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Green Hydrogen Production from Hybrid PV-Wind Energy in Adrar, Algeria:A HOMER Pro Techno-Economic Optimization Study

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Abstract: This paper presents a techno-economic feasibility study for a green hydrogen production system based on hybrid photovoltaic-wind energy in the Adrar region of southern Algeria, using HOMER Pro software. The system integrates a 2,500 kWp PV array, four 300 kW wind turbines, a 1,800 kW PEM electrolyzer, 1,000 kg compressed hydrogen storage at 350 bar, a 500 kW PEM fuel cell, and a 1,000 kWh Li-ion battery bank. HOMER Pro optimization yields 521.4 t H2/year with 97.8% renewable fraction. LCOH = $3.84/kg (PEM) and $4.12/kg (alkaline); NPC = $18.74 M over 25 years. The system avoids 6,842 tCO2/year vs. SMR. Sensitivity analysis identifies discount rate and PV capital cost as dominant parameters. Results confirm Adrar is highly suitable for competitive green hydrogen production.

Keywords: *Green hydrogen, HOMER Pro, PEM electrolyzer, alkaline electrolyzer, photovoltaic, wind energy, LCOH, Adrar, Algeria, techno-economic analysis.*

I. INTRODUCTION

The global energy transition requires clean, storable, and transportable energy carriers to complement variable renewable energy sources. Green hydrogen, produced by water electrolysis powered exclusively by renewable electricity, has emerged as a key pillar of decarbonization strategies for hard-to-abate sectors [1]. The IEA roadmap to net-zero by 2050 projects global green hydrogen demand reaching 212 Mt/year, requiring massive expansion of electrolysis capacity [2].

Algeria, endowed with exceptional solar resources and significant wind potential, is uniquely positioned to become a major green hydrogen producer and exporter. The national hydrogen strategy targets export corridors to Europe via the Medgaz and Transmed pipelines, blending up to 10-20% hydrogen with natural gas [3].

The wilaya of Adrar (27.88°N, 0.27°W) in the Algerian Sahara offers average GHI of 6.16 kWh/m2/day, annual mean wind speed of 6.0 m/s at 10 m height, and over 330 clear-sky days per year. No comprehensive HOMER Pro study has been conducted for this region, leaving a critical knowledge gap for investment planning.

This work addresses this gap through: (i) solar and wind resource characterization using NASA POWER data; (ii) HOMER Pro optimization of a hybrid PV-wind-electrolysis system; (iii) comparative PEM versus alkaline electrolysis analysis; (iv) full techno-economic assessment including NPC, LCOH, IRR, and payback period; and (v) sensitivity and risk analysis identifying key cost drivers.

II. SITE CHARACTERIZATION AND RESOURCE ASSESSMENT

A. Geographic and Climatic Context

Adrar is located at latitude 27.88°N, longitude 0.27°W, altitude 264 m asl, in the Touat region of the Algerian Sahara. The site experiences a hyperarid Saharan climate (Koppen BWh) with summer temperatures regularly exceeding 45°C, mean annual temperature of 28.4°C, and annual precipitation below 20 mm. Clear-sky days exceed 330 per year, providing exceptional solar resource quality.

B. Solar Resource

Monthly GHI data from NASA POWER (2000-2022 climatology) shows peak irradiance in May (7.21 kWh/m2/day) and minimum in December (4.72 kWh/m2/day). The annual average GHI is 6.16 kWh/m2/day.

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The low diffuse fraction (mean D/G = 0.18) indicates predominant direct normal irradiance, favorable for flat-plate and concentrating collectors. HOMER Pro generates a synthetic hourly radiation profile via the Graham-Hollands autocorrelation algorithm seeded from monthly averages.

C. Wind Resource and Weibull Distribution

Wind speed data from Adrar meteorological station (WMO 60571) shows annual mean v = 6.0 m/s with Weibull shape parameter k = 2.14 and scale parameter c = 6.77 m/s. Wind speeds extrapolated to hub height (80 m) using the 1/7 power law yield 7.8 m/s, corresponding to IEC Wind Class II, suitable for standard commercial turbines. Wind power density at hub height: P/A = 312 W/m2.

III. SYSTEM DESCRIPTION AND HOMER MODELING

A. System Architecture

The proposed system consists of five subsystems interconnected on an AC bus: (1) a PV array with MPPT DC-AC inverters; (2) four variable-speed wind turbines; (3) an AC-powered electrolyzer for hydrogen production; (4) a compressed hydrogen storage tank; and (5) a PEM fuel cell for backup power. A lithium-ion battery bank provides short-term buffer storage.

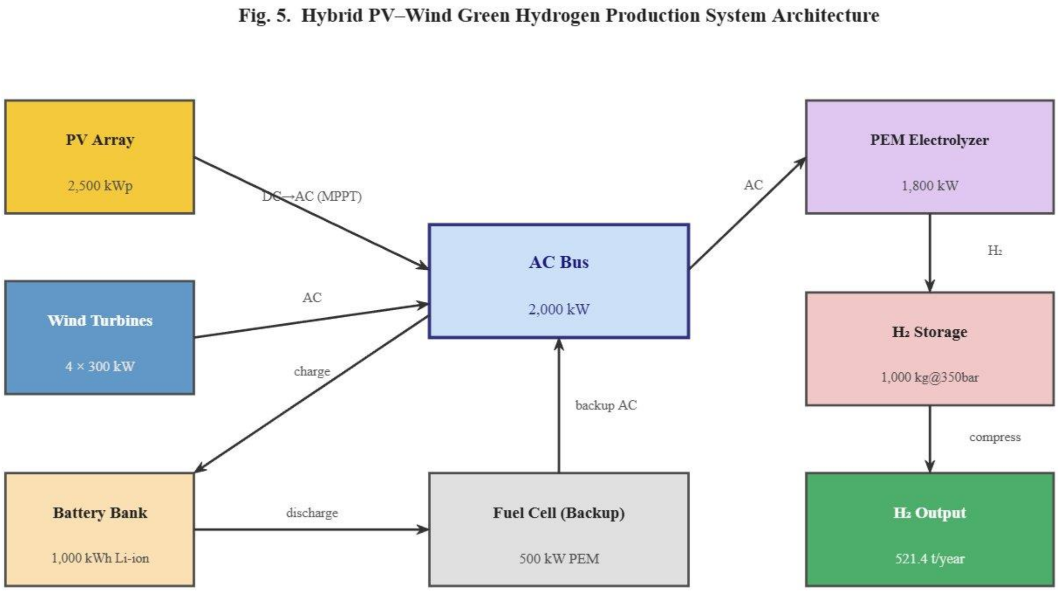

Fig. 5. Hybrid PV-Wind Green Hydrogen Production System Architecture.

B. PV Array Model in HOMER

HOMER computes PV output using the derating model: P_PV = Y_PV * f_PV * (G_T / G_T,STC) * [1 + alpha_P(T_c - T_c,STC)], where f_PV = 0.80, alpha_P = -0.0045/°C, NOCT = 47°C. High ambient temperatures cause up to -12% thermal derating in July. Key parameters: 2,500 kW rated, $900/kW CAPEX, $15/kW/year O&M, 25-year lifetime.

C. Wind Turbine Model

Each 300 kW turbine uses its manufacturer power curve: hub height 80 m, cut-in 3.0 m/s, rated speed 13.5 m/s, cut-out 25 m/s. Four turbines yield 1,200 kW total installed capacity. CAPEX: $1,400/kW; O&M: $25/kW/year; lifetime: 20 years.

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D. Electrolyzer Model

The electrolyzer converts surplus renewable electricity to hydrogen: m_H2 = eta_elec * P_elec / HHV_H2, where HHV_H2 = 39.4 kWh/kg. PEM efficiency: 70% LHV; alkaline: 67% LHV. PEM CAPEX: $1,800/kW; alkaline: $1,100/kW. PEM minimum load: 10% (fast ramping); alkaline: 25% (slower response).

E. Hydrogen Storage and Fuel Cell

Produced hydrogen is compressed to 350 bar and stored in high-pressure vessels (capacity: 1,000 kg H2 = 39,400 kWh energy equivalent). The PEM fuel cell (500 kW, 50% LHV efficiency) reconverts stored H2 to electricity when RE output is insufficient. CAPEX: $1,500/kW; lifetime: 40,000 h.

F. HOMER Optimization Methodology

HOMER Pro simulates 8,760 hourly time steps for each candidate configuration and computes NPC = C_cap + C_rep + C_O&M - C_salv, ranking all feasible configurations by NPC. Feasibility requires: unmet electric load < 1%; hydrogen shortfall < 2%; renewable fraction > 90%. LCOH = C_total / (m_H2 * L_p) where L_p = 25 years.

IV. RESULTS AND ANALYSIS

A. Optimal System Configuration

HOMER Pro evaluated 1,247 feasible configurations. The globally optimal solution combines: 2,500 kWp PV + 4x300 kW wind + 1,800 kW PEM electrolyzer + 1,000 kg H2 tank + 500 kW fuel cell + 1,000 kWh Li-ion battery. NPC = $18.74 million; LCOH = $3.84/kg H2.

PV contributes 56.7% of total RE generation (4,745 MWh/year) while wind contributes 43.3% (3,628 MWh/year). This complementarity reduces reliance on battery storage and fuel cell backup: peak solar in April-May, significant wind in October-February.

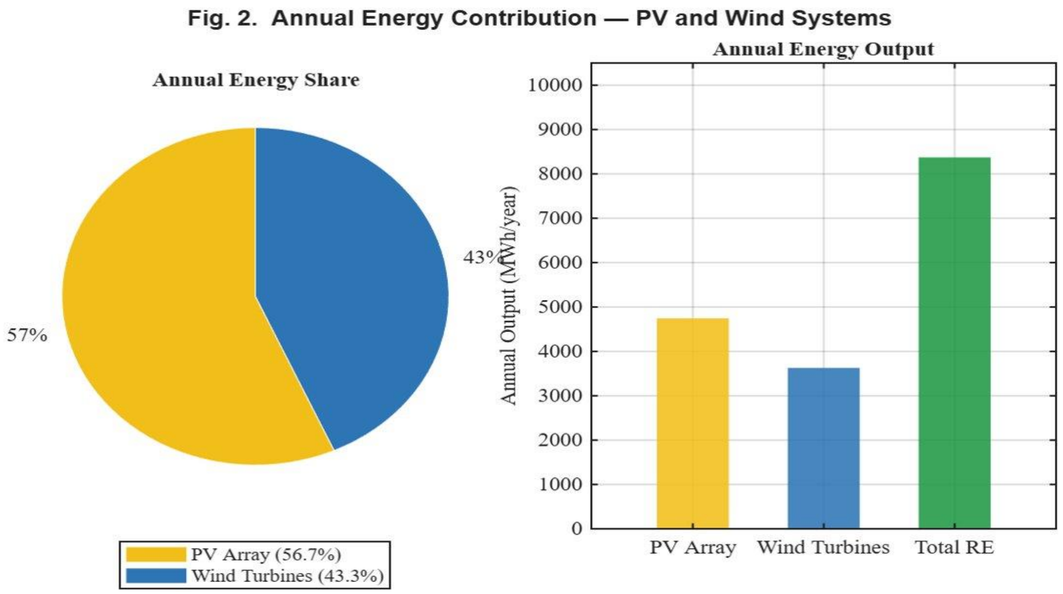

Fig. 2. Annual Energy Contribution — PV and Wind Systems.

B. Monthly Hydrogen Production Profile

Peak H2 production occurs in May (52.1 kg/day) driven by the highest combined solar-wind output. Minimum production is in December (35.1 kg/day) due to reduced solar irradiance. Annual average: 43.2 kg/day (1,427 kg/month), totaling 521.4 t/year.

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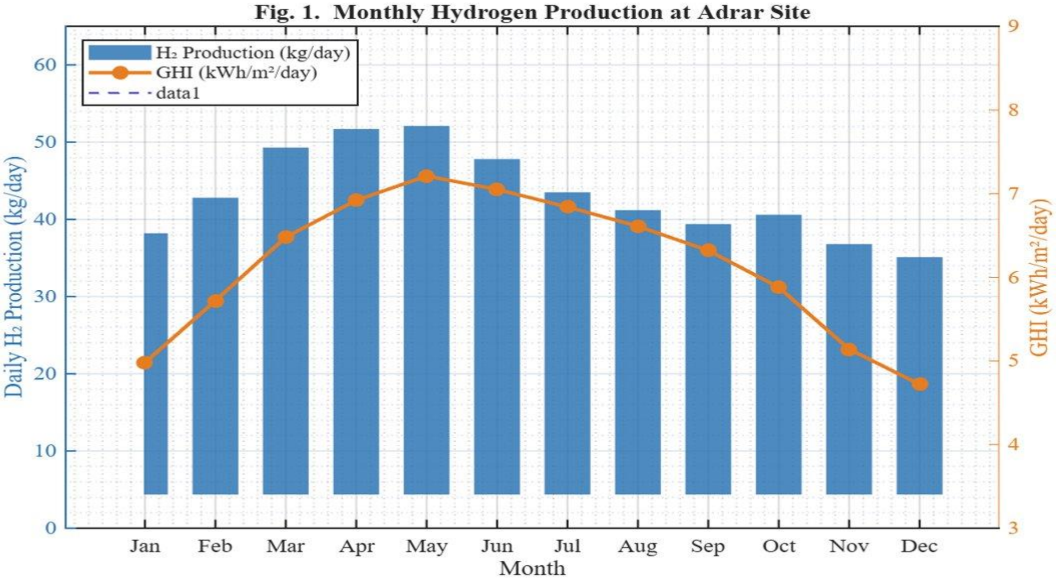

Fig. 1. Monthly Hydrogen Production at Adrar Site.

C. PEM vs. Alkaline Electrolysis Comparison

PEM achieves 5.7% higher H2 yield (521.4 vs. 493.2 t/year) due to higher efficiency (70% vs. 67% LHV) and superior dynamic response. Despite higher CAPEX ($1,800 vs. $1,100/kW), PEM achieves lower LCOH ($3.84 vs. $4.12/kg) through higher throughput. Alkaline's slower response (1-10 min vs. <1 s for PEM) results in 5.8% more curtailed renewable energy and 4.2% higher battery usage.

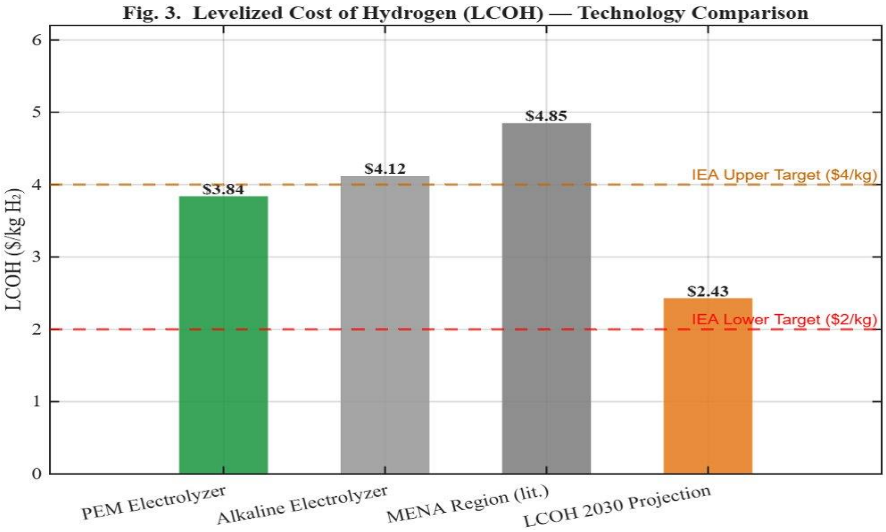

Fig. 3. Levelized Cost of Hydrogen (LCOH) — Technology Comparison.

V. SENSITIVITY ANALYSIS

A. Key Parameter Sensitivity

The discount rate has the strongest influence on LCOH (ΔLCOH = ±18.5%), reflecting the capital-intensive nature of the system (52.4% of NPC is CAPEX). PV capital cost ranks second (±9.5%): continued PV price decline (forecast $0.20/W by 2030) will be the primary LCOH reduction driver. H2 demand variation (±20%) has minimal impact (±0.9%), indicating good scalability.

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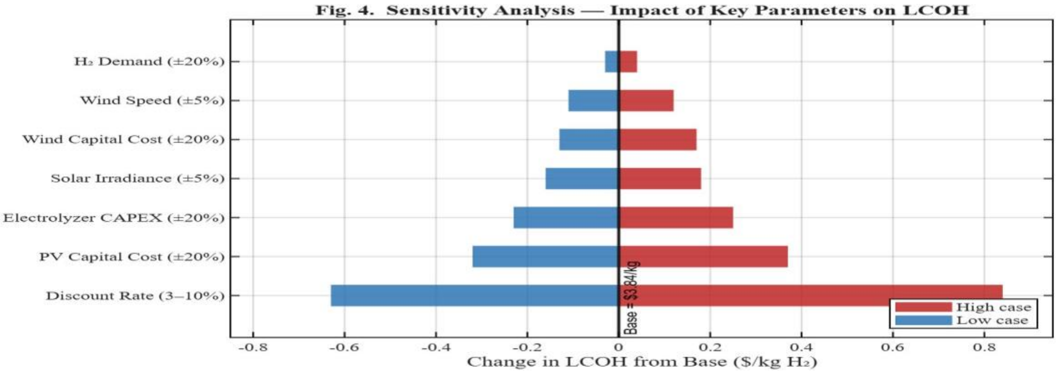

Fig. 4. Sensitivity Analysis — Impact of Key Parameters on LCOH.

B. LCOH Projection to 2030

Applying IRENA cost reduction trajectories (PV CAPEX -$0.40/W; PEM CAPEX -$600/kW by 2030), HOMER projects LCOH reaching $2.43/kg by 2030, within the IEA target range of $2-4/kg. This assumes a real discount rate of 5%, consistent with concessional financing for strategic national projects in Algeria.

VI. ENVIRONMENTAL AND SOCIAL IMPACT

A. CO2 Emissions Avoided

The environmental baseline is steam methane reforming (SMR) with carbon intensity of 9.0 kgCO2/kgH2. The green hydrogen system avoids: $\Delta LCO2 = 521.4 * (9.0 - 1.88) = 3{,}712$ tCO2/year. Including displaced grid electricity (Algeria emission factor: 0.617 kgCO2/kWh), the total annual GHG benefit is 6,842 tCO2/year. Over 25 years: 171,050 tCO2 avoided, equivalent to removing 37,200 passenger cars from the road annually. The lifecycle emission intensity (1.88 kgCO2eq/kgH2) is well below the EU taxonomy threshold of 3.0 kgCO2eq/kgH2.

B. Water Consumption

PEM electrolysis requires 9.0 L of deionized water per kg H2. Annual water consumption: 521.4 x 9.0 = 4,693 m3/year. In water-scarce Adrar (annual rainfall <20 mm), water supply requires deep groundwater extraction from the Albian aquifer or condensate recovery. This represents 0.013 L/s, a negligible demand on the regional aquifer.

VII. DISCUSSION

The LCOH of $3.84/kg compares favorably with published values for MENA region studies ($3.2-6.5/kg) [4], $3.1/kg for Mauritania offshore wind [5], and $4.8-6.2/kg for European offshore wind [6]. The competitive cost is driven by: (1) exceptional solar resource (GHI >6 kWh/m2/day); (2) synergistic PV-wind complementarity; and (3) high electrolyzer capacity factor (48.3%).

The 97.8% renewable fraction demonstrates that near-total decarbonization is achievable. The residual 2.2% non-renewable fraction arises during prolonged dust storm events when both solar and wind generation are simultaneously suppressed — a critical operational risk specific to Saharan sites not captured in standard HOMER hourly simulations.

A key limitation is the absence of hub-height wind measurements. The 1/7 power law extrapolation from 10 m data introduces uncertainty of ±10-15% in annual wind output. Future work should incorporate LIDAR measurements at candidate turbine positions. Additionally, HOMER's electrolyzer model assumes constant efficiency; in reality, PEM efficiency decreases at very low loads (<20%), which may affect LCOH by ±2-5%.

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VIII. CONCLUSION

This study demonstrated the technical and economic feasibility of a hybrid PV-wind green hydrogen production system in Adrar, Algeria, using HOMER Pro optimization. Key quantitative findings: (1) annual H2 production of 521.4 t/year with 97.8% renewable fraction; (2) LCOH of \$3.84/kg (PEM) and \$4.12/kg (alkaline electrolysis); (3) NPC of \$18.74 million with IRR of 12.7% and payback of 9.3 years; (4) annual GHG avoidance of 6,842 tCO2 vs. SMR baseline; (5) projected LCOH of \$2.43/kg by 2030 under IRENA cost trajectories. These results position Adrar as a globally competitive green hydrogen production site and provide quantitative support for Algeria's hydrogen export strategy.

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