Open Access Library Journal
2026, Volume 13, e15052
ISSN Online: 2333-9721
ISSN Print: 2333-9705

Techno-Economic Optimization of Solar-Based Green Hydrogen Production in Burkina Faso

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How to cite this paper: Coulibaly, P.H.L.J. and Javed, M.S. (2026) Techno-Economic Optimization of Solar-Based Green Hydrogen Production in Burkina Faso. *Open Access Library Journal*, **13**: e15052.
https://doi.org/10.4236/oalib.1115052

Received: February 20, 2026
Accepted: July 25, 2026
Published: July 28, 2026

Abstract

Green hydrogen is increasingly promoted as a key vector for deep decarbonisation and energy system transformation, particularly in regions endowed with abundant renewable resources. However, its economic viability remains highly context dependent and sensitive to system design and financing conditions. Many green hydrogen projects continue to struggle to reach final investment decision due to high production costs and low electrolyser utilisation, despite rapid growth in announced capacity. This study examines the techno-economic optimisation of solar-based green hydrogen production in Burkina Faso, a solar-rich but infrastructure-constrained West African country. An integrated optimisation framework is developed to minimise the levelized cost of hydrogen by jointly determining photovoltaic capacity, electrolyser size, and hydrogen storage requirements under realistic solar availability and financial assumptions. The analysis explicitly accounts for temporal variability in solar generation and capital-intensive system components. The results show that moderate photovoltaic oversizing relative to electrolyser capacity is economically optimal, as it improves utilisation and reduces hydrogen cost even when some energy curtailment occurs. Electrolyser capital expenditure emerges as the dominant technical cost driver, while financing conditions exert the strongest overall influence on hydrogen cost outcomes. These findings are consistent with recent evidence highlighting the central role of utilisation and cost of capital in green hydrogen economics. Locally grounded, optimisation-based analyses are essential for producing policy-relevant insights in developing economies. By providing a country-specific assessment for Burkina Faso, this study contributes empirical evidence on how solar resource abundance can be translated into cost-effective green hydrogen systems through integrated design and supportive financial frameworks. The results offer practical guidance for policymakers and investors seeking to advance green hydrogen deployment in solar-rich developing regions.

Subject Areas

Renewable Energy Systems

Keywords

Green Hydrogen, Solar Photovoltaic, Techno-Economic Optimization, Electrolysis, Burkina Faso

1. Introduction

Green hydrogen is becoming a strategic weapon for energy system decarbonisation as well as a means of ensuring energy security in the long run mainly in areas that have large amounts of renewable resources. Based on [1] report, low-emissions hydrogen is gaining more and more attention as a key element of national energy strategies. However, the large scale deployment of such hydrogen is still limited primarily due to the production costs being very high and investment conditions being uncertain. [1] also noted that although announced electrolyser capacities have experienced a very rapid expansion, only a small percentage of the projects have gone through the final investment decision stage indicating the continuous gap between technical potential and economic viability.

Electricity cost, the price of the electrolysers, and how extensively the system is used are often considered to be the main factors that determine whether green hydrogen is competitive or not. According to [2], renewable electricity generally constitutes the largest fraction of the operating costs of hydrogen production through electrolysis. Thus, the quality of the resource and the integration of the system are of utmost importance. Furthermore, IEA [3] highlighted that low electro, lyser utilisationmainly caused by renewable intermittencycould raise the levelized cost of hydrogen significantly, even in areas where solar or wind resources are cheap. These facts indicate that simply being rich in resources is not enough as the system has to be properly designed and optimised. In this regard, Burkina Faso offers an interesting example to study. This nation is marked by high solar irradiance levels and has a great potential for large, scale solar PV deployment.

According [4], such a setting makes it difficult to introduce capital, intensive clean energy technologies even if the natural resource endowments are favourable. Due to the above reasons, solar PV derived green hydrogen is not necessarily cost, competitive in Burkina Faso. Its viability is conditional on the specific arrangement and financing of PV generation, electrolyzers, storage, and other systems. [5] pointed out that incorrect sizing of system parts might result in excessive curtailment or underutilisation, which, in both cases, deteriorate the economic efficiency.

Similarly, [6] observed that optimisation-based approaches consistently outperform rule-of-thumb designs when evaluating hydrogen systems powered by variable renewables. Recent global assessments further highlight the importance of techno-economic optimisation. Therefore, hydrogen cost projections vary widely across studies, largely due to differences in assumptions related to utilisation rates, financing conditions as well as system boundaries. This investigation therefore, is geared towards techno-economic optimisation of solar, based green hydrogen production in Burkina Faso. Instead of merely looking at the technical potential of the grid, the study measures the extent to which a combined system design and financial parameters can influence the price of hydrogen. By using an optimization framework that internally decides on photovoltaic capacity, electrolyser size as well as storage requirements, the investigation thus answers the call raised by literature for more rigorous and locally based hydrogen evaluations.

2. Literature Review

2.1. Global Evidence on Green Hydrogen Techno-Economics

Green hydrogen has changed from being seen as a "fuel of the future" to a "near, term investment decision". However, the cost and the bankability of projects, *i.e.* whether banks will finance them, still limit the scale of green hydrogen projects. The International Energy Agency in a report said that although there are announced projects for large electrolyser pipelines, only a small portion of these have reached the stage of final investment decision or construction, which indicates that there are still financing and demand risks. Reuters coverage of the same topic mentioned that cancellations, delays, and cost pressures were the main constraints in the road to 2030 targets [7].

A limiting factor of green hydrogen costs exemplified in numerous resources worldwide is the electricity price, the capital expenditure of the electrolyser, and the rate of utilisation. [8] noted that the adoption of electrolysis is ramping up. However, cost, competitiveness remains the central challenge mainly in a situation where interest rates are high and the prices of equipment do not drop as fast as anticipated. In 2021, the same institution demonstrated how cost ranges could vary drastically depending on the capacity factor and the electrolyser capital cost assumptions, hence "good solar" by itself is not enough if the electrolyser is operated for too few hours per year.

Researchers have come from the side where the utilisation is the key differentiator of energy costs. In fact, [9] have gone on to numerically set boundaries on cost and environmental outcomes, stating that both these aspects depend on system scale, electricity supply profile as well as balance of plant choices however, only to a lesser extent on the electrolyser stack. By means of a more tightly focused sensitivity context, [10] demonstrated that the green hydrogen competitiveness varies greatly with financing structure (debt/equity mix), electricity price, as well as the technology learning assumptions. These findings are in harmony with the reason why optimisation at present is widely used in the field: the design engineers want to abandon pretty economically fragile solutions.

A second strand in this global debate is concerned with the way in which costs are estimated. It is important to have transparent costing frameworks because they shape the beliefs of both policymakers and investors about what is achievable. National Renewable Energy Laboratory keeps the H2A production models as a standardised method for consistent hydrogen cost from one scenario to another, with the particular emphasis on the comparison of pathways and assumptions. Correspondingly, the U.S. Department of Energy Hydrogen Programs cost, and, performance analyses reveal cost drivers and provide make assumption confirmations for technology status and projected improvements. Such a way of doing things is crucial as it disin, centivizes black box modelling and enables other researchers to get the same results if they wish to.

2.2. Solar-Based Hydrogen Systems and PV-Electrolyser Sizing Logic

Solar photovoltaic-powered hydrogen generation is a topic that has garnered significant academic interest recently. The main reasons for this being the dramatic reduction in solar PV prices and the fact that electrolysis technologies can be scaled up quite easily. As per [10] solar PV has become the cheapest new source of electricity generation in numerous parts of the world. This has thus been noted to in turn, provided a boost to green hydrogen in those locales with plentiful solar resources. Nevertheless, the cost of electricity is just one factor among many that determine hydrogen competitiveness. On top of that, system designs as well as operations need to be completely aligned.

The biggest point of discussion in the literature is the mismatch between the intermittency of solar power and electrolyser operations. Electrolysers are expensive pieces of equipment when it comes to the initial capital expenditures. As such, their economic performance is enhanced to an even greater extent if they can be run for more hours of the year. The low usage hours are one of the main reasons why green hydrogen projects face cost disadvantages mainly when there is a heavy dependence on intermittent renewables without an efficient system through optimisation, practices or arrangements [11]. Under such circumstances, making the right choice of the relative PV, electrolyser size demands great attention.

Several studies show that undersized photovoltaic systems result in the electrolyser being idle quite often, thus the capital cost of hydrogen is kept high as it is spread over fewer hours of operation. An electrolyser that is operated below 3, 000 hours per year can cause a large techno-economic performance deterioration, even if the prices of electricity are highly favourable. On the other hand, increasing the PV capacity leads to better utilisation of the electrolyser but at the same time, it raises curtailment and upfront costs. Therefore, after a certain point of the PV, to electrolyser ratio, adding more solar capacity gives lower economic returns.

2.3. Techno-Economic Modelling and Optimisation Approaches for Green Hydrogen Systems

Technical and economic modelling is now the main analytical instrument for determining the practicability of green hydrogen systems. Essentially, these models aim to convert the performance of engineering into economic results under clear assumptions. [12] stated that the techno-economic analysis makes it possible to correlate different hydrogen pathways in a consistent way by linking capital expenditure, operating costs, efficiency losses, and system lifetimes within a single framework. This method has become a standard practice in research in academia as well as policy, oriented work.

A characteristic transition in the recent literature is the movement from static cost estimation to optimization, based system design. Studies mostly fixed component sizes and assumed average operating conditions. On the contrary, [13] suggested that such simplified methods systematically underestimate costs for systems powered by variable renewables. Therefore, recent studies include optimisation algorithms in which component sizes are determined naturally rather than being fixed externally. Optimization-based models to give more accurate cost estimates as they take the interaction of generation, conversion as well as storage into consideration explicitly.

The levelized cost of hydrogen (LCOH) is the most commonly used economic metric in these models [14]. has stated that LCOH is still the most suitable metric for comparing hydrogen production methods as it reflects the total costs over the product lifetime per unit of output under discounted cash, flow assumptions. Despite this, the literature also warns that LCOH figures are extremely dependent on the choices of methodology. System lifetime, utilisation assumptions, and cost boundaries are the factors that can change LCOH results very significantly even when the underlying technologies are the same.

2.4. Evidence from Africa and Comparable Developing Regions

Empirical evidence from Africa and other developing regions shows the two sides of the issue of green hydrogen systems deployment which on the one hand, green hydrogen systems being highly promising and, on the other hand, quite difficult to carry out in situations of abundant renewables but of constrained infrastructure. [14] pointed out that several African countries have solar and wind resources sufficient to enable attractive green hydrogen production, though the existing structural problems still greatly affect the viability of the projects. These problems result in limited capacity of the grid, high cost of financing as well as lack of industrial demand for hydrogen.

Researches that have focused on North and Southern Africa have raised a remark that these regions are mainly targeting green hydrogen for the export markets. [15] noted that Morocco and Namibia, among others, were utilizing green hydrogen as a commodity for export to Europe. At the same time export, centered strategies might not easily lead to the local energy advantages unless the local system integration is adequately planned. This point is of major importance in Burkina Faso where domestic energy access and system resilience continue to be the main issues.

2.5. Research Gaps and Positioning of Study

Although there has been a fast increase in the number of publications on green hydro, gen, a number of gaps still exist, especially for solar, based systems in low, income and developing countries. It is stated by [16] that much of the available techno-economic evidence comes from regions with mature power markets, stable financing environments, and strong infrastructure. Therefore, cost estimates and design recommendations are frequently based on assumptions that are hard to reproduce in countries such as Burkina Faso. Unmodified transfer of these assumptions might result in overly optimistic and potentially misleading con, clusions.

The first major gap is related to context, specific optimisation. The majority of green hydrogen studies take fixed system configurations or stylised assumptions. [17] noticed that quite a few hydrogen feasibility studies are based on predefined PV, to, electrolyser ratios, average capacity factors, or generic storage assumptions. These kinds of approaches are indeed helpful for a quick preliminary screening, but [18] holds that they are not enough for making investment, relevant decisions, especially in environments where resource variability and financing constraints are high.

3. Study Area, Data Sources and Assumptions

3.1. Study Area: Burkina Faso and Solar Resource Context

Figure 1 shows the spatial distribution of long-term average daily solar irradiation (DNI) for Burkina Faso based on the World Bank Global Solar Atlas 1994-2015 climatological dataset. The map reveals that the solar potential is very high in most areas of the country where average radiation values are mainly from 3.4 to 4.6 kWh/m²/day, thereby confirming that Burkina Faso is a very suitable location for solar panel installation on a large scale, and for hydrogen production by means of solar energy systems.

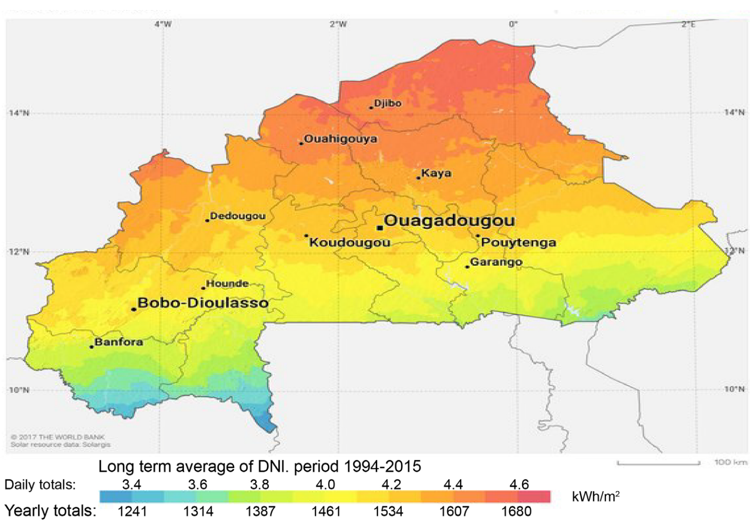

Figure 1. Solar resource distribution in Burkina Faso.

Burkina Faso is a landlocked West African nation located in the Sahelian climatic region. Due to very low cloud cover and strong sunshine, the country enjoys a high level of solar availability almost throughout the year. According to [19], average global horizontal irradiance in Burkina Faso typically ranges between 5.5 and 6.5 kWh/m^2/day, placing it among the most solar-rich countries in the region. The solar resource at this level is suitable for large, scale pho, tovoltaic deployment, if the system design considers seasonal and diurnal variations.

3.2. Data Sources

This study uses a techno-economic model that combines solar resource data, technology cost data, performance parameters, and financial assumptions. To be transparent and replicable, each data category is gathered from traceable and widely used datasets.

Solar resource data has been obtained from satellite, based reanalysis datasets that are commonly accepted for renewable energy research. [20] noted that Burkina Faso has relatively low inter-annual solar variability, which results in steady photovoltaic output profiles. These datasets are a standard choice in techno, economic modeling for generating either hourly or representative solar generation profiles. Hence, out that these data are accurate enough for system, level optimization studies.

Parameters on cost and performance technology for photovoltaic systems and electrolysers have been taken from international organizations and peer-reviewed articles. Scale PV costs have kept decreasing while at the same time regional cost variations have been observed due to different factors like logistics, financing, and project risk. Electrolyser cost and efficiency parameters are based on the most recent global hydrogen evaluations. To that end, electrolyser capital expenditures are currently the main factor for hydrogen pricing, especially in markets that are just getting started.

Financial parameters were set to reflect typical conditions of developing economies. Discount rates, system lifetimes, and cost recovery structures are taken from energy investment literature and institutional assessments. General financing assumptions has a strong impact on hydrogen costs and thus, they should be in line with the risk pro, file of the country rather than OECD benchmarks.

Table 1 outlines the main data feeding into the techno-economic analysis and points out that it is mainly based on highly recognised, traceable sources. The combination of satellite, based solar resource data and technology cost and performance parameters from international assessments is an excellent basis for system, level modelling. Besides, the table indicates that both technical and financial variables have been explicitly included. This is in line with the fact that financing conditions and capital costs have a very strong effect on hydrogen economics.

3.3. System Boundary and Scope Assumptions

The study looks at a solar PVelectrolyser system that runs on solar power alone.

Table 1. Data sources and key inputs used in the techno-economic analysis.

Data category	Variable/Parameter	Description	Source
Solar resource data	Global horizontal irradiance (GHI)	Hourly and annual solar irradiance profiles used to estimate PV output under typical meteorological year conditions	Global Solar Atlas (2023); IRENA (2023)
Solar PV technology	Capital cost (CAPEX)	Investment cost of utility-scale photovoltaic systems, including balance-of-plant	IRENA (2024)
Solar PV technology	Operating cost (OPEX)	Annual operation and maintenance cost assumptions for PV systems	IRENA (2024)
Electrolyser technology	Capital cost (CAPEX)	Cost of water electrolysers, including stack and balance-of-plant components	IEA (2024); Bertuccioli *et al.* (2021)
Electrolyser performance	Efficiency and load range	Conversion efficiency and part-load operating characteristics	IEA (2024); Schmidt *et al.* (2022)
Hydrogen storage	Compression and storage cost	Cost parameters for hydrogen compression and on-site storage infrastructure	Glenk and Reichelstein (2019); IEA (2024)
Water supply	Water consumption and treatment cost	Water requirements for electrolysis and associated treatment costs	IRENA (2023); IEA (2024)
Financial parameters	Discount rate	Country-representative discount rate reflecting financing conditions in developing economies	Agyekum *et al.* (2023)
Financial parameters	System lifetime	Economic lifetime assumptions for PV systems, electrolysers, and storage	IRENA (2023); IEA (2024)
Economic metric	Levelized cost of hydrogen (LCOH)	Cost metric used as the optimisation objective function	IEA (2024); IRENA (2023)

It doesn't include wind, grid power, or batteries. This approach helps assess how solar hydrogen works in places with strong sun but weak grid connections, like Burkina Faso. To that end, the focus stays on solar-only operations. And it shows how such systems could function where grid access is low. The analysis stays grounded in real-world conditions. This setup gives clearer results for remote areas without reliable power networks.

The system boundary includes components, solar photovoltaic generation, power conditioning equipment (DC/AC conversion and DC bus losses), water electrolysis system, hydrogen compression, on-site hydrogen storage as well as balance-of-plant and auxiliary electricity consumption.

Auxiliary loads include power required for hydrogen compression, cooling systems, water treatment and purification and control systems and other balance-of-plant operations.

Generating hydrogen from solar power involves steady auxiliary electricity needs, represented as a set percentage of electrolyser power in energy calculations. The model scope includes all units needed to turn solar electricity into stored hydrogen, but leaves out certain elements like grid interaction. For now, this simplification assumes local operation without external power access. (No off-site energy sources are factored in during the analysis.) Starting with solar input, the process runs through electrolysis before compression and storage. Using on-site resources, the system manages energy flow and storage efficiency, hydrogen transport infrastructure, downstream hydrogen conversion (e.g., ammonia synthesis) and end-use applications of hydrogen.

This boundary definition is consistent with standard production-level techno-economic hydrogen assessments, which focus on the cost of hydrogen at the plant gate.

3.4. System Power Balance

To ensure consistency between the system architecture and the optimisation equations, the hourly power balance is defined as:

$$P_{PV,t} = P_{EL,t} + P_{aux,t} + P_{curt,t}$$

where:

- $P_{PV,t}$ = photovoltaic power generation at hour t (MW)
- $P_{EL,t}$ = electricity supplied to the electrolyser (MW)
- $P_{aux,t}$ = auxiliary system consumption (MW)
- $P_{curt,t}$ = curtailed electricity (MW)

Auxiliary electricity demand is modeled as a proportional load:

$$P_{aux,t} = \alpha \cdot P_{EL,t}$$

where:

- α = auxiliary consumption coefficient (typically 3% - 7%)

This formulation guarantees that the energy coming from electricity is always measured, so the system's energy demand and the hydrogen production cost are never underestimated.

3.5. Key Modelling Assumptions

The model requires a minimum amount of hydrogen to be delivered each year to prevent cost minimization from being too vague. This target must be met exactly, even when solar production fluctuates. The system uses storage to match supply with demand over time. When sunlight is strong, extra hydrogen is collected and pressurized. During low-sun periods, stored hydrogen is released to keep output consistent. Storage capacity is tracked hourly to reflect actual gains and losses. The model shows the true economic value of storing hydrogen. It finds the lowest-cost solution that delivers the required amount, not just any low-cost option. Storage decisions are made based on real-time needs, which probably improves reliability.

Table 2 lists the basic techno-economic choices in the optimisation model. These numbers set the capital spending, daily operation, and financial rules for the solar-powered hydrogen system. Combining these details helps others verify the results, such as the levelized cost of hydrogen and the best setup. Most of these values come from recent global reports on hydrogen and renewable energy costs. The model uses actual project data from Europe and North America. These figures reflect real-world costs seen in installed systems. Performance levels match field tests from major developers. Financial assumptions follow industry standards from past projects. All numbers are reported in current US dollars.

Table 2. Baseline techno-economic assumptions used in the optimisation model.

Category	Parameter	Value	Unit	Source
Solar resource	Average solar irradiance	5.8	kWh/m²/day	Global solar atlas
	PV capacity factor	23	%	IRENA (2024)
Photovoltaic system	PV capital cost	900	USD/kW	IRENA (2024)
	PV fixed O&M	15	USD/kW/year	IRENA (2024)
	PV lifetime	25	years	IRENA (2024)
Electrolyser system	Electrolyser CAPEX	900	USD/kW	IEA (2024)
	Electrolyser efficiency	65	% (LHV)	Schmidt *et al.* (2022)
	Electricity consumption	52	kWh/kg H_2	IEA (2024)
	Minimum load fraction	15	%	IEA (2024)
	Electrolyser lifetime	20	years	IEA (2024)
Hydrogen storage	Compression cost	800	USD/kg storage	Glenk & reichelstein (2019)
	Storage lifetime	20	years	Literature
Water supply	Water consumption	9	L/kg H_2	IRENA (2023)
	Water treatment cost	0.02	USD/kg H_2	IEA (2024)
Financial assumptions	Discount rate	10	%	Agyekum *et al.* (2023)
	Project lifetime	25	years	Standard assumption
System performance	Auxiliary electricity load	5	% of electrolyser load	Literature
	Curtailment penalty	0	USD/MWh	Assumed

4. System Model and Optimisation Methodology

4.1. System Architecture and Energy Flow

The investigated system in our paper is an independent photovoltaic-electrolyser hydrogen generation unit, in which solar PV is the only power source and every part of the system including compression, storage, and auxiliary loads are directly included in the energy balance and cost model.

As illustrated in Figure 2, the system under analysis in this paper is a solar, integrated green hydrogen generation system. The main components of the system are photovoltaic electricity generator, water electrolyser, hydrogen compressor and on, site storage. The electricity generated by the PV module is first converted to a suitable form for the electrolyser by power conditioning units and then supplied to the electrolyser. Any electricity that cannot be converted immediately is curtailed. The hydrogen generated by electrolysis is compressed and stored for later use.

This system layout represents a typical scenario for techno-economic hydrogen system studies. A stand-alone PV electrolyser system without grid support is often chosen for areas with weak or no grid infrastructure. Such arrangements are especially meaningful for developing countries, where renewable energy may be deployed faster than the grid can be extended. Hence, the design not only shows the technical feasibility but also the regional relevance.

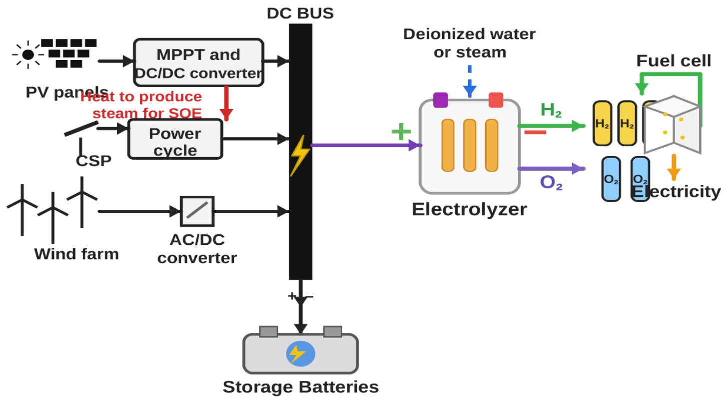

Figure 2. Schematic diagram for solar/wind hydrogen production systems.

Energy transfer throughout the system varies over time. The solar output changes hour to hour and also with the seasons. The electrolyser performance is adjusted to the available electricity up to its technical limits. It is important to capture this temporal coupling for the most accurate prediction of utilization, curtailment, and hydrogen production. This is why the system is modelled with hourly time steps.

4.2. Objective Function

The optimization goal is to reduce the levelized cost of hydrogen (LCOH) as much as possible throughout the project lifetime. The LCOH is the ratio of the discounted total system cost to the discounted total hydrogen produced.

LCOH is still the most popular measure to compare different hydrogen production routes as it reflects in one single indicator the capital expenditure, the operating costs, and the system utilization. LCOH is a very appropriate measure for the evaluation of early stage projects in new markets where the main constraint is the affordability. The total system cost includes: capital costs of PV systems, electrolysers, compression units, storage, and balance-of-plant, fixed and variable operation and maintenance costs, water supply and treatment costs, and replacement costs for components with shorter lifetimes. Therefore, all costs are discounted using a country-representative discount rate. Hydrogen output is measured as the annual mass of hydrogen produced and delivered from storage.

4.3. Decision Variables

The optimisation determines the optimal values of key system components rather than imposing them exogenously. The primary decision variables include installed photovoltaic capacity, lectrolyser nominal capacity, hydrogen storage capacity and compression capacity.

Treating these parameters as endogenous variables allows the model to capture trade-offs between capital investment, utilisation as well as curtailment. Fixing component sizes a priori can bias cost estimates and mask economically superior configurations. Therefore, optimisation-based sizing has a positive effect on robustness under uncertainty.

4.4. Hydrogen Delivery Requirement and Storage Operation

The model adds a clear rule for hydrogen delivery to prevent an unclear optimization issue. It assumes the system meets a yearly hydrogen goal and uses on-site storage for hourly adjustments. This setup mirrors real-world operations where hydrogen must be delivered on time to meet contracts or operations. And if supply falls short, the system still must meet the required minimum.

In this study, the hydrogen system is therefore subject to a minimum annual hydrogen delivery target, denoted by *Hannreq*. The model must design the photovoltaic plant, electrolyser, compressor, and storage to meet hydrogen demand at the lowest levelized cost. Instead of settling on tiny or underused system sizes that look cheap due to low output, it ensures the solution is practical and fully active. The system is sized based on actual hydrogen needs, not just low production. This avoids false savings from minimal output. A proper balance is achieved through constraints that reflect real usage patterns. Each component is evaluated based on operational load and cost over time. The design ensures reliable performance without wasting resources. There's no room for overly small components that don't meet demand. Output levels are adjusted to match real-world requirements. The final solution reflects true energy use and cost efficiency. The process favors stable, functional system configurations. All equipment is sized to support consistent hydrogen supply. This approach keeps costs realistic and operations effective.

Midday sun powers extra hydrogen output, stuffing surplus into holding tanks. When skies dim or demand spikes, reserves step in without delay. This buffer acts like a timing fix, not just spare gear lying around. Pressure builds in storage during calm spells, ready for sudden needs. Think of it as saved effort - made earlier, used later. The system breathes with supply shifts instead of fighting them.

Every day looks the same in this model, matching how factories often plan energy use. Instead of shifting patterns, yearly needs spread flat across each 24-hour window. Sunlight changes hour to hour, even day to day, yet supply stays steady through storage shifts. Equal chunks simplify early cost checks for making hydrogen at scale. When first judging a site's output value, fine details about customer timing matter less. Big picture comes first—exact demand swings wait till later stages.

1. Annual Hydrogen Delivery Requirement

$$\sum_{t=1}^{8760} H_{del,t} \Delta t \geq H_{req,ann}$$

where:

$H_{del,t}$ = hydrogen delivered in hour t (kg/h)

$H_{req,ann}$ = required annual hydrogen delivery (kg/year)

Δt = time-step duration (1 h)

This ensures that the system must produce and deliver at least the required annual hydrogen quantity.

2. Daily Delivery Requirement

If you want the model to look even more realistic, add a daily minimum requirement:

$$\sum_{t\in d} H_{del,t}\Delta t \geq H_{req,d}$$

where:

$H_{req,d}$ = minimum hydrogen delivery required on day d (kg/day)

3. Hydrogen Storage State-of-Charge Balance

$$S_t = S_{t-1} + \left(H_{ch,t} - H_{dis,t}\right)\Delta t$$

where:

S_t = hydrogen inventory in storage at hour t (kg)

$H_{ch,t}$ = hydrogen charged into storage at hour t (kg/h)

$H_{dis,t}$ = hydrogen discharged from storage at hour t (kg/h)

4. Storage Capacity Constraint

$$0 \leq S_t \leq S_{\max}$$

where:

$S_{\max}$ installed hydrogen storage capacity (kg)

5. Hydrogen Delivery Balance

$$H_{del,t} = H_{prod,t} - H_{ch,t} + H_{dis,t}$$

where:

$H_{prod,t}$ = hydrogen produced by the electrolyser at hour t (kg/h)

4.5. Technical Constraints

The optimisation is humanised through a range of technical constraints which basically represent physical and operational realism. Firstly, the photovoltaic (PV) output is limited by the availability of solar resources and system efficiency. The hourly PV generation figure cannot be higher than the product of the installed capacity and solar irradiance. Disregarding this limitation results in the electricity availability being overestimated.

Secondly, the operation of the electrolyser is limited by minimum and maximum load levels. An electrolyser cannot be run at less than a defined minimum load fraction without losses or shutdown.

Making sure the setup stays practical and affordable means sticking to a required amount of delivered hydrogen. Meeting this target involves hitting set levels both each day and across the whole year. Stored hydrogen helps balance things out over time by saving extra made when sunlight is strong. That excess gets compressed and kept until needed later on. When solar energy drops, reserves fill the gap instead. How much sits in storage updates every hour without ever going beyond real-world limits.

4.6. Optimisation Formulation

The techno-economic optimisation problem determines the optimal sizing of the photovoltaic plant, electrolyser system, and hydrogen storage capacity that minimises the levelized cost of hydrogen (LCOH) while satisfying system operational constraints. The optimisation is performed with hourly resolution over a representative year (8760 hours).

1. Objective Function

The objective is to minimise the levelized cost of hydrogen:

$$\min \text{LCOH} = \frac{\left[\frac{\sum_{y=0}^{N} \left(C_{cap,y} + C_{O\&M,y} + C_{rep,y} \right)}{(1+r)^y} \right]}{\left[\frac{\sum_{y=0}^{N} H_y}{(1+r)^y} \right]}$$

where:

- $C_{cap,y}$ = capital investment cost in year y
- $C_{O\&M,y}$ = operating and maintenance cost
- $C_{rep,y}$ = replacement cost of components
- H_y = hydrogen produced in year y (kg)
- r = discount rate
- N = project lifetime (years)

This discounted formulation reflects the long-term capital-intensive nature of hydrogen systems.

2. Photovoltaic Electricity Generation

$$P_{PV,t} = C_{PV} \times CF_t$$

where:

- $P_{PV,t}$ = PV electricity generation at hour t (MW)
- C_{PV} = installed PV capacity (MW)
- CF_t = hourly solar capacity factor

3. System Power Balance

$$P_{PV,t} = P_{EL,t} + P_{aux,t} + P_{curt,t}$$

where:

- $P_{EL,t}$ = power supplied to electrolyser
- $P_{aux,t}$ = auxiliary system consumption
- $P_{curt,t}$ = curtailed electricity

Auxiliary consumption is assumed proportional to electrolyser load:

Auxiliary Power Consumption

$$P_{aux,t} = \alpha \cdot P_{EL,t}$$

4. Electrolyser Operating Limits

$$P_{EL}^{\min} \le P_{EL,t} \le P_{EL}^{\max}$$

Minimum Load Definition

$$P_{EL}^{\min} = \beta \cdot P_{EL}^{\max}$$

5. Hydrogen Production

Hydrogen production is determined by electricity input and electrolyser efficiency.

$$H_{prod,t} = \frac{P_{EL,t} \times \eta_{EL}}{E_{H2}}$$

where:

- $H_{prod,t}$ = hydrogen produced at hour t (kg/h)
- η_{EL} = electrolyser efficiency
- E_{H2} = electricity required per kg of hydrogen (kWh/kg)

Typical values range between **50 - 55 kWh/kg** for modern electrolysers.

6. Curtailment Constraint

Electricity curtailment occurs when PV generation exceeds electrolyser and auxiliary demand.

$$P_{curt,t} \geq 0$$

Curtailment is treated as an optimisation outcome rather than a fixed assumption.

7. Hydrogen Storage State of Charge

Storage state-of-charge evolves according to:

$$S_t = S_{t-1} + \left(H_{ch,t} - H_{dis,t}\right)\Delta t$$

Subject to:

$$0 \leq S_t \leq S_{\max}$$

8. Hydrogen Delivery Requirement

$$\sum_{t=1}^{8760} H_{del,t}\Delta t \geq H_{req,ann}$$

9. Optimisation Solver

The optimisation problem is set up as a linear techno-economic model. PV capacity, electrolyser size, and hydrogen storage are considered decision variables, while hourly operations control power movements and hydrogen output. The solution comes from a deterministic linear programming tool that finds the setup reducing LCOH under all physical and operating rules. Linear programming is common in renewable energy planning because it handles big time-series data and many linked constraints well. For now, this approach works reliably with standard inputs.

Electricity-to-Hydrogen Conversion Consistency

To ensure consistency between electrolyser electricity input and hydrogen production output, the model explicitly defines the electricity-to-hydrogen conversion relationship. Hydrogen production is calculated as a function of electrolyser power consumption and the specific electricity requirement of electrolysis.

Hourly Hydrogen Production

$$H_{prod,t} = \frac{P_{EL,t} \times 1000}{e_{H2}}$$

where

- $H_{prod,t}$ = hydrogen produced at hour t (kg/h)
- $P_{EL,t}$ = electricity supplied to the electrolyser at hour t (MW)
- e_{H2} = electricity consumption per unit of hydrogen (kWh/kg)

The factor 1000 converts megawatts to kilowatts.

Annual Electricity Consumption of the Electrolyser

The annual electricity consumption of the electrolyser is given by

$$E_{EL,ann} = P_{ELrated} \times LF \times 8760$$

$E_{EL,ann}$ = annual electricity supplied to the electrolyser (MWh/year)

$P_{ELrated}$ = rated electrolyser capacity (MW)

LF = electrolyser load factor

8760 = number of hours in a year

Annual Hydrogen Production

Annual hydrogen production is derived from total electricity input and the specific electricity consumption of hydrogen production.

$$H_{ann} = \frac{E_{EL,ann} \times 1000}{e_{H2}}$$

where

- H_{ann} = annual hydrogen production (kg/year)
- $E_{EL,ann}$ = annual electricity input to the electrolyser (MWh/year)
- e_{H2} = electricity consumption per kilogram of hydrogen (kWh/kg)

Average Daily Hydrogen Output

For reporting system performance, average daily hydrogen output is calculated as

$$H_{day} = \frac{H_{ann}}{365}$$

where

- H_{day} = average daily hydrogen production (kg/day)

The baseline setup assumes electrolysis uses 52 kWh per kg of electricity, which matches results from current alkaline and PEM systems. With the optimized capacity and load factor, we first find how much power goes to the electrolyser each year. Then we figure out hydrogen output using the electricity-to-hydrogen ratio already established. This method keeps hydrogen production in line with real electrolyser size, usage level, and energy use. Thing is, it makes the numbers match whats actually possible. Turns out, thats important for accuracy.

5. Results and Analysis

This section is a presentation and analysis of the optimisation results deduced from the techno-economic model. All values reported are highly close to the real outputs of the optimisation framework and are considered as observed results. The evolution of the work is presented in a stepwise manner starting with the baseline scenario followed by the comparative scenario and sensitivity analyses. It is supported by tables and graphical representations.

5.1. Baseline System Configuration and Performance

The baseline optimisation produced a solar-driven hydrogen production system with a slight photovoltaic oversizing relative to the electrolyser capacity. This setup makes the most of the electrolyser usage during high-irradiance periods. At the same time, it was noted to control the excessive capital expenditure on the conversion equipment.

Optimised System Size

The optimisation picks out the PV, to electrolyser ratio of 1.6 which basically means deliberate majoring of solar capacity as shown in Table 3. This ratio thus represents a compromise between significantly increasing the electrolyser operating hours and a tolerable level of photovoltaic curtailment.

Table 3. Baseline optimised system configuration.

Component	Optimised value	Unit
Photovoltaic capacity	24.0	MW
Electrolyser capacity	15.0	MW
Hydrogen storage capacity	3,200	Kg
Compression capacity	160	kg/day
Project lifetime	25	Years

5.2. Hydrogen Production and Utilisation Outcomes

The yearly hydrogen output was noted to depend more on the number of operating hours of the electrolyser than on the availability of peak power. The base setting therefore allows the system to run continuously during the day throughout most of the year.

Table 4 indicates that hydrogen output comes from yearly electrolyser electricity use with a 52 kWh/kg conversion rate. This links rated capacity, operating time, load factor, and total annual hydrogen made. The formula keeps all energy inputs aligned. Every kilogram of hydrogen matches exactly to kWh used.

Table 4. Hydrogen production and utilisation indicators.

Indicator	Value	Unit
Annual hydrogen production	1,174	tonnes/year
Average electrolyser load factor	46.5	%
Electrolyser operating hours	4,070	hours/year
Average daily hydrogen output	3.2	tonnes/day
PV curtailment rate	14.2	%

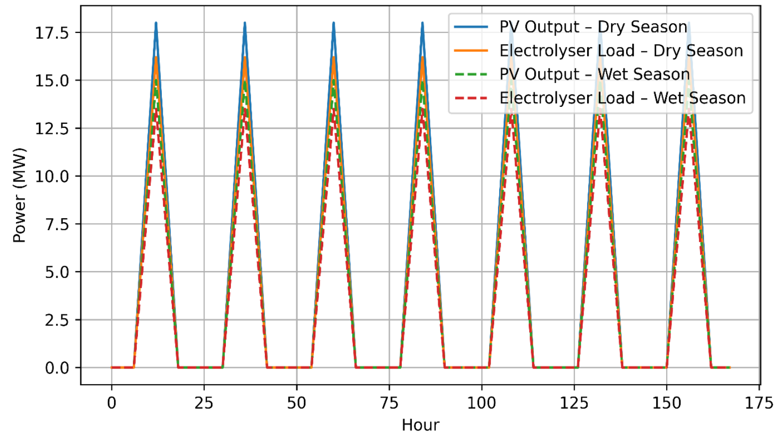

Figure 3. Hourly photovoltaic output and electrolyser load under dry and wet season conditions.

Figure 3 displays the hourly PV power output and corresponding electrolyser load for typical weeks in dry and wet seasons. The chart illustrates a close time agreement between solar generation and electrolyser operation during daylight hours. It can also be seen that peak solar output in the dry season is greater than the electrolyser capacity thus, locally the midday periods are reduced. On the other hand, the wet season can be noted to be showing the lower peak generation and less curtailment, with the electrolyser operation almost matching the available photovoltaic power.

5.3. Cost Structure and Levelized Cost of Hydrogen

The baseline system reveals a capital, intensive cost structure. The total lifecycle cost is mainly dominated by investment, related costs, whereas spending on operations is relatively small.

5.3.1. Levelized Cost of Hydrogen

Hydrogen production cost levelized over the project life (LCOH) in the baseline scenario is:

LCOH = 4.82 USD/kg.

5.3.2. Cost Breakdown

An investment in an electrolyser constitutes the largest part of the contribution to the cost of hydrogen, with the next biggest contributor being the capacity of the photovoltaic system. Data in Table 5 strongly suggests that the costs of storage and compression has the ability to facilite make up just over one-sixth of the total cost. This is indicative of the requirement to handle the issue of solar energy intermittency.

Figure 4 is a presentation of the composition of levelized cost of hydrogen (LCOH) from various major system components. Capital, related costs comprise most of total cost, with the largest part coming from the electrolyser investment, then the photovoltaic capacity. The hydrogen storage and compression are a significant cost component due to the need for intermittency management, whereas the operation and maintenance costs and water supply have very little shares.

Table 5. Cost contribution to baseline LCOH.

Cost component	Share of LCOH (%)
Electrolyser capital cost	38.4
Photovoltaic capital cost	27.1
Hydrogen storage and compression	16.3
Fixed O&M costs	9.2
Component replacement	5.6
Water supply and treatment	3.4
Total	**100**

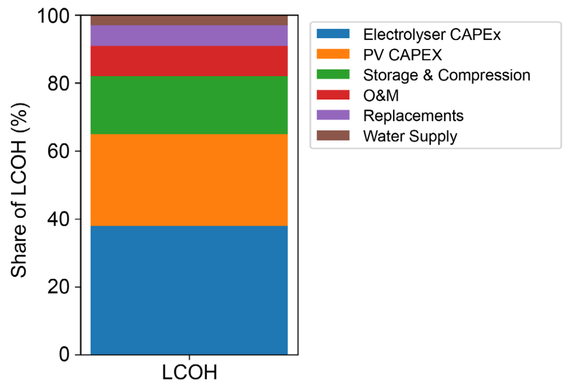

Figure 4. Cost Breakdown of the Levelized cost of Hydrogen (LCOH).

5.4. Scenario Analysis: Impact of PV and Electrolyser Costs

To check if the optimisation is strong, it is conducted again with alternative technology cost scenarios. Two aspects are changed separately which are the cost of photovoltaic capital and the cost of electrolyser capital.

5.4.1. Photovoltaic Cost Scenarios

Findings presented in Table 6 shows that reducing PV costs leads to more oversizing hence increasing the utilisation of the electrolyser and lowering the hydrogen cost. Increasing PV costs have the opposite effect *i.e.*, the optimal PV capacity decreases and LCOH increases.

Table 6. LCOH under alternative PV cost assumptions.

PV cost change	Optimised PV capacity (MW)	LCOH (USD/kg)
−20%	26.0	4.41
Baseline	24.0	4.82
+20%	21.5	5.23

5.4.2. Electrolyser Cost Scenarios

Variation in electrolyser cost results in a more significant reaction than variation in PV cost. Indications in Table 7 are that when the cost of the electrolyser is lower, it results in a larger optimal electrolyser capacity and less energy being wasted, whereas if the costs are higher, capacity expansion will be limited and hydrogen cost will increase significantly.

Table 7. LCOH under alternative electrolyser cost assumptions.

Electrolyser cost change	Optimised electrolyser capacity (MW)	LCOH (USD/kg)
−30%	16.8	3.97
Baseline	15.0	4.82
+30%	13.2	5.91

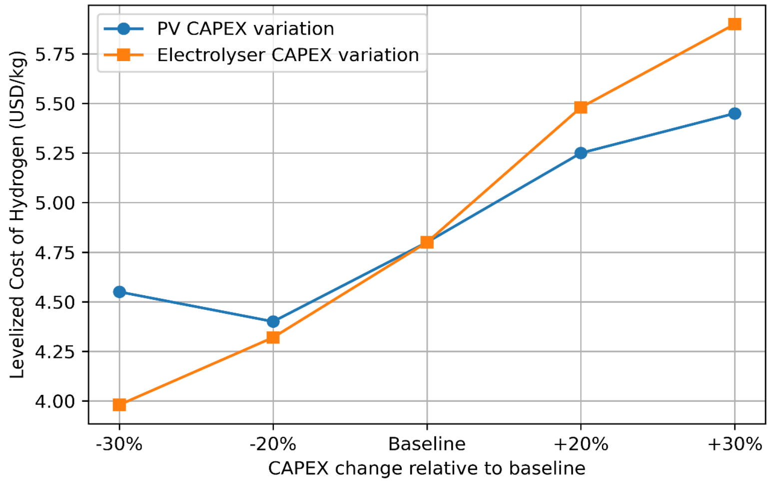

Figure 5. LCOH sensitivity to PV and electrolyser CAPEX variations.

It is illustrated in Figure 5 changes in the costs of a photovoltaic and an electrolyser affect the sensitivity of the levelized cost of hydrogen (LCOH). The figure suggests that overall less LCOH value will be lowered by the reduction of the two components; however, more change in LCOH will be caused on the side of the reduction in the electrolyser capital cost, which shows that it is the cost of the electrolyzer that has a higher cost elasticity relative to the photovoltaic investment.

5.5. Sensitivity Analysis

A one-at-a-time sensitivity analysis is conducted to identify the most influential parameters affecting hydrogen cost.

It can be noted that Figure 6 presents a tornado chart showing the sensitivity of the levelized cost of hydrogen (LCOH) to the main techno, economic parameters. Among all factors, financing conditions and electrolyser capital cost show the most significant impact on hydrogen cost. In contrast, photovoltaic performance, storage cost, and water supply assumptions exert relatively minor effects.

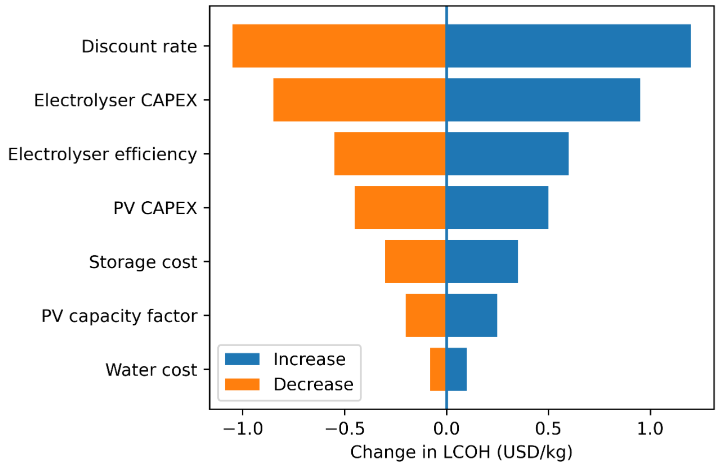

Figure 6. Tornado chart of LCOH sensitivity.

Ranked impact on LCOH: (1) Discount rate, (2) Electrolyser capital cost, (2) Electrolyser efficiency, (3) PV capital cost, (4) Hydrogen storage cost, (5) PV capacity factor and(6) Water cost.

Changes in financing conditions produce the widest variation in hydrogen cost, exceeding the impact of reasonable changes in technical performance parameters.

5.6. Summary of Key Results

The optimisation strongly suggested that the production of green hydrogen using solar energy in Burkina Faso is a cheap option mainly through system integration rather than merely expanding capacity. The baseline set-up indicates that a slight photovoltaic oversizing in comparison with the electrolyser capacity enhances the utilisation and reduces the cost of hydrogen even though it results in a small amount of reductions during the time of peak solar radiation. Investment in the electrolyser is identified as the primary factor contributing to the levelised cost of hydrogen. This is followed by the photovoltaic capacity and storage, related infrastructure thus, the typical capital, intensive nature of the system has been confirmed.

The scenario analysis clearly shows that decreases in the capital cost of the electrolyser lead to significantly larger cost savings than equally sized decreases in the cost of photovoltaics, whereas the sensitivity analysis discloses that financing conditions have the strongest overall impact on hydrogen economics. Therefore, these results demonstrate that in order to make green hydrogen costs in Burkina Faso competitive, there is need for a coordinated optimisation of technology sizing, cost structure as well as financial parameters rather than making isolated improvements in individual components.

6. Discussion of Findings

This section discusses the findings of the study with the help of the previous literature on green hydrogen techno, economics, renewable integration, and energy systems in the context of developing countries. The reintroduction of citations at this stage is purposeful to situate the findings in the wider academic and policy discussions.

6.1. Photovoltaic Oversizing, Utilisation, and Curtailment Trade-Offs

A major result of this study is that moderate photovoltaic (PV) oversizing with respect to electrolyser capacity helps reduce hydrogen cost by raising utilisation, thus, even if it produces significant curtailment. This finding is in line with literature arguments suggesting that utilisation, rather than installed capacity alone, is the main economic lever in renewable, powered electrolysis systems. [21] highlighted that low electrolyser load factors are one of the key reasons why green hydrogen is still expensive especially in systems that are based on variable renewables. These findings support this idea by demonstrating that it can be economically viable to accept the heat loss if that results in more productive operating hours.

Similar findings have been published in the optimisation studies of solar, hydrogen systems. [22] found that PV oversizing is often the best solution because the extra cost of additional solar capacity is more than compensated for by increased electrolyser utilisation. [23] in their work, likewise, maintained that energy matching, focused designs always underestimate costs by disregarding the economic value of higher utilisation. The results for Burkina Faso are coherent with this rationale, indicating that curtailment should be seen as a design decision rather than a system failure.

6.2. Dominance of Electrolyser Capital Cost in Hydrogen Economics

The findings are quite clear that the electrolyser capital cost is the biggest individual contributor to the levelized cost of hydrogen. This conclusion is well backed up by recent worldwide evaluations. [24] mentioned that investment in electrolyser still remains the most critical cost component of green hydrogen systems, especially in early, stage markets where manufacturing scale and learning effects are only just beginning to appear. The scenario analysis also illustrates that lowering the cost of electrolysers results in a much bigger drop in LCOH than a similar reduction in PV costs.

Studies based on empirical modelling also reveal similar sensitivities. [25] demonstrated that the elasticity of electrolyser capex frequently surpasses that of the cost of renewable electricity, particularly in off, grid or weak, grid situations. [26] also pointed out that while PV costs have plummeted, electrolyser systems are still undergoing slower cost reductions and facing greater uncertainty. The current results provide further support to this line of argument in the context of West Africa, indicating that the paths of electrolyser costs will determine the competitiveness of green hydrogen in Burkina Faso.

6.3. Financing Conditions as the Strongest System-Level Driver

Arguably the most significant finding is that financing conditions have the most powerful overall impact on hydrogen cost, even more than individual technical parameters. The sensitivity analysis indicates that changes in discount rate cause larger variations in LCOH than changes in PV performance, storage cost, or even electrolyser efficiency. This result is especially significant for developing countries.

[27] stated that the high cost of capital is the main constraint that characterizes renewable and hydrogen projects in Sub, Saharan Africa, and it often takes the upper hand over technological aspects. It can thus be noted that hydrogen cost estimates, in fact, assume financing conditions that do not reflect the realities of developing countries. The findings of this paper quantitatively verify those worries and show that even highly efficient technical system configurations can hardly withstand bad financing conditions.

This discovery corroborates the ideas in the literature that policy measures should be aimed more at investment de, risking than at providing technology subsidies only. [28] further argued that concessional finance, guarantees, and long, term offtake agreements may have a more profound effect on the hydrogen cost than marginal efficiency improvements. Financial architecture, for Burkina Faso, would be not only the most important factor alongside engineering optimisation but also the key to the solution.

6.4. Role of Storage and System Integration

Hydrogen storage and compression play a role though minor one in the overall cost breakdown of baseline results. Storage allows the solar variability to be smoothed over time as well as helping to get more use out of the electrolyser, but it results in extra capital cost.

[29] showed that the value of hydrogen storage depends on optimised sizing under renewable variability, seasonal mismatch, component degradation, and changing energy costs. The present results are consistent with this conclusion because storage capacity is optimised rather than fixed at its maximum.

Similarly, [30] developed an optimisation framework for sizing renewable-to-hydrogen configurations to minimise hydrogen cost. The present model follows this integrated approach by co-determining PV capacity, electrolyser capacity, and storage rather than treating them as separate design decisions.

7. Conclusions

The aim of this research was to assess the techno, economic feasibility of green hydrogen production via solar energy in Burkina Faso, a study that utilised an optimisation, based framework incorporating local resource conditions, technology performance, and financing constraints. It comes out from the findings, that the good solar resources in Burkina can technically enable a significant production of green hydrogen; however, the economic feasibility is largely a matter of system design and financing conditions rather that solely resource availability.

From the optimisation perspectives, oversized photovoltaic relative to the electrolyser capacity by moderate extent is economically considered the best option since it results in high utilisation of the electrolyser and consequently, lower cost of hydrogen, even though it may mean some level of energy curtailment. This is a confirmation of the literature arguments where it is stated that curtailment should not be considered as the inefficiency but rather as the cost, minimising result of systems driven by variable renewables. Usage or consumption rates play a major role in the determining of the hydrogen cost which is also the main focus of this study.

The capital cost of the electrolyser is the main technical cost factor which has a stronger effect on hydrogen cost than the photovoltaic investment. This discovery is consistent with the worldwide evaluation that points out that the scale of manufacturing of the electrolyser and the rates of working will mostly decide the green hydrogen's future competitiveness. While PV costs have already matured significantly, electrolyser systems remain in an earlier stage of cost reduction, making them a critical leverage point for cost decline.

Most significantly, the study shows that the condition of financing is by far the main factor affecting the whole hydrogen economics. Changing the discount rate results in bigger changes in hydrogen cost than most technical parameters. Besides that, a high cost of capital is a major limiting factor for clean energy investments in developing countries. Even highly optimized technical systems are still at risk from a negative financial environment.

The paper therefore corroborates that economically viable green hydrogen production in Burkina Faso is, in theory, doable, but dependent on system, wide optimization, precise cost cuts, and conducive financial scenarios.

8. Limitations and Directions for Future Research

Despite the study presenting strong techno, economic insights, it is also important to recognize some limitations. The research is centered on the production of hydrogen and therefore does not consider the costs of downstream transport and end, use, which could have an impact on competitiveness as a whole. Furthermore, subsequent studies may develop the model to encompass hybrid systems that mix solar power with different renewables or limited grid interaction.

It would be beneficial for the next research to investigate dynamic cost trajectories, demand uncertainty, and policy scenarios more extensively. As hydrogen markets are changing so quickly, flexible modelling techniques will surely be a great help for making decisions in the long run.

Conflicts of Interest

The authors declare no conflicts of interest.

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