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Economic evaluation of solar-hydrogen hybrid system with installed power of 1 MW and 5 MW in İskenderun Organized Industrial Region

Ahmet Arslan, Battal Doğan

Department of Energy Systems Engineering, Faculty of Technology, Gazi University, Ankara, Turkiye

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ABSTRACT

In the study, the production potential of hydrogen production for İskenderun organized industrial zone was evaluated. Considering the geographical characteristics of the region, the potential of 30000 hours of electricity and hydrogen production per year for solar power plants that have been established or are likely to be established is examined. In the study, 4 different scenarios were selected and economic analysis was carried out. In scenarios 1 and 2, the cost of H_2 (hydrogen) was calculated by integrating a 120 kW AEM (anion electrolyte membrane) electrolyzer in addition to the 1 MW solar power plant and storing the produced hydrogen in type 1 (low pressure, metal material tank) and type 4 (high pressure composite material tank) tanks. In scenarios 3 and 4, a 1 MW AEM electrolyzer is used with the solar power plant increased to 5 MW. In these scenarios, the hydrogen produced is stored in type 1 and type 4 tanks and the H_2 cost for transportation to the end user is calculated. In addition, in 4 scenarios, different evaluations were made considering the situation with and without the solar power plant included in the system. The production cost of H_2 gas reaching the end user is more economical in the system including the solar power plant. For example, when scenario 2 is considered, while the production cost of H_2 gas is \$16.22/kg in the system without solar power plant, this value is calculated as \$10.69/kg in the hybrid system where solar power plant is included. In the 4 scenarios where solar to hydrogen hybrid system was created, the production cost of H_2 gas was determined as 58.87 \$/kg, 10.69 \$/kg, 6.65 \$/kg and 4.87 \$/kg, respectively.

Keywords: Solar-hydrogen, renewable energy, hybrid system, green hydrogen

INTRODUCTION

The energy sector is in constant evolution as a fundamental element of modern societies. The increasing demand for energy increases the importance of sustainable, environmentally friendly and renewable energy sources that aim to ensure global energy security and combat climate change (Sachdev et al., 2015). The limited reserves and high carbon emissions of fossil fuels are increasingly being replaced by renewable energy sources (Kumar et al., 2010). Legislative changes in recent years have encouraged the use of renewable energy, energy saving and efficient energy use. Renewable energy sources such as solar, wind, geothermal, hydroelectric, bioenergy and hydrogen make significant contributions to sustainable energy production by reducing environmental impacts (Sayed et al., 2023). These developments have led researchers to focus on renewable energy sources (Olabi, 2017; Bocklisch, 2015).

Among renewable energy sources, solar energy attracts attention with its ease of use and wide application possibilities in various fields (Suberu et al., 2014). Solar energy can be used in a wide range of applications from daily life to housing, from agriculture and communication to industry, from power plants to military services (Kutlu, 2002). In Dağtekin's study, (2012) it was aimed to provide the electricity required for the evaporative cooling system of a broiler house with a capacity of 20.000 with solar energy. Within the scope of this study, a 15 kWe photovoltaic (PV) power plant was planned to generate 22,935 kWh of electricity on an area of 98.01 m^2 and it was calculated that this system would reduce annual CO_2 emissions by 20.259 kg. Furthermore, the net payback period of this PV system is stated as 9.2 years. The economic analysis of the solar power plant planned to be established in Sivas Cumhuriyet University campus was carried out by Sarı and Özyiğit (2020). In this study where monocrystalline and polycrystalline modules were compared, it was concluded that monocrystalline modules provide higher efficiency, but polycrystalline modules are more economical. In a 30-year period, the energy sales revenues were calculated as \$4.140.900 for monocrystalline modules and \$4.111.100 for polycrystalline modules. Karaağaç et al. (2020) conducted a solar energy system design and cost analysis for a chicken farm. In the study, it was determined that the average monthly electricity consumption of the farm was 2.778 kWh, the

Corresponding Author: Battal Doğan, battaldogan@gazi.edu.tr

monthly cost of this consumption was 1.290 TL and the total annual cost was 15.480 TL. It was calculated that the average monthly production of the solar panel system to be installed on the roof of the farm was 2.875 kWh and the total annual production was 34.510 kWh, and it was reported that the payback period of this system was 6 years.

Electricity generated by solar panels can sometimes be insufficient to meet instantaneous energy demands (Babu & Ponnambalam, 2017). In this case, hydrogen stands out as an important alternative, as solar-generated electricity can be used to produce green hydrogen with the help of electrolyzers. This hydrogen can then be stored to meet energy demand or utilized in various sectors such as industry and industry (Wu et al., 2015). The fact that hydrogen is a clean energy carrier and produces only water vapor and energy as a result of combustion offers a solution that is compatible with carbon emission reduction targets. In this context, hydrogen integration into solar power plants can contribute to making energy systems more reliable, flexible and environmentally friendly (Ferrero & Santarelli, 2017). In the literature, there are many studies on the utilization of electricity generated from renewable energy sources in green hydrogen production. For example, Akyüz (2010) investigated the potential of hydrogen production using solar and wind energy in the Balıkesir region and economically evaluated that 20.3 kg of hydrogen can be produced annually with 1 kW wind energy and 0.56 kW electrolysis unit. Veziroğlu and Şahin (2008) compared solar to hydrogen energy system with synthetic fossil fuel system in terms of production costs, environmental impacts and utilization. Abbas et al. (2023) investigated the possibilities of solar hydrogen production in four main cities of Iraq. Using a 22.0 kWp off-grid photovoltaic system and an 8.0 kW alkaline electrolyzer, the simulations showed that the annual hydrogen production ranged from 1713.92 kg to 1891.12 kg, oxygen production ranged from 1199.74 kg to 1323.78 kg, and water consumption ranged from 7139.91 L to 7877.29 L. The production cost of hydrogen was calculated as 3.79 dollars per kilogram.

Nnabuife et al. (2024) investigate the integration of wind and solar energy in green hydrogen production. They stated that hybrid systems reduce the overall hydrogen production and infrastructure costs while increasing the use of renewable energy sources, resulting in a reduction in the balanced cost of hydrogen (LCOH) ranging from 3.5 to 8.9 Euro per kilogram.

Al-Ghussain et al. (2022) investigate the feasibility of green hydrogen production using solar, wind and hybrid PV-wind renewable energy systems (RES) in Jordan for the year 2050. The results show that the PV-based system has the highest demand-supply ratio (>99%), but the wind-based system is more economically viable with installed capacities of RES, ESS and PEM of only 23.88 GW, 2542 GWh and 20.66 GW. They also calculated the highest hydrogen annual production rate (172.1×10 tonnes) and the lowest hydrogen cost as 1.082 USD/kg.

Nasser et al. (2022) evaluated a case study in Egypt, investigating hydrogen production using solar energy, wind energy and electrolyser. As a result of their calculations, the system can produce 1.912 kg of hydrogen per year, energy efficiency is 16.42% and exergy efficiency is 12.76%. As a result of the economic analysis, LCOH is 3.73-4.656 $/kg and LCOCH (compressed variable balanced hydrogen cost) is 5.922-7.35 $/kg, and the payback period ranges from 7 to 13.85 years. At the same time, they stated that the system will provide CO_2 emission reduction up to 689.4 tonnes during its lifetime.

Liu et al. (2023) evaluated the WSH-MES system designed by combining wind, solar and hydrogen energy. According to the case study in Zhangbei, the system produces 931.39 kg of hydrogen in one year, providing 16.03% energy efficiency and 17.94% exergy efficiency. According to the calculations, it provides payback in 3 years with a net present value of $5.06 million and reduces 4.220.000 tonnes of CO_2 emissions.

The main reasons for installing the system in İskenderun OSB are presented in **Table 1**.

Table 1. Reasons for preference of IOSB

Category	Details
Strategic location and infrastructure	**Port and logistics facilities:** İskenderun Port is an important gateway to the Mediterranean Sea and provides ease of transportation of raw materials and products by sea. This offers a great advantage for hydrogen distribution. **Industrial zone infrastructure:** The region has the necessary infrastructure for heavy industry. In addition to basic services such as electricity, water, natural gas and transportation, logistics and support services required by industrial enterprises are available.
Energy and raw material access	**Renewable energy potential:** The region is suitable for renewable energy projects due to its proximity to solar and wind energy sources. This provides a significant advantage for sustainable energy use in hydrogen production. **Access to raw materials:** The raw materials (water) to be used in hydrogen production are readily available within İskenderun's existing industrial ecosystem.
Large scale industrial facilities and market potential	**Steel and chemical industry:** Green hydrogen can be produced in industrial annealing furnaces instead of purchasing H_2. **Potential customers:** Large industrial organizations operating in the region could be potential large-scale customers of hydrogen. This ensures strong demand for hydrogen.
Environmental and economic benefits	**Carbon reduction:** The use of hydrogen reduces carbon emissions by replacing fossil fuels. This plays an important role in achieving environmental sustainability goals. **Economic incentives:** Turkiye offers various incentives for renewable energy and low-carbon technologies. These incentives can make hydrogen investments more attractive.

IOSB: İskenderun Organized Industrial Zone

This study examines the potential of hybrid energy systems that can be integrated with 1 MW and 5 MW solar power plants planned to be built in İskenderun Organised Industrial Zone. The study aims to economically evaluate these hybrid systems combining hydrogen production and storage systems. Different from the literature, four different scenarios are created and the costs of green hydrogen produced from each scenario are compared. The scenarios were created by taking into account the main components of the system, namely solar power plants, anion exchange membrane (AEM) electrolysers used in hydrogen production and different types of tanks used for hydrogen storage (type 1-low pressure metal tanks and type 4-high pressure composite tanks). The research analysed how the total costs are shaped based on the initial investments and annual operating costs of these systems. Accordingly, the economic efficiency of hybrid energy systems is evaluated through the cost advantages of hydrogen production processes integrated with solar power plants.

METHODS

Photovoltaic System

İskenderun Organized Industrial Zone operates in İskenderun district of Hatay. The sunshine duration (hours) of Hatay province taken from the official page of the General Directorate of Meteorology is given in the table below (**Table 2**) (GEPA, 2024).

Solar panels are made up of a combination of photovoltaic cells. These panels are able to convert sunlight directly into electrical energy. Photovoltaic cells are made up of thin layers, usually of semiconductor materials such as silicon (Maghami et al, 2016). When sunlight hits the surface of the cells, electrons are released and the movement of these electrons creates an electric current. Solar energy is a clean and renewable resource and plays an important role in combating climate change by reducing greenhouse gas emissions (Jacobson & Delucchi, 2011). However, studies show that the efficiency of photovoltaic systems is between 15% and 20% (Maghami et al, 2016). The amount of electricity produced by solar energy is calculated using equation 1 (Arslan et al., 2024).

$$W = P.t.d \tag{1}$$

This includes electrical power (W), installed capacity (P), daily operating hours of the plant (t) and the number of days it operates in a year (d) (**Figure 1**).

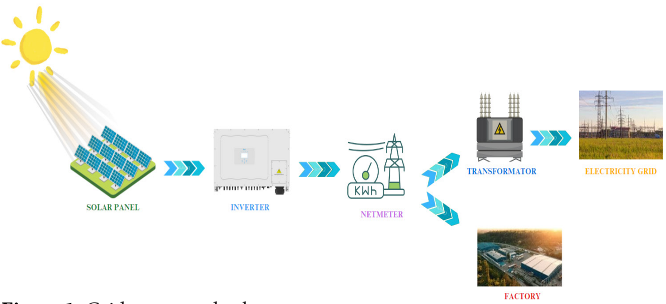

Figure 1. Grid connected solar energy system

Electrolyzer

An electrolyzer is a device designed to trigger chemical reactions using electric current from an electricity source (usually a battery or solar panel). In this process, a special substance called an electrolyte takes place inside the electrolyzer. The electric current travels between two electrodes inside the electrolyzer, the cathode and the anode. When water is electrolyzed, the water molecules are transformed into two separate gaseous forms, hydrogen and oxygen, as a result of chemical reactions, as shown in equation 2 (Garrigós et al., 2010).

$$H_2O + \text{Electricity} \rightarrow H_2 + 1/2\, O_2 \tag{2}$$

The power required for the electrolyzer (P_E) being the current density (i) and the cell voltage (V) (Nasser, & Hassan, 2023):

$$P_E = i \times V \tag{3}$$

Compressor

Compressors are mechanical devices used to convert gases from their low-pressure state to a higher pressure. These devices reduce the volume contained in the gases, making them more dense at the molecular level. Isentropic compression represents an idealized situation. Compression is assumed to take place in a frictionless and fully reversible environment. This work done by the compressor is given in equation 4. Calculation is made by taking inlet pressure (P_1), outlet pressure (P_2), inlet temperature (T_1) ve and k=1.4 (Kumar et al., 2017).

$$W_{comp} = \frac{kRT_1}{k-1}\left[\left(\frac{P_2}{P_1}\right)^{(k-1)/k} - 1\right] \tag{4}$$

The polytropic work done by the compressor (W_{comp}), can be calculated from the following equation depending on the inlet pressure (P_1), inlet temperature (T_1) and outlet pressure (P_2) with n=1.3 (Al-Mamari et al., 2023):

$$W_{comp} = \frac{nRT_1}{n-1}\left[\left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1\right] \tag{5}$$

Isothermal compression is a compression process that takes place at a constant temperature. In this case, the internal energy of the gas increases, but its entropy remains constant. In equation 6, the amount of power required for compressor operation under isothermal compression conditions can be calculated (Li et al., 2020). Here the gas constant (R), of hydrogen is the inlet pressure (P_1) nd outlet pressure (P_2).

$$W_{comp} = RT_1 \ln\frac{P_2}{P_1} \tag{6}$$

Hydrogen Storage Tank

Although hydrogen has high energy, it is a low-density gas. Therefore, it is difficult to store and transport. Among pressurized storage tanks, type 1 and type 4 tanks have notable differences in construction and performance. Type 1 tanks are manufactured with all-metal construction and the metal body carries the entire structural load. These tanks can withstand low storage pressure and have a relatively high weight. They have a gravimetric density of about 1% and cost around 83 USD/kg. Type 4 tanks, on the other hand, are high-tech and are manufactured using high-density polyethylene (HDPE) lining and full carbon fiber or carbon glass composite material with metallic protrusions. In these tanks, the load is carried entirely by the composite material and the storage pressure can be up to 1000 bar. Type 4 tanks are lighter than type 1 tanks and their gravimetric density ranges from 4.4% to 5.7%. Their cost is higher than type 1, at USD 633/kg. Hydrogen storage tanks are designed to store hydrogen under high pressure or in liquefied form. The volume of the tank is determined from the following equation depending on the tank temperature (T_{tank}), the gas constant of hydrogen (R), the mass of hydrogen stored in the tank (M_{tank}) and its pressure (P_{tank}) (Shaygan et al., 2019).

Table 2. Average insolation periods for Hatay province

Hatay	January	February	March	April	May	June	July	August	September	October	November	December	Average
Average insolation time (hours)	3.3	4.6	6	7.3	9.1	10.8	11	10.3	9.1	7	5.1	3.3	7.2

$$V_{tank} = \frac{M_{tank} T_{tank} R}{P_{tank}} \quad (7)$$

Solar Energy System

In the study, the turnkey project cost for a photovoltaic field with 1 MW and 5 MW capacity is approximately 1000 $/kWp. Table 3 below shows the price list of the detailed components of the system.

SCENARIOS FOR HYDROGEN PRODUCTION IN HYBRID SYSTEM

In this study, different scenarios for green hydrogen production using a hybrid system are considered. Each scenario is focused on optimizing critical elements of the process such as cost effectiveness and storage solutions. Using solar energy as a sustainable source, these scenarios aim to demonstrate how green hydrogen production can be realized with different configurations and equipment. In the following sub-headings, the unique configurations and operational details of each scenario are presented to determine the most suitable solution for hydrogen production (Figure 2).

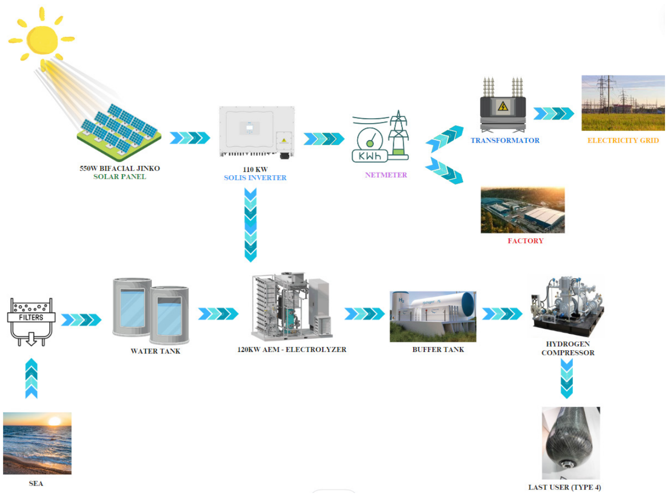

Figure 2. Workflow diagram of the hybrid system for scenario 1

The number of equipment such as electrolyzers, compressors, tanks, solar panels and inverters used in scenario 1 and the features considered in their selection are presented in Table 4.

Table 4. System elements used in scenario 1 and their properties

Scenario 1	
Electrolyzer 1 piece	120 kW
Electrolyzer output pressure	35 Bar
H_2 compressor inlet pressure	35 Bar
H_2 compressor output pressure	350 Bar
H_2 compressor gas flow rate	25 Nm^3/h-3kg/h
Buffer tank capacity 1 piece	(1Nm^3=1000 L water volume=type 1 tank with 2.835 kg H_2 capacity)
Type 4 tank 180 pieces (350 Bar)	10.8 L water volume tank
Daily H_2 production (7 hours of sunbathing)	15.73 kg
Solar panel (2150 units)	550 W
Inverter (9 units)	110 kVA

Scenario 2

Scenario 2, as shown in Figure 3, all the materials used in scenario 1 are the same, but the storage tank for delivery to the end user is changed. The effect of the different type of storage tank on the H_2 cost of delivering hydrogen to the end user was evaluated. For scenario 2, the compressor power and tank specifications used in scenario 1 are changed. The rest of the system elements are the same. The compressor outlet pressure used for scenario 2 is 200 bar. This reduces the cost in scenario 2. The industrial cylinders (type 1) used to store H_2 gas have a water volume of 50 L and 66 units were used.

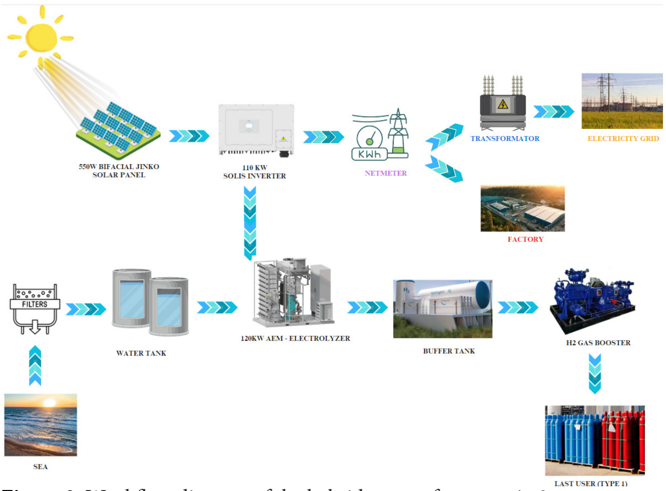

Figure 3. Workflow diagram of the hybrid system for scenario 2

Table 3. Materials and details for photovoltaic field

1 MW components	Materials and details	Price
Photovoltaic panels	550 W Panel	$120.00/piece
Inverters	110 kW Inverter	€3.250,00/piece
Assembly and infrastructure materials	Roof mounting systems, cables, fasteners	Constriction: $16.27/kWp DC cable 1x6: 0.84 $/m
Electrical components	Distribution panels, switchgear, transformers, measurement systems	Ges panel: $20.000/piece GES scada panel: €2.200/piece transformer 4000kV: $70.000,00
Safety and protection equipment	Grounding systems, lightning protection systems, fire protection systems	Earthing 1000 €/system
Infrastructure and construction	Roof assessment, permits and licenses	$14000/system
Software and monitoring systems	-	Scada integration: scada panel included price
Auxiliary components	Maintenance and repair equipment	1500 $/system

Scenario 3

In the solar power plant with an installed capacity of 5 MW, the flow chart of which is given in Figure 4, the production of hydrogen with the help of an electrolyzer and its sale to buyers is considered as scenario 3. With the inclusion of a 1 MW AEM electrolyzer in the system, it is determined that 132 kg H_2 can be produced in a 7-hour sunshine period per day and the remaining electricity is transferred to the grid in this scenario.

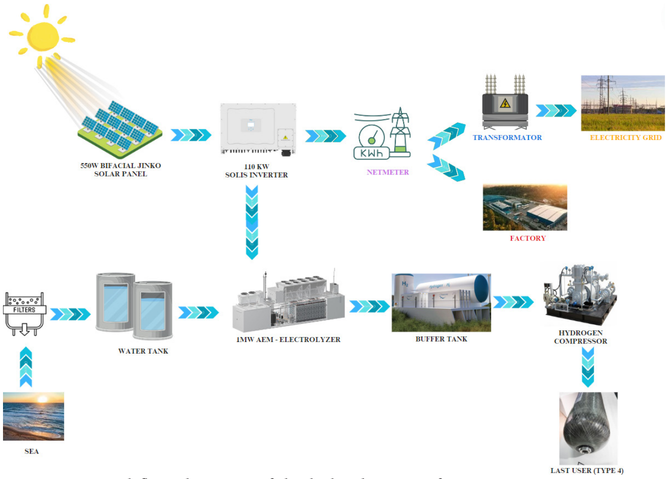

Figure 4. Workflow diagram of the hybrid system for scenario 3

For the equipment used in scenario 3 such as electrolyzer, compressor, tanks, solar panels and inverter, factors such as capacity and cost were taken into consideration. The technical specifications of each equipment were evaluated to determine the most suitable materials for the scenario (Table 5).

Table 5. System elements used in scenario 3 and their properties

Scenario 3	
Electrolyzer	1000 kW
Electrolyzer output pressure	35 Bar
H_2 compressor inlet pressure	35 Bar
H_2 compressor output pressure	450 Bar
H_2 compressor gas flow rate	210 Nm³/hour
Buffer tank capacity	28.5 H_2 capacity (2 500 NL tanks)
Type 4 storage tank 9 units (450 Bar-1500 L)	390 kg H_2 capacity tank
Daily H_2 production (7 hours of sunbathing)	132 kg
Solar panel (2150x5 pieces)	550 W
Inverter (45 units)	110 kVA

Scenario 4

Scenario 4 is designed by changing only the tank type by using the equipment in scenario 3 as can be seen in Figure 5. As in scenario 3, the final economic value of 132 kg of H_2 gas produced with 7 hours of sunshine time was determined by considering all costs. The materials to be used for scenario 4 are the same as in scenario 3 and only the compressor size and tank type are changed. In scenario 4, 540 type 1 storage tanks and a 200-bar compressor were selected to press H_2 gas to these tanks.

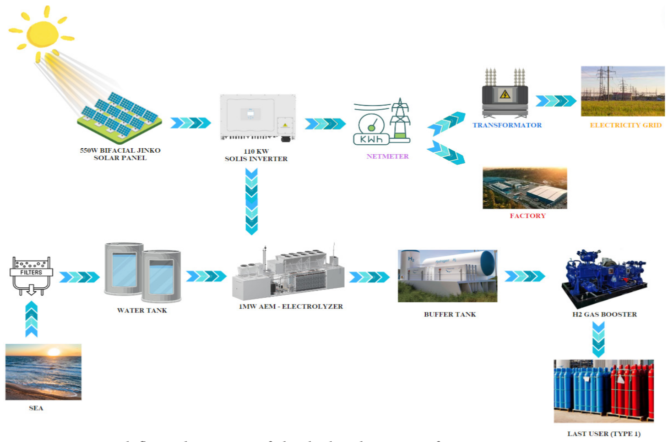

Figure 5. Workflow diagram of the hybrid system for scenario 4

RESEARCH FINDINGS

In the study prepared within the scope of the economic evaluation of the solar to hydrogen hybrid system for 1 MW and 5 MW solar power plants to be established in İskenderun organized industrial zone, the equipment suitable for hybrid power plants were selected and their prices were obtained from commercial companies. Initial investment cost, engineering procurement and construction (EPC) services and maintenance costs are included in the designed system. In Table 6, the system prepared without a solar power plant and operating 7 hours a day is evaluated. EPC services

Table 6. Costs of system elements not including solar power plan

	Scenario 1				Scenario 2		
	Equipment	Initial investment amount (CAPEX $)	Maintenance cost ($/year)		Equipment	Initial investment amount (CAPEX $)	Maintenance cost ($/year)
1	AEM electrolyzer	385.000		1	AEM electrolyzer	385.000	
3	H_2 compressor	200.000		3	H_2 compressor	100.000	
4	Buffer tank	25.000	428.000	4	Buffer tank	25.000	107.760
5	Type 4 storage tank	1.530.000		5	Type 1 storage tank	28.800	
6	EPC services	214.000		6	EPC services	53.880	
Total price ($)			2.782.000		Total price ($)		700.440
	Scenario 3				Scenario 4		
	Equipment	Initial investment amount (CAPEX $)	Maintenance cost ($/year)		Equipment	Initial investment amount (CAPEX $)	Maintenance cost ($/year)
1	AEM electrolyzer	1.500.000		1	AEM electrolyzer	1.500.000	
3	H_2 compressor	900.000		3	H_2 compressor	500.000	
4	Buffer tank	60.000	555.000	4	Buffer tank	60.000	455.876
5	Type 4 storage tank	315.000		5	Type 1 storage tank	219.375	
6	EPC services	277.500		6	EPC services	227.938	
Total price ($)			3.607.500		Total price ($)		2.963.189

AEM: Anion electrolyte membrane, EPC: Engineering procurement and construction, CAPEX: Capital expenditures and maintenance costs are calculated annually to show in the table. The cost of the equipment used in the system is presented for different scenarios. In scenarios 1 and 2, all equipment is similar and only the storage tank is different. Type 4 tank increases the cost of the system. In scenario 1 the cost of the storage tank is 1530000 $ while in scenario 2 this value is 28800 $ due to the type 1 tank.

While calculating the cost of hydrogen when it reaches the end user, EPC Services and maintenance costs are calculated based on 30000 hours of operation of the system. The production cost of H_2 gas reaching the end user for the scenarios is given in **Figure 6**. The 120 kW AEM electrolyzer used in scenarios 1 and 2 produced 67375 kg of H_2 gas in 30000 hours, while the 1 MW AEM electrolyzer used in scenarios 3 and 4 produced 566250 kg of H_2 gas. Upon 30000 hours of operation of the system without a solar power plant, the total cost in scenario 1 was calculated as 4338850 $, in scenario 2 as 1092580 $, in scenario 3 as 5626312 $ and in scenario 4 as 4621442 $. As shown in **Figure 6**, the cost of H_2 gas calculated using these values was 64.40 $/kg in scenario 1, while this value was determined as 16.22 $/kg in scenario 2. The cost of H_2 in scenarios 3 and 4 using 1 MW electrolyzer was calculated as $9.94/kg and $8.16/kg, respectively.

The economic analysis of the hydrogen production system given in **Table 6** in the study is shown in **Table 7** by adding a solar power plant to the hydrogen production system according to the operating conditions of 7 hours per day. In the hybrid system, EPC services and maintenance costs vary compared to the hydrogen production system. The amount of electricity produced from the solar power plant is calculated on the basis of 30000 hours and the electricity sales price is accepted as 0.08 $. The profit from the electricity generated is subtracted from the total cost. Type 4 tank increases the cost of the system. Due to the increase in the amount of hydrogen in the hybrid system, the cost of the storage tank in scenario 3 is $315000, while in scenario 4 this value is $219375 due to the type 1 tank.

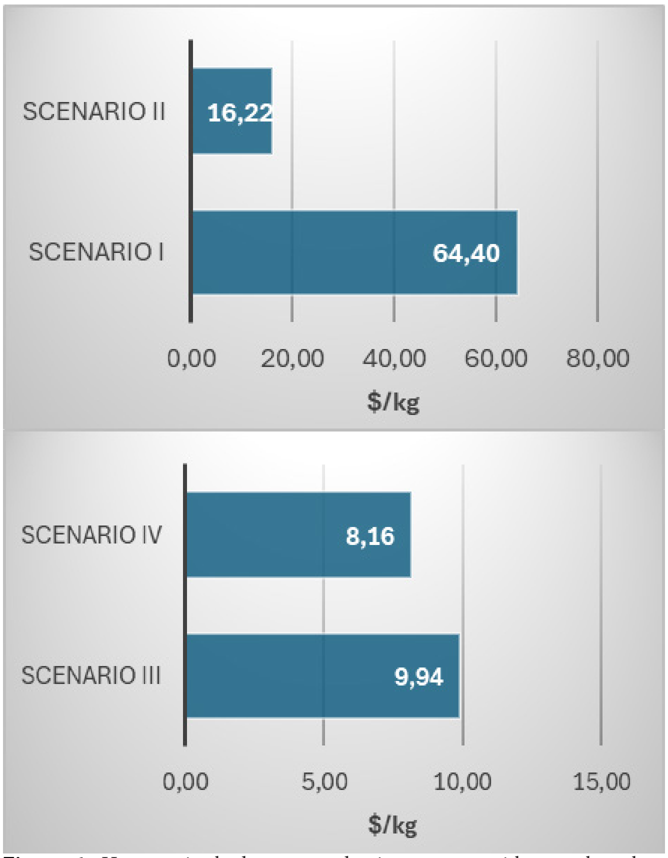

Figure 6. H_2 cost in hydrogen production system without solar plant connected

The 120 kW AEM electrolyzer used in scenarios 1 and 2 produced 67375 kg of H_2 gas in 30000 hours and the 1 MW AEM electrolyzer used in scenarios 3 and 4 produced 566250 kg of H_2 gas. The total cost in scenario 1 is calculated as 6366350 $, in scenario 2 as 3120079 $, in scenario 3 as 15763812 $ and in scenario 4 as 14758943 $. The profit from the sale of electricity was deducted from the scenarios upon the operation of the system's solar power plant for 30000 hours. Calculated using

Table 7. Costs of system elements included in the solar power plant

	Scenario 1				Scenario 2		
	Equipment	**Initial investment amount (CAPEX $)**	**Maintenance cost ($/year)**		**Equipment**	**Initial investment amount (CAPEX $)**	**Maintenance cost ($/year)**
1	AEM electrolyzer	385.000	628.000	1	AEM electrolyzer	385.000	307776
2	1 MW solar power plant	1.000.000		2	1 MW solar power plant	1.000.000	
3	H_2 compressor	200.000		3	H_2 compressor	100.000	
4	Buffer tank	25.000		4	Buffer tank	25.000	
5	Type 4 storage tank	1.530.000		5	Type 1 storage tank	28.800	
6	EPC services	314.000		6	EPC services	153888	
Total price ($)			4.082.000		Total price ($)		2.000.544
	Scenario 3				**Scenario 4**		
	Equipment	**Initial investment amount (CAPEX $)**	**Maintenance cost ($/year)**		**Equipment**	**Initial investment amount (CAPEX $)**	**Maintenance cost ($/year)**
1	AEM electrolyzer	1.500.000	1.555.000	1	AEM electrolyzer	1.500.000	1.455.876
2	5 MW solar power plant	5.000.000		2	5 MW solar power plant	5.000.000	
3	H_2 compressor	900.000		3	H_2 Compressor	500.000	
4	Buffer tank	60.000		4	Buffer tank	60.000	
5	Type 4 storage tank	315.000		5	Type 1 storage tank	219.375	
6	EPC services	777.500		6	EPC services	727.938	
Total price ($)			10.107.500		Total price ($)		9.463.194

AEM: Anion electrolyte membrane, EPC: Engineering procurement and construction, CAPEX: Capital expenditures these values, the cost of H_2 gas in scenario 1 is 58.87 \$/kg while in scenario 2 this value is calculated as 10.69 \$/kg. The cost of H_2 in scenarios 3 and 4 using 1MW electrolyzers is calculated as \$6.45/kg and \$4.87/kg, respectively (Figure 7).

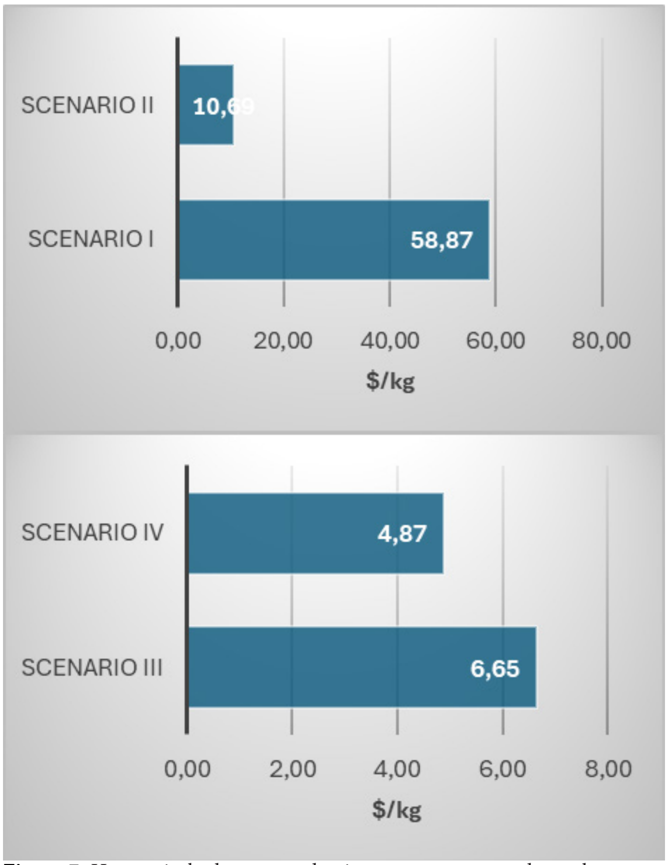

Figure 7. H_2 cost in hydrogen production system connected to solar power plant

DISCUSSION

According to the overall results of the study, solar to hydrogen hybrid systems become more economically advantageous when integrated with a solar power plant. This reveals the potential of solar energy as a renewable and sustainable energy source for hydrogen production. The establishment of such hybrid systems in regions with high solar energy potential such as İskenderun Organised Industrial Zone will provide both economic efficiency and contribute to energy independence. The correct design and optimisation of hybrid energy systems will play an important role in the energy sector in the future. Reducing hydrogen production costs becomes possible with the integration of renewable energy sources. The addition of solar power plants provides significant reductions in production costs. In the selection of storage tanks, factors such as safety and efficiency as well as cost should not be ignored. In the future, the implementation of such hybrid systems on a larger scale will create a significant transformation in the energy sector by encouraging the integration of renewable energy sources.

CONCLUSION

In this study, the economic feasibility and hydrogen production costs of solar to hydrogen hybrid systems for İskenderun Organised Industrial Zone are investigated. The evaluations made under different scenarios clearly revealed the economic advantages of hybrid systems. Hydrogen production costs are quite high in the calculations made without including the solar power plant. In a system with 1 MW solar power plant and 120 kW AEM electrolyser, the hydrogen production cost is determined as 64.40 \$/kg when type 4 tank is used and 16.22 \$/kg when type 1 tank is used. In the case of electricity production with solar power plant, the electricity production cost of hybrid systems decreases. In the systems using type 4 tank and type 1 tank, solar energy assisted hydrogen production costs were calculated as 58.87 \$/kg and 10.69 \$/kg, respectively. This clearly demonstrates the economic contribution of solar energy to the system. The costs, which are 9.94 \$/kg and 8.16 \$/kg without solar power plant, decrease to 6.45 \$/kg and 4.87 \$/kg, respectively, when solar power plant is included. This finding shows that larger scale hybrid systems are more economically advantageous. The type of storage tank was also found to have a significant impact on costs. Type 4 tanks stored hydrogen at higher costs, while type 1 tanks reduced costs.

ETHICAL DECLARATIONS

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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