind farm establishment: a case study. Journal of Engineering, Design and Technology, 18 (4), pp. 821-845.

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

[47] 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.

[48] Sedaghat, A., Mostafaeipour, A., Rezaei, M., Jahangiri, M. and Mehrabi, A., 2020. A new semi-empirical wind turbine capacity factor for maximizing annual electricity and hydrogen production. International Journal of Hydrogen Energy, 45(32), pp. 15888-15903.

[49] 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.

[50] Sedaghat, A., Alkhatib, F., Eilaghi, A., Mehdizadeh, A., Borvayeh, L., Mostafaeipour, A., Hassanzadeh, A. and Jahangiri, M., 2020. Optimization of capacity factors based on rated wind speeds of wind turbines. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, pp. 1-22.

[51] Kalbasi, R., Jahangiri, M. and Tahmasebi, A., 2021. Comprehensive investigation of solar-based hydrogen and

electricity production in Iran. International Journal of Photoenergy, 2021, p. 6627491.

[52] Jahangiri, M. and Riahi, R., 2022. Potential of wind hydrogen production in Afghanistan. 8th Iran Wind Energy Conference, Iran University of Science and Technology, Tehran, Iran, pp. 1-4.

[53] 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.