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Modeling solar and hydrogen-based electricity generation in the Algerian Sahara with HOMER Pro

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Abstract

Renewable energy sources offer a sustainable alternative to fossil fuels, addressing the dual challenges of rising global energy demand and increasing pollutant emissions. Despite growing technological advances, there remains a need for reliable systems capable of providing stable electricity under extreme environmental conditions. This study addresses this gap by designing and modeling a hybrid energy system that integrates solar power with a hydrogen module to ensure consistent electricity production in harsh desert climates. The system was developed using advanced simulation software, incorporating photovoltaic panels, wind turbines, batteries, electrolysers, fuel cells, and inverters, allowing comprehensive technical and economic evaluation. The analysis identified an optimal configuration that maximizes efficiency while minimizing costs. Results indicate that the system can deliver substantial annual electricity generation predominantly from solar energy, demonstrating the feasibility and effectiveness of combining renewable sources with hydrogen storage. These findings highlight the potential of hybrid renewable-hydrogen systems to provide sustainable, reliable, and environmentally friendly energy solutions in regions with extreme climatic conditions. The study offers practical insights for the design and deployment of future energy infrastructures that prioritize both performance and sustainability.

***Keywords**:* HOMER Pro; hydrogen energy; hybrid systems; renewable energy; solar power; sustainable electricity.

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1. INTRODUCTION

Non-renewable energy sources come from natural reserves that diminish with use, as their availability is finite and their regeneration takes millions of years. Examples include coal, oil, and natural gas. Moreover, burning these fuels releases harmful gases into the atmosphere, contributing to global warming. To address this issue, modern science has shifted its focus toward clean, sustainable, and eco-friendly renewable energy alternatives, such as solar energy (Hayat, 2019), wind energy (Keyhani et al., 2010), and bioenergy (Woolf et al., 2016), as substitutes for fossil fuels in heat and electricity generation. Among these alternatives, hydrogen energy has gained significant attention as a promising future fuel, as it is a clean source that produces no harmful emissions when burned, especially when derived from renewable resources (Brahim & Gemni, 2026).

The amalgamation of solar energy with hydrogen production systems signifies a notable progression towards sustainable electricity generation, especially in isolated areas like the Algerian Sahara. This combination utilizes the ample solar irradiation of the Sahara to produce green hydrogen, which functions as a clean fuel and energy storage solution. A new study by Souid (2023) underscores the viability of this strategy within Algeria's distinct climatic circumstances, characterized by abundant sunlight and favorable temperatures that can enhance solar energy systems.

The tuning of electrolysis devices is essential for improving hydrogen production efficiency, as noted by Faouzi (2023). Efficient coupling of PV and electrolyzers improves system performance under variable solar inputs, addressing intermittency challenges (Zhang et al., 2025). The deployment of photovoltaic (PV) systems to facilitate electrolysis eliminates reliance on conventional energy sources and mitigates challenges associated with energy intermittency. Employing HOMER Pro software for system optimization allows for the analysis of various configurations to identify the most efficient integration of photovoltaic and hydrogen systems, hence facilitating energy resilience in regions with restricted access to existing grid infrastructures.

Furthermore, recent pilot-scale evaluations have underscored the multifaceted advantages resulting from the integration of photovoltaic systems with desalination and hydrogen production (Solar-powered desalination and hydrogen generation show compelling techno-economic advantages in Algerian contexts (Chahtou & Taoussi, 2025). Chahtou et al., (2026) assert that this combination offers a sustainable energy solution while simultaneously mitigating significant water scarcity challenges in the region. The incorporation of desalination systems facilitates the effective use of renewable energy to generate drinkable water concurrently with hydrogen production, rendering it especially advantageous in dry regions where both energy and water resources are essential for socioeconomic advancement.

Studies have shown that the efficiency of electrolysis processes can be markedly enhanced with optimal energy input from photovoltaic sources. Utilizing sophisticated algorithms in HOMER Pro, researchers can assess diverse operational strategies, including energy dispatch techniques and system design variables, to improve the overall efficiency of hydrogen production. This modeling and simulation facilitates decision-making for the future implementation of solar-hydrogen systems in Algeria's rural areas.

The diverse economic evaluations of this technology indicate favorable cost-benefit outcomes, implying that the financial investment in solar-hydrogen integration may be warranted by long-term savings in energy and water supply. The evaluation of the levelized cost of hydrogen generated from renewable sources has demonstrated a declining trend due to advancements in technology and increased scale, hence reinforcing claims from previous studies on the economic feasibility of these integrated systems (Khatib et al., 2023).

In tackling future energy requirements in Algeria, the integration of solar energy and hydrogen modules not only enhances local energy independence but also advances overarching societal objectives of alleviating climate change effects by diminishing carbon emissions from energy generation. Therefore, additional investigation into policy frameworks, technical standards, and public-private partnerships will be crucial for the effective implementation and expansion of these hybrid systems, especially in demanding contexts such as the Sahara.

The growing information indicates that the Algerian Sahara has the requisite characteristics for the efficient implementation of solar-hydrogen systems. By improving these systems using technologies such as HOMER Pro, stakeholders can attain enhanced energy efficiency and foster sustainable development trajectories. These improvements may significantly affect local populations and the environment, advancing Algeria toward a more sustainable energy future. The utilization of HOMER Pro software for optimizing hybrid renewable energy systems has garnered considerable interest in recent years, especially in rural and off-grid contexts where traditional power generation methods are unreliable or impractical. A thorough research by Maatallah and Dahadj (2023) demonstrates the potential advantages of using hydrogen modules in hybrid photovoltaic (PV) and wind systems. Their research demonstrates that such integration can significantly improve the dependability and efficiency of energy supply in remote areas, especially those resembling the distinctive environmental conditions of the Algerian Sahara.

Hydrogen, as an energy storage medium, mitigates the intermittent characteristics of solar and wind resources, thereby offering a remedy for energy demand during times of diminished generation. This resource serves as both an emergency backup and a means of decarbonizing the energy landscape. Subsequent research, like that by Mouffok et al. (2024), emphasizes the potential for enhancing household energy autonomy through the synergistic integration of hydrogen with photovoltaic and battery systems. Utilizing HOMER Pro's functionalities, these studies outline diverse configurations and operational techniques that enhance efficiency while minimizing capital and operational expenditures in certain circumstances.

Recent academic research underscores the benefits of employing HOMER Pro for identifying optimal system sizing and configuration in accordance with the limits of the Algerian Sahara. Ghaitaoui et al. (2024) underscore the software's capacity to simulate several potential system designs, facilitating the assessment of the economic viability of diverse energy combinations, including hydrogen generation and storage integration. This adaptability is essential as it facilitates customized systems that may efficiently address regional energy requirements while considering local environmental factors, including elevated sun irradiation and temperature fluctuations.

Touhami et al. (2024) demonstrate the usefulness of HOMER Pro in assessing the economic ramifications of implementing hybrid systems in remote Algerian settlements. Their findings indicate that optimum layouts decrease overall energy costs while enhancing energy security. The incorporation of hydrogen systems was acknowledged as a crucial element for stabilizing the energy supply, thereby rendering renewable energy systems both sustainable and dependable over prolonged durations.

The literature underscores the critical function of HOMER Pro in addressing the intricacies of renewable energy optimization, especially in the context of incorporating advanced technologies like hydrogen production and storage. The capacity to simulate diverse scenarios allows players in the Algerian Sahara to make educated decisions about energy investments and infrastructure development, considering local intricacies and challenges. The analyzed research not only confirms the technical viability of these systems but also provides a platform for future inquiries into hybrid energy solutions designed for dry and isolated environments. The techno-economic assessment of hybrid systems utilizing solar and hydrogen technology has emerged as a feasible option for energy production in remote areas, especially in arid environments like the Algerian Sahara. The research by Messana M’oboun et al. (2025) elucidates the significant potential of integrating solar energy with hydrogen production to address the increasing electrical demands in these areas. Their findings indicate that hybrid systems can markedly diminish dependence on fossil fuels, which are frequently both expensive and logistically difficult to transport to isolated regions.

Simultaneously, Benmedjahed (2024) investigates the optimization of energy supply chains, including hydrogen technologies within solar energy systems. This analysis highlights the economic feasibility of shifting from traditional diesel generators and fixed solar photovoltaic (PV) systems to dynamic solar-hydrogen modules. These modules can efficiently regulate electrical loads by meeting both base and peak energy requirements, tackling significant issues related to the intermittent energy generation characteristic of solar power. According to Olubayo and Olanrewaju (2025), employing hydrogen as an energy carrier in these hybrid systems offers a substantial benefit, enabling the storage of excess solar energy for later use.

Molu et al. (2023) highlight the significance of modern modeling tools, including HOMER Pro software, in doing thorough feasibility evaluations of solar-hydrogen hybrid systems. The advanced computational features of HOMER Pro allow users to simulate diverse scenarios and configurations, optimizing the integration of hydrogen production, storage systems, and energy consumption patterns. These thorough assessments not only enhance the techno-economic appeal of these hybrid systems but also enable the investigation of diverse operating strategies customized to the specific resource availability in the Sahara.

Recent literature indicates a trend of evaluating renewable hydrogen as a crucial element in the energy framework of the Algerian Sahara. Rachid and Najmi (2024) persuasively contend that hydrogen production via solar-powered electrolysis can facilitate energy autonomy for isolated communities. Alharthi (2024) reinforces this idea, proposing that investment in solar-hydrogen systems is consistent with overarching promises to diminish greenhouse gas emissions and foster environmental sustainability.

The combination of solar energy and hydrogen technologies offers a complex answer to the issues encountered by remote areas in Algeria. This synthesis improves the discourse on renewable energy integration and advocates for legislative reforms to promote the adoption of hybrid energy systems. The research indicates that the demand for sustainable energy solutions is critical, and the capacity of solar-hydrogen hybrid systems to provide efficient, reliable, and clean energy is increasingly acknowledged as vital for enhancing resilience and self-sufficiency in vulnerable regions.

1.1. Purpose of study

This research aims to generate electrical power using a renewable source, solar energy, in conjunction with a hydrogen unit, where hydrogen is produced, stored, and used by fuel cells. To determine the annual production and energy contribution of the Illizi Desert region in Algeria, the HOMER Pro software is used to simulate, optimize, and size the system without addressing the economic aspect.

2. MATERIALS AND METHOD

2.1. System description

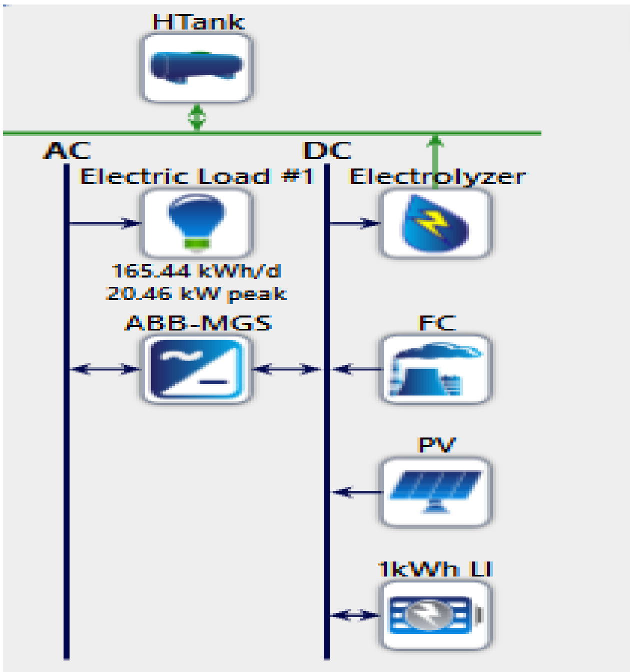
In this study, an off-grid system is designed, consisting of solar photovoltaic (PV) (Parida et al., 2011), a battery, a fuel cell generator (FC) (Appleby, 1994), an electrolyser (Koh et al., 2010), an inverter, and a hydrogen module for electricity generation. The selection of PV and FC is because they are complementary to each other for continuous generation. Due to the absence of sunlight throughout the night, solar energy is unable to meet the demand for electricity over 24 hours. Therefore, a battery is added to store excess electricity production for later use, and a hydrogen unit is added to produce hydrogen, which is then stored and used to power the fuel cell for energy production at night or in the absence of solar radiation.

2.2. System simulation

HOMER Pro software is used to simulate and size hybrid PV/FC/Electrolyzer systems. See Figure 1. This software is used to develop renewable energy systems, such as biomass, photovoltaics, wind turbines, batteries, hydraulic systems, and combined heat and electricity production. It is easy to use, allowing for the design of microgrid systems for various sectors. Optimisation and sensitivity analysis evaluate the economic and technical feasibility of a large number of technology options, calculate differences in system costs, and identify weather data for each region of the world, including wind speed, solar radiation, ambient temperature, and others. It has been widely used in numerous publications (Hassani et al., 2020; Boucenna et al., 2023).

Figure 1

Hybrid energy system diagram



2.3. Study location

Illizi was chosen to design the study system. It is located in southwest Algeria, at 26.77°N latitude and 8.3°E longitude (Bentoumi et al., 2024). Its climate is desert, hot and dry. The average solar radiation reaches 7.5 kWh/m²/day, with a clarity index of 0.7, and its temperature ranges between 12 and 32°C throughout the year (see Figures 2 and 3).

Figure 2

Solar radiation and clearness

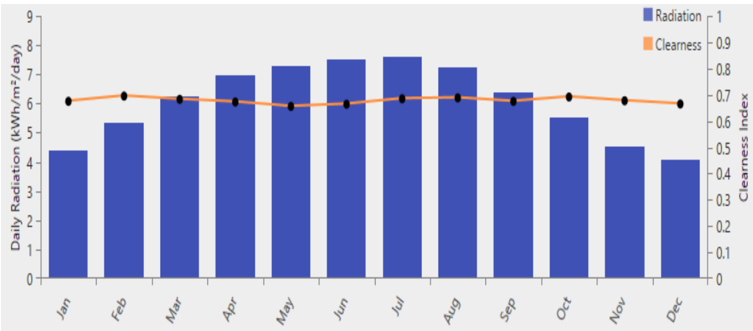
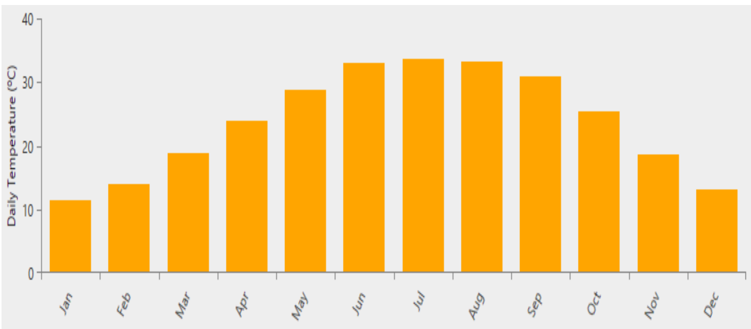


Figure 3

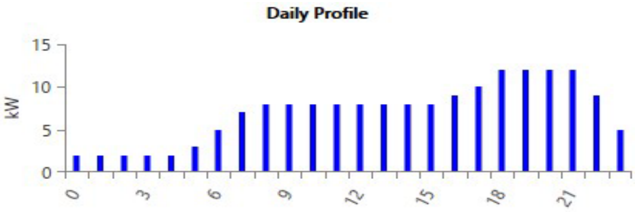
Change of ambient temperature



2.4. Load profile

The daily load profile in Fig.4 shows that the average energy consumption is 165.44 kWh/day, and the peak consumption is in the evening period from 4 pm to 9 pm.

Figure 4
Electric load



2.5. System components

This work's hybrid renewable energy system consists of PV, battery, FC, electrolyser, HTank, and inverter. Table 1 represents the characteristics of each component.

Table 1
System specifications, (a) Power sources, (b) Hydrogen module

(a)

PV Panel	Battery	Inverter
Model: Generic flat plate PV Abbreviation: PV Capacity (kW): 1 Temperature coefficient: -0.5 Operating Temperature (°C): 47 Efficiency (%): 13 Manufacturer: Generic	Model: Generic 1 kWh Li-Ion Abbreviation: 1 kWh Li Nominal voltage (V): 6 Nominal capacity (kWh): 1 Round-trip efficiency (%): 90 Maximum charge current (A): 167 Maximum discharge current (A): 500	Model: ABB MGS100 Abbreviation: ABB-MGS Efficiency: 95% Capacity (kW): 1

(b)

Component	Name	Abbreviation	Manufacturer
Generator	Fuel cell	FC	Generic
Electrolyzer	Electrolyzer	Electrolyzer	Generic
Electrolyzer	Hydrogen Tank	HTank	Generic

3. RESULTS

The simulation and optimisation results of the system using Homer Pro software are displayed in Table 2. The system's components are determined to be 54.6 kW of photovoltaic power because the location has high solar radiation, 160 of battery, 20 kW of fuel cell generator, 10 kW of electrolyser, 27.2 kW of inverter, and 20 kg of hydrogen tank.

Table 2
System's architecture

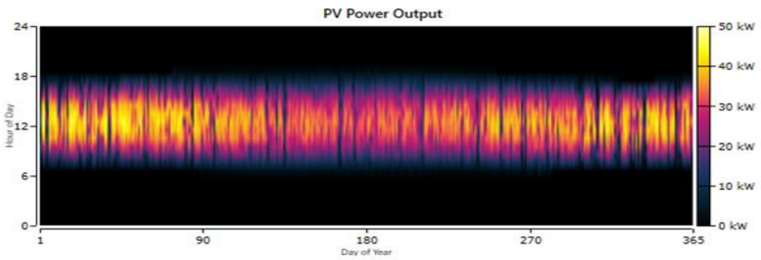
Component	Size	Unit
PV	54.6	kW
FC	20	kW
Battery	160	/
ABB-MGS	27.2	kW
Electrolyzer	10	kW
HTank	20	kg

Figure 5 illustrates the power output from the PV and FC, battery charging, and power input to the electrolyser. The figure shows that the photovoltaic cells operate between 8 a.m. and 6 p.m. due to the presence of solar radiation. In Figure 5(b), we notice that the battery-charging period is of greatest interest from midday until close to sunset, which is why the photovoltaic cells generate more electricity than the system needs. Figure 5(c) illustrates the power input to the electrolyser. The photovoltaic system with a battery is efficient, meaning that it largely meets the electrical energy needs without resorting to the hydrogen unit. The period during which the electrolyser benefits from this is during the operation of the solar panels, i.e., during the day, and thus hydrogen is produced and stored. Figure 5(d) illustrates the power extracted by the fuel cell, which appears to be operating during sunset, i.e., when the photovoltaic cells are not generating energy.

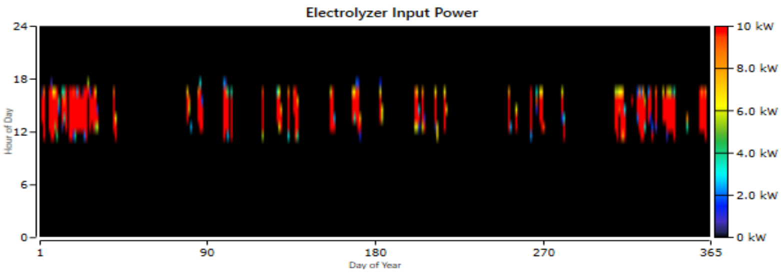
Figure 5

Power: (a) PV power output, (b) battery charging, (c) electrolyser power input, (d) FC power output.

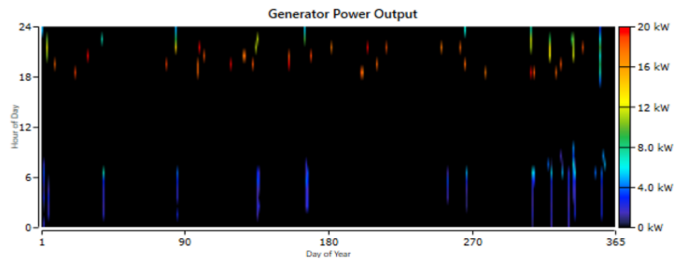
(a)



(b)



(c)



(d)

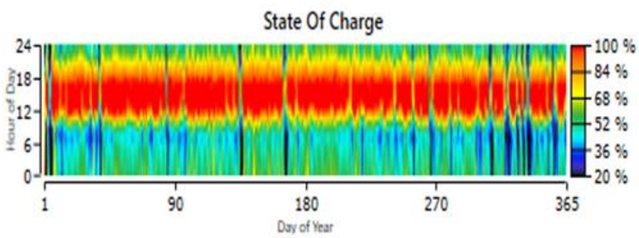
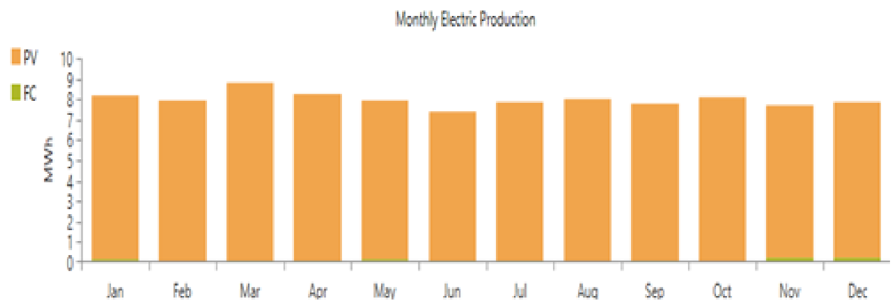


Figure 6 shows the average monthly electricity production from the fuel cells and solar panels. We note that the amount of electricity generated by the panels is significantly higher than by the fuel cells, demonstrating the efficient operation of the solar-battery system. Furthermore, production fluctuates from month to month due to variations in solar radiation, with monthly production averaging approximately 9 MWh.

Figure 6

Monthly average electric generation



The annual energy production and the percentage contribution of each component are shown in Table 3. The data indicates that, with 95791 kWh/yr energy generated, the solar photovoltaic panels were the biggest contributor and producer of 94646 kWh/yr (98.8 %). Fuel cells came with 1145 kWh/yr (1.19 %).

Table 3

Production summary

Component	Production (kWh/yr.)	Percent (%)
PV	94 646	98.8
FC	1145	1.19
Total	95 791	100

4. DISCUSSION

The simulation outcomes confirm that a PV battery hydrogen system is technically feasible for meeting off-grid electricity loads in the Illizi region, with photovoltaics providing nearly all annual production (98.8%) and hydrogen serving a minor backup function. This aligns with previous research emphasizing the strong solar potential of the Algerian Sahara (Souid, 2023) and supporting claims that renewable hydrogen is a viable clean fuel pathway (Brahim & Gemni, 2026). The system's operational behavior, daytime PV dominance, battery charging during peak irradiance, and fuel cell dispatch after sunset, corroborate findings by Maatallah & Dahadj (2023) and Mouffok et al. (2024), who described hydrogen as a reliability enhancer rather than a baseline power source in remote renewable microgrids.

The results are also consistent with prior modeling studies employing HOMER Pro for renewable-hydrogen integration. The optimized PV-dominant configuration mirrors the conclusions of Touhami et al. (2024) and Ghaitaoui et al. (2024), who demonstrated that HOMER Pro identifies solutions that leverage local resource abundance and system reliability requirements. Furthermore, the limited but functional electrolyzer operation observed here supports Faouzi (2023) and Zhang et al. (2025), who stressed that electrolyzer performance depends on surplus PV availability and proper dynamic coupling. Similarly, the feasibility of generating and storing hydrogen during daytime surplus aligns with pilot studies by Chahtou & Taoussi (2025) and Chahtou et al. (2026), demonstrating technical compatibility between PV systems and hydrogen production in desert climates.

A notable difference from some previous studies lies in the small contribution of the fuel cell, which contrasts with configurations where hydrogen played a larger supply role, particularly when batteries were absent or minimized (Messana M'oboun et al., 2025; Benmedjahed, 2024). The substantial battery capacity in the present system reduced the need for hydrogen utilization, indicating that the storage hierarchy strongly influences system behavior. Additionally, unlike studies exploring multi-service deployments such as water desalination (Chahtou et al., 2026), this system targeted electricity only, narrowing hydrogen demand. Nevertheless, by operating without fossil fuels or grid input, the findings reinforce broader claims that solar-hydrogen systems can enhance autonomy and decarbonization in remote areas (Rachid & Najmi, 2024; Alharthi, 2024), providing supportive technical evidence for larger energy transition strategies in the Algerian Sahara.

5. CONCLUSION

This study evaluated the feasibility of integrating photovoltaic generation with a hydrogen-based storage unit to supply off-grid electricity in the Illizi region of Algeria. The proposed system combined photovoltaic cells, batteries, fuel cells, an electrolyser, an inverter, and hydrogen storage, and was sized through simulation using HOMER Pro. The optimized configuration required 54.6 kW of PV capacity, a 20-kW fuel cell, a 10-kW electrolyser, a 27.2 kW inverter, and a 20 kg hydrogen tank, confirming that localized solar resources can be effectively converted into electrical energy and stored in multiple forms. The system demonstrated strong generation performance, supplying approximately 9 MWh of electricity per month and yielding an annual total of 95 791 kWh, of which 94 646 kWh originated from PV and 1 145 kWh from the fuel cell.

Overall, these findings suggest that coupling solar energy with hydrogen storage provides a technically viable route for powering remote desert regions such as Illizi, where grid access is limited and environmental protection is a priority. The heavy contribution of photovoltaic production and the supplementary role of hydrogen indicate that such hybrid systems can enhance energy security, extend supply beyond daylight hours, and reduce dependence on conventional fossil-based solutions. Given Algeria's abundant solar potential and growing interest in clean energy pathways, integrating hydrogen energy into solar-powered power plants presents a promising future strategy, contributing both to sustainable development goals and to the reduction of carbon emissions in ecologically sensitive environments.

Conflict of Interest: The authors declare no conflict of interest.

Ethical Approval: The study adheres to the ethical guidelines for conducting research.

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