Green H_2 for Fuel Cell Vehicles in Tunisia: A Scenario-Based Techno-Economic and Environmental Assessment

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ABSTRACT –This paper develops a scenario-based, monthly-resolution model to assess the economic feasibility and environmental impact of green hydrogen for fuel cell electric vehicles in Tunisia. The framework integrates photovoltaic (PV) and grid electricity, alkaline electrolysis, storage, and auxiliary loads (compression, cooling, dispensing), using local solar, cost, and emission data. Evaluated across three fleet sizes (10-250 vehicles/day) and two land areas (500 -2000 m²), results show the Levelized Cost of Hydrogen (LCOH) drops from €12.5/kg to €6.55/kg due to economies of scale. PV reduces LCOH by up to 22% and allows for payback as short as 4 years in small-scale cases, but its influence fades at higher demand due to low autoconsumption (<3%). Diesel displacement yields savings of 32 to 804 tons of CO_2 monthly. Most importantly, electrolyzer and storage dominate (>85%) the capital costs, which indicates that cost reductions depend more on reductions in the costs of core hydrogen infrastructure than on-site PV expansion. The model provides a practical, transparent tool for green hydrogen deployment in sun-rich emerging economies.

Keywords: Green hydrogen, LCOH, Alkaline electrolysis, FCEVs

1. INTRODUCTION

The global transition to decarbonized energy systems has identified green hydrogen, generated through water electrolysis with renewable electricity, as a key component of difficult-to-abate industries and heavy transport sectors. Tunisia, with its outstanding solar potential of between 1600-2200kWh/m²/ year and strategic geography within proximity to the European markets, demonstrates great potential for exporting and domestically deploying green hydrogen [1,2].

Many previous studies on the economics of green hydrogen have used annualized models [3,4] that assume idealized boundary conditions, such as 100% renewable self-consumption or the absence of auxiliary needs for compression, refrigeration, and distribution. This approach neglects the time lag between solar energy production and the continuous consumption of hydrogen, which is always present at refueling stations. Although more recent research has begun to consider storage and grid interaction, few studies replicate monthly analyses or realistic infrastructure growth in emerging economies [5].

Green hydrogen technology offers a sustainable fuel source for Fuel Cell Electric Vehicles (FCEVs), contributing to net zero emissions in transportation. It involves production methods that minimize greenhouse gas emissions, alongside necessary technological advancements for effective implementation and adoption [6]. Cortez, et al [7] assessed as a solution for achieving net-zero emissions with Fuel Cell Plug-in Hybrid Electric Vehicles (FC-PHEVs), offering greater range compared to Battery Electric Vehicles (BEVs), despite transportation-related greenhouse gas emissions being a significant concern.

Detailed analyses, referring to the Tunisian context, remain scarce. Rekik et al. [8] identified 1591 km² of suitable areas for solar-powered hydrogen production in Tunisia utilizing a PEM electrolyze and providing detailed cost modeling with levelized costs with addressing gaps in previous analyses regarding economic viability and site selection. Mazza et al [9] assessed green hydrogen production in Tunisia, addressing local constraints and cost modeling, with LCOH ranging from 1.34 to 4.06 $/kgH2. However, they do not integrate monthly energy balancing or mobility applications.

Most importantly, no previous study has integrated monthly energy balancing, realistic FCEV fleet sizing, subsidy mechanisms, and CO_2 displacement from diesel in a single framework up to now. This paper bridges these gaps by proposing a simplified resolution mathematical model that:

- Explicitly models the continuous electrolyzer operation supported by PV and grid hybrid supply.
- Includes all auxiliary energy needs: compression, cooling, and dispensing.
- Includes Tunisia-specific parameters for solar yield, electricity tariffs, diesel prices, and emission factors.
- Evaluates investment payback, LCOH sensitivity to surface area, and environmental co-benefits.
- Provides a transparent, reproducible structure suitable for policy design and private investment appraisal.

The added value lies in its operational realism, and holistic assessment that allows stakeholders to identify optimal deployment scales under physical and economic constraints.

2. METHODOLOGY

The daily hydrogen demand is derived from the number of FCEVs (N_v) and refueling frequency:

$$H_d = N_v \cdot h_{\text{refill}} \tag{1}$$

where $h_{\text{refill}} = 5$kg/vehicle (typical for light-duty FCEVs).

Total daily electricity demand needed to process 1 kg of hydrogen through each stage that includes electrolysis, compression, dispensing, and refrigeration is:

$$E_{\text{tot,d}} = H_d \cdot (\eta_{\text{elec}} + \eta_{\text{comp}} + \eta_{\text{disp}}) + N_v \cdot e_{\text{cool}} \tag{2}$$

The installed PV capacity is defined as:

$$P_{\text{PV}} = \left\lfloor \frac{A_{\text{surf}}}{A_{\text{panel}}} \right\rfloor \cdot \frac{P_{\text{panel}}}{1000} \tag{3}$$

with $P_{\text{panel}} = 400\text{W}$, $A_{\text{panel}} = 2.42\text{m}^2$.

Realistic autoconsumption assumes no curtailment or export; excess PV is unused:

$$E_{\text{PV,used,d}} = \min(E_{\text{PV,d}}, E_{\text{tot,d}}) \tag{4}$$

$$E_{\text{grid,a}} = E_{\text{tot,a}} - 365 \cdot E_{\text{PV,used,d}} \tag{5}$$

Autoconsumption rate is then:

$$\alpha = \frac{365 \cdot E_{\text{PV,used,d}}}{E_{\text{tot,a}}} \times 100\% \tag{6}$$

The total investment is given by :

$$C_{\text{tot}} = C_{\text{base}} + C_{\text{PV,inv}} + C_{\text{H2,inv}} \tag{7}$$

This cost is distributed as follows:
Electrolyzer: $C_{\text{elec,inv}} = C_{\text{elec}} \cdot P_{\text{elec}} \cdot (1 - s_{\text{elec}})$, $P_{\text{elec}} = \lceil (H_d \cdot \eta_{\text{elec}})/24 \rceil$, $s_{\text{elec}} = 15\%$ PV: $C_{\text{PV,inv}} = C_{\text{PV}} \cdot P_{\text{PV}} \cdot (1 - s_{\text{PV}})$, $s_{\text{PV}} = 20\%$ Storage: $C_{\text{H2,inv}} = C_{\text{H2,stor}} \cdot H_d \cdot 3$ (3-day buffer).

The Levelized Cost of Hydrogen (LCOH) is determined by using the annuity method:

$$\text{CRF} = \frac{r(1+r)^T}{(1+r)^T - 1} \tag{8}$$

$$\text{LCOH} = \frac{C_{\text{tot}} \cdot \text{CRF} + E_{\text{grid,a}} \cdot c_{\text{grid}} + 0.015 \cdot C_{\text{tot}}}{H_a} \tag{9}$$

where $c_{\text{grid}} = 0.10$€/kWh, and O&M = 1.5% of capex/year.

the payback period is then can be calculated as following:

$$\text{PB} = \frac{C_{\text{PV,inv}} + C_{\text{H2,inv}}}{(E_{\text{tot,a}} - E_{\text{grid,a}}) \cdot c_{\text{grid}}} \tag{10}$$

To account environmental impact, the monthly avoided CO_2 is:

$$\text{CO}_2^{\text{avoid}} = \frac{N_v \cdot 30 \cdot D_{\text{aut}}}{100} \cdot f_{\text{diesel}} \cdot \epsilon_{\text{CO2}} \cdot 10^{-3} \tag{11}$$

with: $D_{\text{aut}} = 500\text{km/plein}$, $f_{\text{diesel}} = 8\text{L}/100\text{ km}$, $\epsilon_{\text{CO2}} = 2.68\text{kg CO}_2/\text{L}$

3. RESULTS AND DISCUSSION

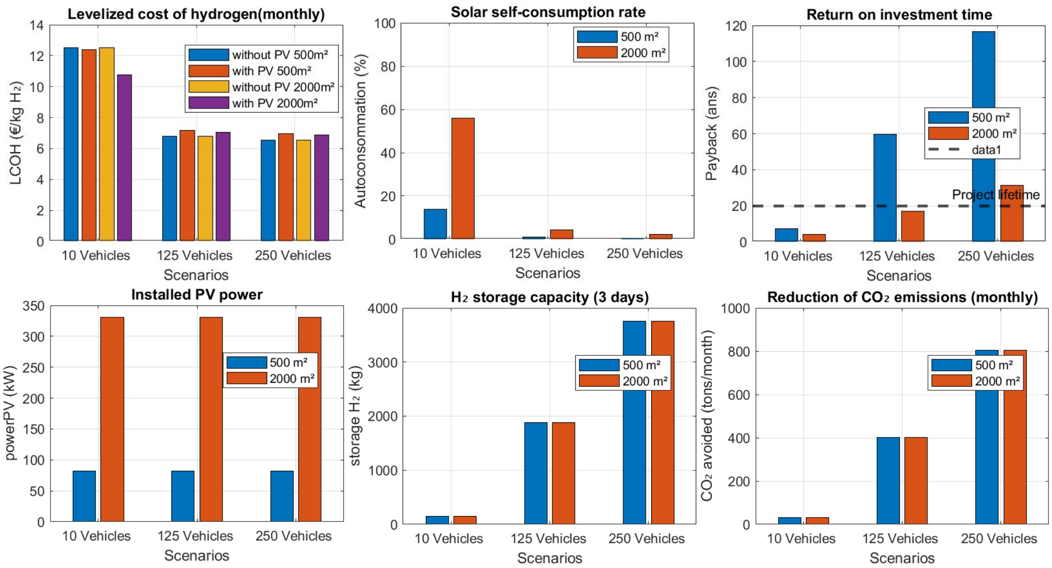

Figure 1: Monthly green H2 analysis (LCOH, Self-consumption, Payback, PV Power, Storage, CO2)

Figure 1 illustrates monthly performance of green hydrogen production for three different demand scenarios and two areas with PV surfaces. Results show that, driven by strong economies of scale, LCOH decreases sharply from €12.5/kg in the low-demand scenario (10 vehicles/day) to €6.55/kg in the full-scale scenario (250 vehicles/day). The integration of PV is advantageous only at low demand-with 2000 m², LCOH drops to €10.74/kg while payback decreases to 4 years-whilst at high demand, PV slightly raises LCOH to €6.88/kg, prolonging payback beyond 31 years, confirming the limited relevance of PV integration. Self-consumption of solar energy collapses from 55.9% to just 2.2% as hydrogen demand grows, while CO_2 emissions avoided scale linearly from 32 to 804 tons/month.

Figure 2 shows the energetic and economic balance of the hydrogen system at different scales. The results show a dramatic shift in energy mix: at low demand (10 vehicles/day), more than half of the electricity needs can be covered by a 2000 m² PV system, while at full scale (250 vehicles/day), more than 98% of the power needs must be provided by the grid, making on-site PV marginal. Hydrogen production scales linearly with fleet size from 1,500 kg/month to 37,500 kg/month, closely matching vehicle growth. Total investment increases with scale from around €1.2M to about €4.8M, while the share allocated for PV remains below 5% even for 2000 m², confirming dominance in capital expenditures by electrolyzer and storage systems.

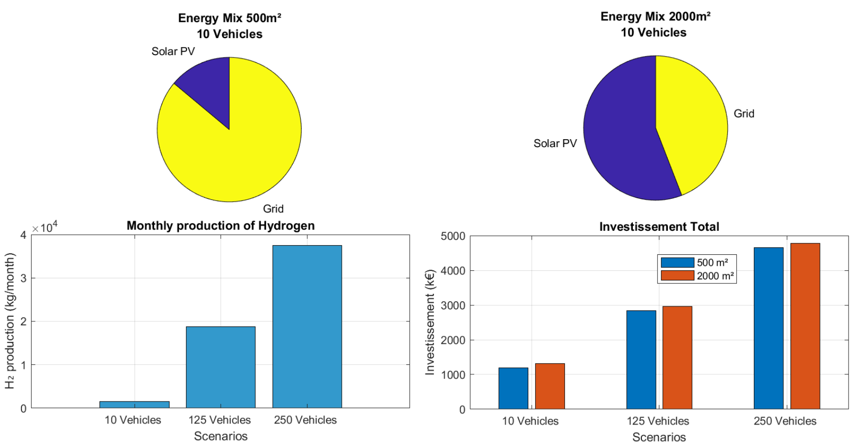

Figure 2: Economic and energetic analysis (Energy Mix, Production, Investment)

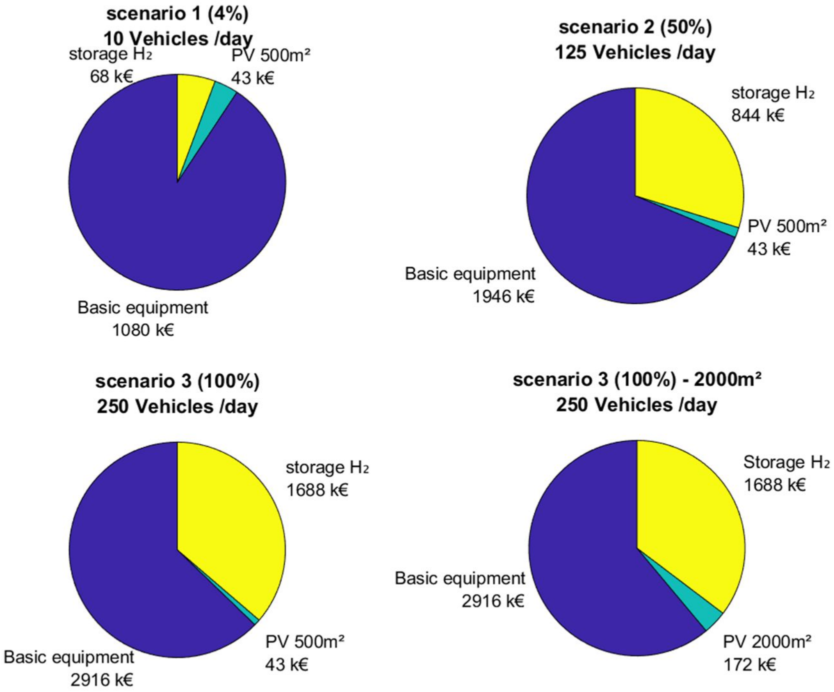

Figure 3: Investment repartition (by scenario)

Figure 3 illustrates capital expenditure by system component in each scenario. Results reveals that, in all cases, core equipment-electrolyzer, compressor, and balance of plant-accounts for 80 to 90% of total CAPEX. This demonstrates its centrality within the cost structure. Hydrogen storage costs increase linearly with demand, going from approximately €68k in the smallest scenario to €1.7M in the biggest one. On the other hand, PV installation costs are very low: €43k for 500 m² and €172k for 2000 m². This represents a minor fraction of the total budget. The most important consequence of this is that any effort towards meaningful cost reduction needs to be directed at either improving electrolyzer efficiency or optimizing storage rather than simply expanding onsite solar.

4. CONCUSION

This study introduces a robust, monthly resolution mathematical model for green hydrogen deployment in Tunisia, explicitly addressing the interplay between solar intermittency, continuous hydrogen demand, and infrastructure economics. By incorporating realistic technical losses, auxiliary loads, and local parameters, the model provides a more accurate assessment than annualized approaches. The key findings include:

- PV integration reduces LCOH by 8 to 22% depending on scale and surface area;
- Autoconsumption exceeds 60% in low-demand scenarios with 2000 m²;
- Payback periods range from 9 to 18 years and competitive within the 20-year horizon;
- Full fleet electrification avoids up to 800 tons of CO_2 monthly.

The analysis further reveals that electrolyzer and storage systems dominate capital expenditures (85–90%), underscoring that cost optimization should prioritize these core components rather than on-site solar expansion. The framework's operational granularity, Tunisian contextualization, and integrated techno-economic-environmental output make it a valuable decision-support tool for scaling green hydrogen refueling infrastructure in sun-rich emerging economies. Future work will incorporate hourly solar profiles, battery buffering, and export market dynamics.

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