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Technical and Economic Analysis of Renewable Hydrogen Production: A Focus on the Role of Subsidies

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Abstract

The production of hydrogen from renewable energy sources like wind and solar power in Iran is crucial due to the country's abundant wind and solar potential. Tabriz and Jask, known for their strong wind and sunlight, have been chosen for a study on renewable hydrogen production. This research evaluates the impact of government subsidies on this production for the first time in Iran. Using HOMER V.2.81, a 25-year analysis was conducted on energy, economics, and the environment. Different technologies were used to convert wind and solar electricity into hydrogen, with costs of $0.145/kWh in Tabriz and $0.125/kWh in Jask. A 100 kW diesel generator is needed for both stations, with optimal wind turbine sizes of 20 kW and solar cells at 140 kW. The payback period is less than 2 years compared to traditional diesel systems, with significant reductions in pollutants. Solar hydrogen production through water electrolysis is highlighted as the most effective method. Subsidies positively impact wind and solar systems, reducing payback periods and increasing surplus electricity. Solar-produced hydrogen surpasses that from wind when considering these subsidies.

Keywords: Water electrolyzer, Green hydrogen, Renewable electricity, Emissions penalty, Random variability.
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1. Introduction

In 2020, global hydrogen production was around 94 million tonnes per year, with an expected rise to 530 million tonnes per year by 2050 [1]. Presently, 96% of hydrogen production is based on fossil fuels (47% natural gas, 27% coal, and 22% oil) [2], and approximately 4% is derived from water electrolysis, projected to reach about 12% by 2050 [3]. Figure 1 illustrates the hydrogen demand in various sectors of some countries [1]. The significant difference between 2020 and 2050 arises from a considerable reduction in hydrogen demand in refineries, a threefold increase in demand in the chemical sector, and an elevated requirement in the transportation sector. According to Figure 1, Iran's demand in 2020 has risen from approximately 0.2 kWel per capita to 0.6 kWel per capita in 2050.

Renewable hydrogen, due to the decreasing costs of solar and wind energy production, is considered a key component for global energy transmission. However, green hydrogen is still expensive. According to Figure 2, to produce one million tonnes of green hydrogen annually, a 10 GW electrolyzer capacity is required, which necessitates the conversion of 20 GW of wind and solar energy to hydrogen, entailing a cost of $30 billion [4].

Based on estimates, in the coming years, due to technological advancements, each kilogram of renewable hydrogen will cost around $3 [4], which is still $1-1.5 more expensive than gray hydrogen. The cost gap between renewable hydrogen production and gray hydrogen requires special attention from the government in terms of financial support and subsidies. This issue ensures that renewable hydrogen production remains both economically viable and sustainable [5]. In Figure 3, the levelized cost of green hydrogen in 2050 is estimated [5].

Subsidies and financial incentives can have a significant impact on the trend of renewable hydrogen production in Iran. These impacts can be presented in several ways:

a) Encouragement of investment in hydrogen production: Subsidies and financial incentives may motivate companies and investors to invest in renewable hydrogen production projects in Iran. These actions could facilitate the reduction of capital costs and enhance the competitiveness of the hydrogen industry in the country.

b) Facilitated access to financial resources: Subsidies and financial incentives can simplify the provision of financial resources for renewable hydrogen production projects, accelerating the industry's development.

c) Reduction in production costs: By offering financial facilities and discounts for renewable hydrogen projects, the costs of hydrogen production could decrease, potentially increasing the demand for this clean energy source.

d) Increase in local production: Subsidies and financial incentives can assist in the development of local renewable hydrogen production in Iran, reducing dependence on fossil fuel-dependent hydrogen imports.

e) Alignment with sustainability goals: Encouraging the production of hydrogen from renewable sources can increase Iran's capacity to achieve environmental sustainability goals and decrease greenhouse gas emissions.

Considering these factors, more precise policies and measures organized by the Iranian government and interactions with the private industry can bring about positive impacts on the trend of renewable hydrogen production in the country. Furthermore, striking a balance between financial support and safeguarding the government's financial interests is essential for the optimal utilization of the country's financial resources. Table 1 reviews recent studies in the field of renewable hydrogen production in Iran. The aim of presenting this information is to emphasize the existing scientific gaps and amplify the innovation in the current work.

Based on the provided explanation regarding the importance of utilizing renewable hydrogen and considering previous studies, it is observed that a comprehensive review of the maximum potential of renewable wind and solar power in Iran has not yet been conducted. Instead, studies have been limited to specific regions. Therefore, in the present study, scenarios with and without subsidies have been chosen to investigate the impact of subsidies on renewable hydrogen. The wind power generation in Tabriz and solar power generation in Jask were calculated using HOMER V.2.81 software. Then, using analytical equations, the amount of hydrogen produced by four methods-water electrolysis, steam methane reforming, biological methods, and thermochemical water splitting-was calculated at these stations. This current study is the first to numerically compare the potential of various hydrogen production technologies and can serve as a roadmap for future studies.

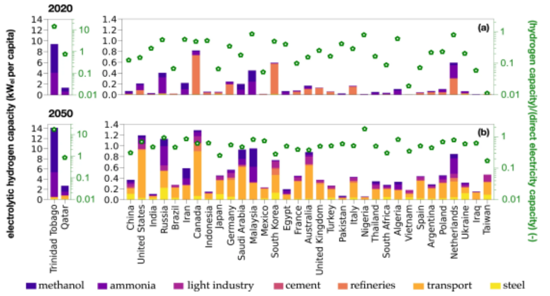

Fig. 1. The demand for hydrogen in various sectors of selected countries [1].

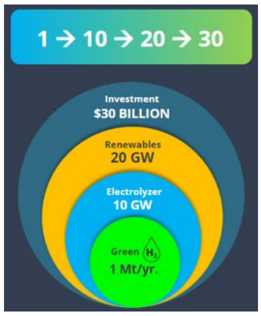

Fig. 2. Financial and equipment estimate for the annual production of one million tons of green hydrogen [4].

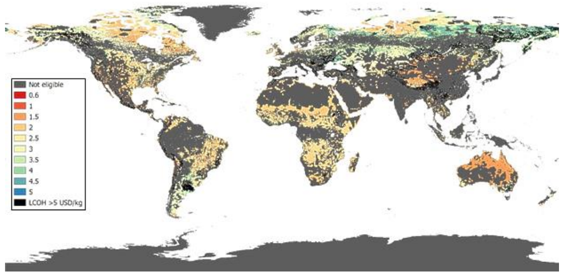

Fig. 3. Levelized cost map of green hydrogen worldwide in 2050 [5].

2. Location under study

Figures 4 and 5 show the wind and solar potential maps of Iran, respectively. On the wind map (Figure 4), the location of the Tabriz station is indicated, and on the solar map (Figure 5), the location of the Jask station is marked. It should be noted that Maps 1 and 2 depict the average annual wind speed and solar radiation at 103 meteorological stations in Iran. These data are based on a 20-year average and have been extracted from NASA's website. Based on statistics and information, Jask, located at a latitude of 25.64° N and a longitude of 57.77° E with an average elevation of -2 m above sea level, is one of the cities in the southern province of Hormozgan, Iran, situated on the coast of the Sea of Oman. The population of this city was 16,869 in the year 2016. According to the Köppen-Geiger climate classification, this city falls under the BWh category, which characterizes it as a region with a "hot desert climate" [18].

Table.1.
Recent studies conducted in the field of renewable hydrogen production in Iran

Reference, Year	The goal of the work	Investigated energies	Result	Methodology	Location	Difference with the present work
Mostafaeipour et al. 2022 [6]	Technical, economic, and environmental analysis of the impact of various solar panels on hydrogen production in a combined heat and power system in off-grid and on-grid modes	Solar	The cheapest produced hydrogen for off-grid and on-grid modes is $77.97/kg and $29.33/kg, respectively.	HOMER	Jask, Iran	- The objective under study is different. - The system under study is different. - Wind energy has not been examined. - Only water electrolysis has been investigated.
Dehshiri and Firoozabadi 2022 [7]	Locating a solar power plant for electricity and hydrogen production	Solar	Sirjan is the most suitable site, where 30.77 tons of hydrogen are produced annually at a price of $2.54 per kilogram.	The SWARA method and the MARCOS ranking method.	Kerman province	- The methodologies differ. - The examined objectives are different. - The climate under consideration is different. - Wind energy has not been examined. - Only electrolysis has been examined.
Jahangiri et al. 2022 [8]	Ranking of stations in Iran in the field of simultaneous solar power and hydrogen production while considering losses and types of solar trackers	Solar	The examination of 13 criteria showed that Yasuj is the most suitable station, producing hydrogen in the range of 671.5 to 457.4 kg.	PVsyst 6.7 and MCDM methods	Iran	- The methodology is different. - Wind energy has not been examined. - Only water electrolysis has been examined. - The goal was to find a suitable station, not to find the maximum hydrogen production.
Almutairi et al. 2022 [9]	The economic assessment of wind hydrogen production for 4 different wind turbines	Wind	The most suitable station is Ahar, producing 2.9 MWh of electricity annually at a cost of 0.045 $/kWh and generating 47.2 tons of hydrogen priced at 1.38 $/kg.	MCDM method	East Azerbaijan	- The methodology differs. - Solar energy has not been examined. - The climate under investigation is different. - The goal under study is different. - Only water electrolysis has been reviewed.
Rod et al. 2022 [10]	Assessment of the environmental and economic impact of using hydrogen in Iran's transportation sector	Solar, wind, and combined gas cycle	Steam methane reforming is a relatively clean and efficient method. The highest hydrogen production is with the electrolysis of water method.	Numerical analysis	without considering a specific station	- The methodology is different. - Climate was not examined. - Wind energy was not studied. - Most of the hydrogen production methods were different. - The goal was to find the optimal hydrogen production technology.
Dehshiri and Amiri 2023 [11]	Assessment of sustainable hydrogen production strategies based on renewable energies in Iran	Renewable energies	The strategy of cooperation and coordination between energy investors and various industries in Iran for developing hydrogen projects with the least expenses is the most efficient approach.	SWOT analysis and MCDM methods	without considering a specific station	- The methodology is different. - The discussion did not cover wind and solar hydrogen production through water electrolysis and other methods. - Climate was not examined.
Geshnigani , 2023 [12]	Assessment of large-scale wind hydrogen production capacity using four different wind turbines	Wind	Dezful is the most suitable station, and the EWT 900-52 wind turbine is the most suitable turbine, producing an annual output of 20.36 tons of hydrogen.	Numerical analysis	5 stations in Khuzestan province	- Solar energy has not been examined. - The climate under consideration is different. - The goal under scrutiny is different. - Only water electrolysis has been examined.
Rahimirad and Sadabadi 2023 [13]	The policymaking of the development and utilization of green hydrogen technology in Iran employing 9 different strategies	Renewable energies	Setting the role of green hydrogen technology in energy policy as the first priority.	AHP, SWOT, F-TOPSIS, F-VIKOR	without considering a specific station	- The methodology is different. - The discussion about wind and solar hydrogen production using water electrolysis and other methods was not raised. - Climate considerations were not taken into account.

Mirzakhani and Pishkar 2023 [14]	Power supply for a remote village and energy-economic-environmental analyses at the household level	Solar, wind, fuel cell	The wind-diesel generator system, with a cost of $0.735 per kWh, is the most cost-effective option. It produced 50.7 kg of hydrogen annually.	HOMER	Tamin village in Sistan and Baluchestan province	- The objective of the study was different. - The system under study was different. - The climate and location under examination were different. - Only water electrolysis was investigated.
Kakavand et al. 2023 [15]	Technical and economic assessment of green hydrogen and ammonia production for export	Solar and wind	Calculating the actual cost of producing green hydrogen/ammonia.	HOMER PRO	Various stations in Iran	- The methodology is different. - The research objective is different. - Only water electrolysis has been examined. - The climate and location under study are different.

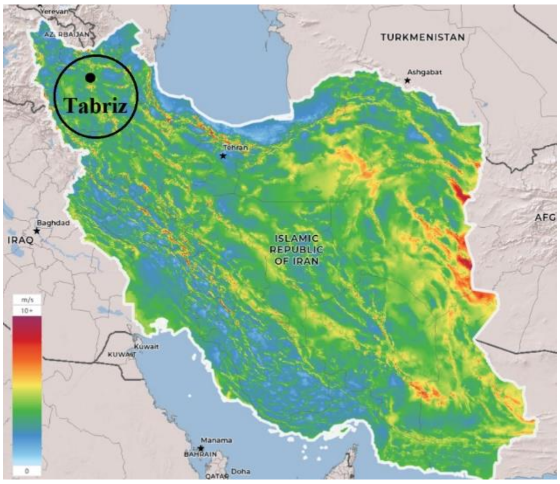

Fig. 4. Tabriz location on Iran's wind map [16]

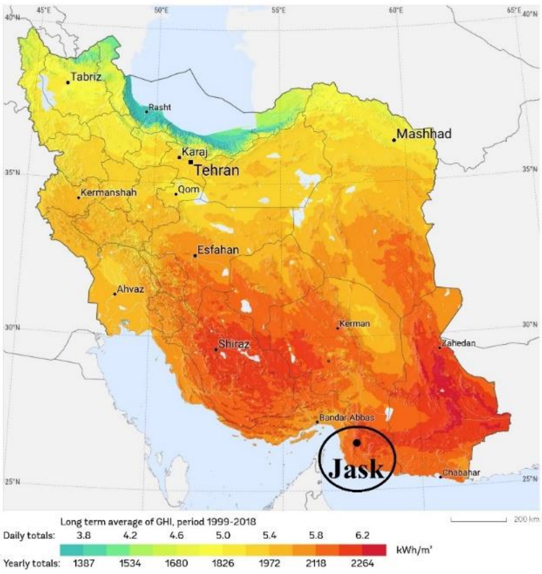

Fig. 5. The location of Jask on Iran's solar map [17].

Tabriz, the capital of East Azerbaijan Province, is the third-largest city in Iran by area, with a population of approximately 1,584,855 people (based on the 2016 census). Situated at a latitude of 38.08° N and a longitude of 46.30° E, Tabriz is located in the northwest of Iran. According to the Köppen-Geiger climate classification, this city

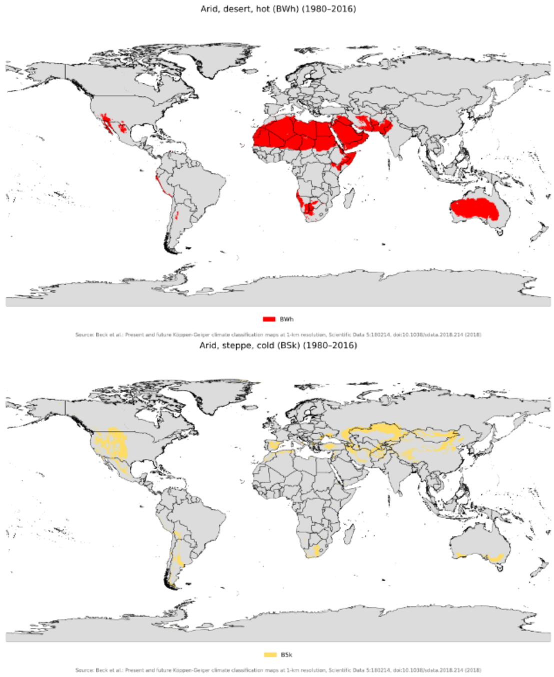

Fig. 6. Regions of the world encompassing BWh climates (above) and BSk climates (below) [19].

falls under the BSk category, characterizing it as a region with a "cold semi-arid" climate.The average elevation of Tabriz above sea level is approximately 1361 m [18]. To identify the regions of the world with BWh and BSk climates, these climates are illustrated on the map in Figure 6 [19]. It can be observed that significant portions of the continent of Australia, central and southwestern regions of Asia, North and South Africa, and western regions of North and South America have these climate types.

3. Methodology

In Figure 7, the data provided by the HOMER software for assessing wind and solar power is presented. Additionally, the software outputs are explained. The HOMER software, designed by the National Renewable Energy Laboratory in the United States, is tasked with analyzing and optimizing renewable hybrid systems and ranks various systems based on financial analysis [21, 20].

The equations governing the software, including power generated by solar cells and wind turbines, diesel generator efficiency, battery performance equations, and economic calculations, are presented in Table 2. The schematic diagram of the system under investigation is presented in Figure 8. The system employs batteries and a diesel generator for backup in emergency conditions, with the objective of supplying electricity to an area with 100 households [30]. The system includes solar panels for the city of Jask and wind turbines for Tabriz.

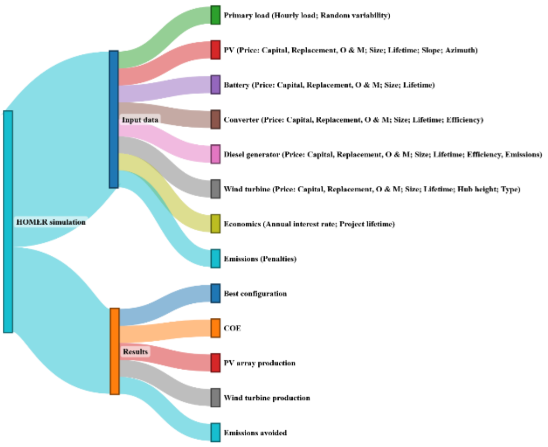

Fig. 7. Chart of HOMER software input and output parameters

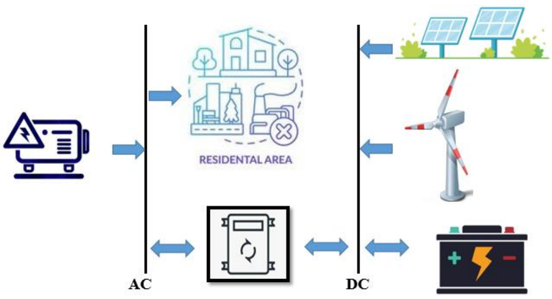

Fig. 8. Schematic diagram of the system under investigation in the current study.

4. Required data

Table 3 presents the energy required per kg of hydrogen produced using different methods. It's important to note that the average energy required has been considered in the calculations. This means that methods one, two, three, and four require 45, 75, 60, and 85 kWh of energy, respectively, to produce 1 kg of hydrogen. In Table 4, the necessary simulation data, including technical and price-related information about the equipment used, are detailed. Other necessary simulation data, including solar radiation intensity in Jask and wind speed in Tabriz, are presented in Figures 9(a) and 9(b). From Figure 9(a), it is evident that the annual average radiation and the annual average clearness index are 6.18 kWh/(m2-day) and 0.68, respectively.

Figure 9(b) illustrates that the annual average wind speed is 1.6 m/s, with the maximum average wind speed of 9.7 m/s occurring in July. Other information required for the simulation includes: the price of diesel per liter, $0.006 [36], the project's useful life of 25 years [37], and an annual real interest rate of 18% [38]. Furthermore, penalties for pollutants for each ton of CO2, CO, SO2, and NOx, amount to $3.1, $57, $560, and $184, respectively [39]. In Figure 10, the most critical simulation data, the required power, is detailed. The average annual power demand is 1488 kWh/day, considering a 15% coefficient for daily fluctuations and a 20% coefficient for hourly changes.

Table.2.
Governing equations

Parameter	Equation	Reference
Power generated by solar cells	$P_{PV} = Y_{PV} \cdot f_{PV} \cdot \frac{\overline{H}_T}{\overline{H}_{T,STC}}$	[22]
Power generated by wind turbines	$P_{WT} = \frac{\rho}{\rho_O} \cdot P_{WT,STC}$	[23]
Diesel generator efficiency	$\eta_{gen} = \frac{3.6\ P_{gen}}{\dot{m}_{fuel} \cdot LHV_{fuel}}$	[24]
Battery performance	$P_{batt,max} = \frac{Min(P_{batt,kbm\ or\ mcr\ or\ mcc})}{\eta_{batt,c}}$	[25]
Calculation of total current net cost	$total\ NPC = \frac{C_{ann,total}}{\frac{i(1+i)^N}{(1+i)^N-1}}$	[26]
Calculation of cost per kWh of generated electricity	$COE = \frac{C_{ann,total}}{E_{load\ served}}$	[27]
Produced wind and solar hydrogen	$M_{H2} = \frac{(P_{PV}\ or\ P_{WT}) \cdot \eta_{ele}}{HHV_{H2}}$	[28, 29]

Table.3.
The energy required per kilogram of produced hydrogen in various methods.

Method	The energy required per kWh
Electrolysis of water	40-50 [31]
Steam methane reforming with carbon capture and utilization	70-80 [32]
Biological hydrogen production	20-100 [33]
Thermochemical water splitting	70-100 [34]

Based on the results, it is found that the cheapest wind and solar power in Iran are $0.145/kWh and $0.125/kWh, respectively. Additionally, it's noted that wind and solar alone cannot meet the demand and, in both cases, the 100 kW diesel generator must be used. The optimal wind turbine size used is 20 kW, and the optimal solar cell size is 140 kW. As more renewable energy is generated in Jask compared to Tabriz (2.6 times more), there are more converters used in Jask compared to Tabriz. An important point observed from the results is the very short payback period (less than 2 years) compared to the traditional system (only diesel generator). In Jask, because less use of the diesel generator is made, its capacity factor is lower than in Tabriz. In contrast, the capacity factor of wind turbines is greater than solar cells. Due to the increased renewable energy production in Jask, battery losses, especially the electrical converter losses, are higher. Another important note is the reduction in pollutants, about 161 tons in Tabriz and 263 tons in Jask, resulting from renewable electricity production compared to the traditional system (only diesel generator). In the system examined in Tabriz, there is no surplus electricity, while in Jask, there is an annual surplus of about 65 MWh, which, if sold to the grid, can further reduce the price of the generated solar electricity per kWh.

The results of electricity production and consumption over three days of the year for Tabriz and Jask are presented in Figures 11a and 11b. The results indicate that wind power cannot meet all the electricity demands at any time, but solar power not only meets all the needs during daytime hours but also generates surplus electricity. This aligns with the findings presented in Table 5.

In Table 6, the amount of wind and solar hydrogen production at the Jask and Tabriz stations using four different methods (water electrolysis, steam methane reforming, biological, and thermochemical water molecule cracking) is provided.

The results show that the highest hydrogen production is solar-based and obtained through water electrolysis in Jask, with a quantity of 4524 kg/year. The highest wind-based hydrogen production is also through water electrolysis, with 821.5 kg/year in the city of Tabriz.

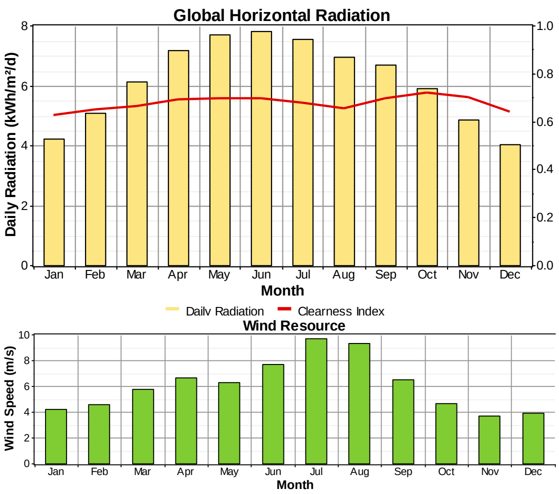

Fig. 9. Monthly average solar radiation in Jask; and Tabriz.

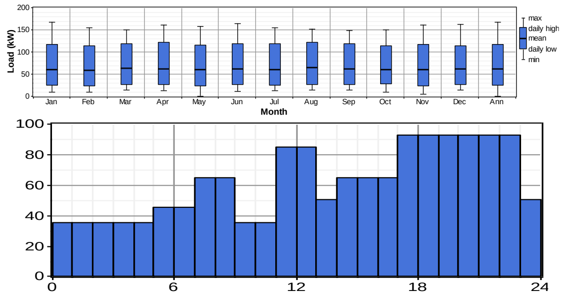

Fig. 10. Electricity consumption profile throughout the year and within 24 hours.

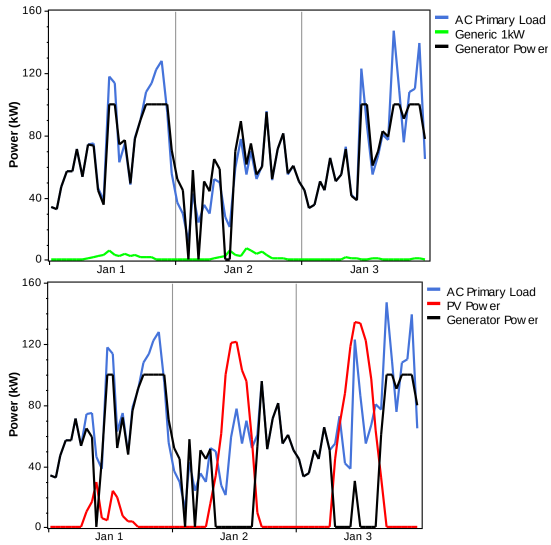

Fig. 11. Results of electricity generation and consumption over three days of the year a) Tabriz b) Jask

Another important observation from Table 6 is that after water electrolysis, the highest hydrogen production is through the biological method, followed by steam methane reforming and thermochemical water molecule cracking methods, respectively. Another important point is that even in Tabriz, which is the most suitable Iranian city for wind energy, solar hydrogen production exceeds wind hydrogen production. This is due to the more favorable solar conditions compared to wind in this city. However, the higher cost of wind equipment compared to solar equipment is one of the reasons for this. Another reason is that in Tabriz, the optimal wind system is 20 kW, while the optimal solar system is 100 kW. The results of granting a 50% subsidy on the purchase and replacement of renewable energy system equipment for Tabriz and Jask are presented in Table 7. The results indicate a greater impact of the subsidy provided on the wind system in Tabriz. However, the solar system in Jask remains economically superior. The subsidy of about 21.2% results in reducing the total Net Present Cost (NPC) for the wind system, while this percentage is about 12.8% for the solar system. Considering the subsidy, both systems under study use more batteries.

In other words, the subsidy will have the most significant effect on the energy storage section. Moreover, according to the results in Table 7, accounting for the subsidy has no impact on the amount of wind energy produced. It only leads to cost reduction. But in the solar system, it will increase the amount of solar electricity generated.

Table.4.
Simulation data requirements with HOMER

Equipment	Price			Size (kW)	Other technical information
	Capital	Replacement	Operating & maintenance		
PV [35]	350	350	10	0-200	Lifetime: 25 years, Derating factor: 80%
Wind turbine [36]	2000	2000	20	0-200	Lifetime: 20 years, Hub height: 25 m Type: Genreic 1 kW
Battery [35]	174	174	5	0-300	Type: Trojan T-105, Lifetime: 845 kWh
Converter [35]	138	138	10	0-200	Lifetime: 15 years, Efficiency: 95%
Diesel generator [35]	200	200	0.5	0-200	Lifetime: 15000 hr, Efficiency: 50% CO factor: 6.5 g/L, Destination of fuel Carbon: $CO_2 = 99.5\%, CO = 0.4\%$

Table.5.
Simulation results conducted by HOMER software for the top scenarios based on wind and solar (without considering subsidies).

Station	Optimal system	total NPC and COE	Payback time (years)	Wind/solar production	Capacity factor of wind turbine/PV and Diesel generator	Losses of Battery and converter (kWh/y)	Emissions avoided (kg/y)	Excess electricity (kWh/y)
Tabriz	:Wind scenario: Wind turbine: 20 kW Diesel generator: 100 kW Trojan T-105: 200 Converter: 60 kW	429093$, 0.145 $/kWh	1.99	43493 kWh/year (8% of total)	24.8% , 58.2%	6004, 4241	161186	0
Jask	Solar scenario: solar PV: 140 kW Diesel generator: 100 kW Trojan T-105: 200 Converter : 120 kw	371263 $, 0.125 $/kWh	1.81	271474 kWh/year (43% of total)	22.1% , 40.5%	6485, 12414	263355	64895

Table.6.
Results of statistical analysis of wind and solar hydrogen production at the investigated stations using various methods (without considering subsidies)

	Electricity generation (kWh/year)		H_2 production (kg/year) Electrolysis of water		H_2 production (kg/year) Steam methane reforming		H_2 production (kg/year) Biological		H_2 production (kg/year) Thermochemical water splitting	
Station	PV	Wind	PV	Wind	PV	Wind	PV	Wind	PV	Wind
Jask	271,474	18,392	4524.6	347.4	2714.7	208.4	3393.4	260.6	2395.4	183.9
Tabriz	151,329	43,493	2522.2	821.5	1513.3	492.9	1891.6	616.2	1335.3	434.9

Another important point is that after considering the subsidy, the payback period, compared to a traditional system (only diesel generator), decreases more in the wind system than in the solar system.

In other words, the payback time for the wind system will be shorter than that for the solar system. Regarding the battery and converter losses, due to the increased number of batteries after subsidies, more DC to AC or vice versa conversion occurs, resulting in higher losses. Assessing the generated pollutant levels reveals that considering the subsidy has a greater effect on the wind system compared to the solar system. With the inclusion of a 50% subsidy, prevention of pollutant production in the wind system of Tabriz increases by approximately 17.1 tons per year, while for the solar system in Jask, it's about 3 tons per year. The surplus electricity for the wind system in Tabriz was zero in the unsubsidized state, but when the subsidy is considered, it reaches 136 kWh per year. This amount nearly doubles for the solar system in Jask, reaching 129,807 kWh per year. As the electricity produced by the wind system remains unchanged after the subsidy, the amount of hydrogen produced by wind in Tabriz remains the same. However, since the amount of solar electricity produced has increased, solar hydrogen, using methods like electrolysis, methane steam reforming, biological, and thermochemical splitting of water, increases by approximately 1293, 776, 970, and 684 kg per year, respectively.

Table 7. Simulation results conducted by the HOMER software for the best wind and solar-based scenarios (considering 50% subsidy)

Station	Optimal system	total NPC, COE	Payback time (years)	Wind/solar production	Capacity factor of wind turbine/PV and Diesel generator	Losses of Battery and converter	Emissions avoided (kg/y)	Excess electricity (kWh/y)
Tabriz	Wind scenario: Wind turbine: 20 kW Diesel generator: 100 kW Trojan T-105: 260 Converter: 60 kW	338051$, 0.114 $/kWh	1.23	43493 kWh/year (8% of total)	24.8% , 59.5%	13763 kWh/y , 7946 kWh/y	178291	136
Jask	Solar scenario: solar PV: 180 kW Diesel generator: 100 kW Trojan T-105: 300 Converter : 120 kw	323655 $, 0.109 $/kWh	1.73	349038 kWh/year (50% of total)	22.1% , 40.4%	15530 kWh/y , 14140 kWh/y	266389	129807

5. Conclusion

The production of electricity from renewable energy sources is receiving significant attention worldwide as a crucial method to generate hydrogen and reduce greenhouse gas emissions. In this regard, utilizing solar energy in areas with the highest solar radiation and wind energy in regions with the most wind becomes one of the most economical and efficient approaches. In the present study, a renewable system based on a diesel generator as a backup is investigated in the city of Jask (considered the most suitable solar city in Iran) and in Tabriz (considered the most suitable windy city in Iran). Analyses are conducted using HOMER V.2.81 software, and subsequently, the amount of hydrogen production by four different methods (water electrolysis, steam methane reforming, biological, and thermochemical water splitting) is calculated using analytical relations. Another innovation in this study is the presentation of a 50% government subsidy for renewable energy production. For the first time, the impact of these policies on electricity and hydrogen production is examined and analyzed. These analyses hold significant importance for sustainable development and clean energy production in Iran. The significant outcomes of this work are as follows:

- The results demonstrate that generating electricity from renewable sources (wind and solar) in Tabriz and Jask, Iran, has a significant economic and environmental impact.
- Renewable electricity production in the optimal wind station (Tabriz) and the optimal solar station (Jask) costs $0.145/kWh and $0.125/kWh, respectively.
- Diesel generators are compulsorily used as backup in both wind and solar scenarios.
- The payback time in renewable energy systems is significantly less than in traditional systems based on diesel generators (less than 2 years).
- Renewable electricity generation results in reducing pollutants by approximately 161 tons in Tabriz and 263 tons in Jask.
- Jask has the capability to generate surplus electricity, which can contribute to reducing the price of solar electricity by selling it to the grid.
- Solar hydrogen is produced more than wind hydrogen, especially through water electrolysis.
- The subsidies provided to renewables have a positive impact on the economy and the environment, reducing the payback time.
- Considering subsidies leads to increased solar electricity production and reduces battery and converter losses.

Nomenclature

ρ_0	Air density under standard temperature and pressure conditions (1.225 kg/m^3)
i	Annual interest rate (%)
$\overline{H_T}$	Incident radiation on the cell's surface on a monthly basis (kW/m^2)
Y_{PV}	Output power of solar cell under standard conditions (kW)
COE	Levelized cost of electricity ($/kWh)
N	Useful life-time (year)
NPC	Net present cost ($)
$\eta_{batt, c}$	Batteries charge efficiency (%)
PV	Photovoltaic (-)
$C_{ann,total}$	Total annual cost ($)
$E_{load\ served}$	Real electrical load by system (kWh/year)

f_{PV}	Derating factor (%)
HHV_{H_2}	Higher heating value of the hydrogen (39.4 kWh/kg)
M_{H_2}	Mass of hydrogen (kg/year)
SWOT	Strengths, weaknesses, opportunities, and threats (-)
MCDM	Multi-Criteria Decision Making (-)
$\overline{H_{T,STC}}$	Incident radiation on the cell's surface under standard conditions (1 kW/m^2)
$P_{batt, max}$	Maximum battery charge power (kWh)
$P_{batt, kbm}$	Maximum battery charge power base on kinetic battery model (kWh)
$P_{batt, mcc}$	Maximum battery charge power base on maximum charge current (kWh)
$P_{batt, mcr}$	Maximum battery charge power base on maximum charge rate (kWh)
P_{PV}	Output power of PV cells (kW)
P_{WTG}	Wind turbine output power (kW)
$P_{WTG, STP}$	Wind turbine output power under standard conditions (kW)
ρ	Real air density (kg/m^3)
LHV_{fuel}	Lower heating value of the fuel (MJ/kg)
η_{gen}	Electrical efficiency of generator (%)
P_{gen}	Electricity produced by diesel generators (kW)
$\dot{m}_{fuel}$	Fuel consumption of generator (units/hr)
η_{ele}	Electrolyzer efficiency (%)
O & M	Operating and maintenance (-)

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