

TOWARD AN INTEGRATED INVESTMENT MODEL FOR THE GREEN HYDROGEN VALUE CHAIN IN ALGERIA: A COMPARATIVE ASSESMENT WITH THE GERMEN EXPERIENCE

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Abstract

This study analyzes Algeria's green hydrogen value chain in comparison with Germany's advanced model, focusing on renewable electricity generation, electrolysis, storage, transport, and end-use applications. Algeria possesses exceptional solar resources enabling low-cost electricity (0.025–0.035 USD/kWh) and potential green hydrogen production costs of 4–6 USD/kg. However, challenges such as limited storage infrastructure, underdeveloped transport networks, nascent industrial demand, and incomplete regulatory frameworks constrain sector development. Germany, in contrast, combines higher renewable electricity costs (0.06–0.08 USD/kWh) with mature storage systems, extensive pipeline networks, diversified industrial end-use, and supportive policies, providing a benchmark for integrated hydrogen deployment. Comparative analysis highlights Algeria's strategic advantages and identifies critical gaps, informing the design of a comprehensive investment model.

This model emphasizes domestic and foreign investment, public-private partnerships, technology transfer, and regulatory development to enable a sustainable, export-oriented hydrogen industry. The findings contribute to understanding the interplay between natural resources, infrastructure, and policy in establishing a competitive green hydrogen sector, offering actionable guidance for transitioning from pilot projects to industrial-scale deployment.

Keywords: Green hydrogen; Value chain; Renewable electricity; Algeria; Germany; Investment model; Energy transition; Industrial development

1. Introduction

The global energy transition is accelerating, placing emissions reduction and carbon neutrality at the heart of national and international policies. In this context, green hydrogen has emerged as a pivotal solution for linking renewable electricity production to emission-intensive industrial and transport sectors, thereby granting it a strategic role in reshaping energy value chains (IEA, 2023) (IRENA, 2022). However, abundant energy resources alone are insufficient; building an integrated value chain covering production, electrolysis, storage, transport, and end-use is required to ensure economic viability and environmental sustainability.

This study highlights Algeria's position in the green hydrogen economy through a comparative analysis with the German model, which serves as a technical and institutional benchmark. The research aims to map Algeria's hydrogen value chain, analyze its readiness at each stage, derive practical lessons from the German experience, and propose an integrated investment model. This model connects Algeria's solar potential with financing mechanisms, technology transfer, and advanced technologies to activate a sustainable local and export market. The study addresses a current knowledge gap by analyzing the value chain from an investment and governance perspective, providing direct tools for policymakers and investors interested in developing the green hydrogen sector in Algeria (BMWK, 2023) (Enerdata, 2024).

1.1 Problem Statement

Despite Algeria's exceptional renewable energy potential, particularly its solar resources, the country has not yet developed an integrated and competitive green hydrogen value chain capable of supporting industrial diversification and sustainable economic growth. Current efforts remain fragmented across the stages of generation, electrolysis, storage, transport infrastructure, and industrial use, characterized by limited institutional coordination and weak alignment with international best practices. This situation hinders Algeria's ability to position itself as a strategic supplier in the emerging global hydrogen economy and to benefit from the high value-added stages of the chain.

1.2 Research Gap

The existing literature on green hydrogen in Algeria primarily focuses on technical or resource-based assessments, such as solar potential, electrolyzer costs, and export feasibility. Few studies adopt a value chain governance perspective or provide a comparative analysis with advanced economies like Germany.

Furthermore, there is a lack of analytical frameworks that integrate the institutional, regulatory, technological, and industrial dimensions of green hydrogen development in emerging markets. This gap limits the understanding of how Algeria can design coordinated policies to develop, localize, and manage the green hydrogen value chain sustainably.

1.3 Study Objectives

The study aims to:

1. Map and analyze the green hydrogen value chain across its main stages: generation, electrolysis, storage, transport, and end-use.
2. Compare Algeria's position with the German model as an example of integrated value chain development.
3. Identify the institutional, regulatory, and infrastructure gaps that affect the value chain's performance in Algeria.
4. Propose strategic pathways to enable an integrated, competitive, and sustainable green hydrogen value chain in Algeria.
5. Support policy formulation for industrial development, the energy transition, and sustainable economic diversification.

1.4 Scientific Contribution:

This study contributes to the literature by moving beyond resource-based assessments of green hydrogen in Algeria and proposing a value-chain-based investment model that integrates regulatory, financial, technological, and industrial dimensions. Unlike existing studies, the proposed framework translates structural gaps into targeted investment levers, offering a policy- and investor-oriented roadmap applicable to solar-rich emerging economies.

1.5 Research Questions

1. How is the green hydrogen value chain currently structured and governed in Algeria?
2. What lessons can be learned from the German experience in developing an integrated hydrogen value chain?
3. What institutional, infrastructural, and technological gaps hinder the performance of the value chain in Algeria?
4. How can Algeria develop and integrate the hydrogen chain to enhance industrial value creation and its competitiveness on the international stage?

1.6 Significance of the Study

This study makes an academic contribution by integrating value chain governance, sustainable development, and the energy transition into a unified analytical model for green hydrogen—a perspective that is largely absent in Algerian research.

From a practical standpoint, the study provides officials, policymakers, and investors with a structured framework for designing industrial strategies, enabling technology transfer, attracting investment, and building a long-term competitive advantage in the global hydrogen market. The findings directly support Algeria's national energy transition goals and its ambition to become a strategic actor in Euro-Mediterranean hydrogen corridors.

2. Theoretical Framework and Literature Review

2.1 Theoretical Framework

The analysis of the green hydrogen value chain and the proposed investment model are grounded in a set of theoretical frameworks that explain the dynamics of the energy transition, industrial capacity building, and economic value creation through clean technologies. The key theories are summarized below:

- **Value Chain Theory:** This framework explains how value is created through a series of interrelated activities, helping to analyze the stages of green hydrogen production and identify strengths and weaknesses within each stage. It supports the comparison between Algeria and Germany in terms of efficiency, integration, and institutional readiness (Porter, 1985).
- **Energy Transition Theory:** This literature emphasizes that the shift to a low-carbon economy requires the interaction of technological, policy, and market factors. It helps explain the differing paces of transition and levels of infrastructure investment between Algeria and Germany (IEA, 2023).
- **Sustainable Investment Theory:** This theory underscores the need for investments to align with environmental, social, and governance (ESG) criteria. It is directly relevant to the proposed investment model, focusing on creating an enabling regulatory environment and de-risking investments (EIB, 2024).
- **Technological Innovation & Diffusion Theory:** This theory explains the technology readiness gap between nations and highlights the critical role of technology transfer and international partnerships, such as Algerian-German cooperation (Fraunhofer, 2024).
- **Hydrogen Circular Economy Framework (EIB, 2024):** This framework aids in assessing the efficiency of resource use and carbon footprint reduction across the value chain, forming a basis for a sustainable investment model.

Proposed Conceptual Framework:

Building on these theories, the study's conceptual framework is structured across three interconnected levels:

- **Level 1 - Value Chain Elements:** Renewable production, Electrolysis, Storage & Transport, Industrial use.
- **Level 2 - Investment Determinants:** Legal framework, Financing, International partnerships, Infrastructure, Industrial demand.
- **Level 3 - Expected Outputs:** Emissions reduction, Increased export capacity, National value-added creation, Integration with the European market, Attraction of foreign investment.

This framework enables the construction of a sustainable investment model based on the linkages between the Value Chain, Investment Determinants, and Outputs.

2.2 Literature Review

Green hydrogen represents a central pillar of the global energy transition. Recent years have witnessed a significant expansion in research concerning value chains, international experiences, and investment models. Recent reports from international agencies such as IEA (2023) and IRENA (2024) indicate that the development of green hydrogen depends primarily on three interrelated elements: reducing the cost of renewable electricity, improving the performance of electrolysis technologies, and developing value chains that connect production to storage, transport, and end-use. These reports clarify that technical maturity alone is insufficient unless accompanied by regulatory and financial reforms that ensure investment attractiveness and market stability.

The literature has increasingly focused on international experiences, particularly Germany's, which has become a global model for value chain integration through its national strategy and the direction of investments exceeding €10 billion into infrastructure, technologies, and end-use industries (BMWK, 2024). German studies, such as those by Fraunhofer (2024) and Agora Energiewende (2023), confirm that significant industrial demand is the primary driver for cost reduction and achieving economies of scale.

Other studies, such as those by the World Bank (2023) and the EIB (2024), have addressed the factors influencing the readiness of emerging economies to invest in green hydrogen, including the availability of renewable resources, the potential for infrastructure development, and the attractiveness of the regulatory framework for international investors.

In the Maghreb and Algerian context specifically, reports by GIZ, Tractebel (2021), and CEREFÉ (2024) have provided preliminary assessments of green hydrogen production potential and the challenges associated with value chains, particularly concerning transport and storage infrastructure and the role of local industries in creating demand. However, studies that link the entire value chain to an integrated investment model in an emerging country like Algeria are almost non-existent, making this paper a novel scientific contribution that connects technical, institutional, and economic analysis within a comparative framework with the German experience.

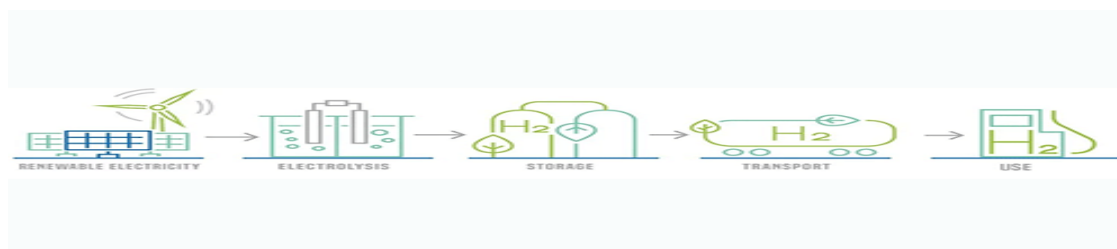
3. Literature Review

Contemporary literature treats green hydrogen as a pivotal element in the global energy transition. Studies relevant to this paper's value chain and investment model focus on four main areas:

3.1 Green Hydrogen Value Chain Studies

Reports by the Hydrogen Council (2024) and IEA (2023-2024) indicate that the value chain consists of four interconnected stages:

Figure 1: The Green Hydrogen Value Chain from Renewable Electricity to End



Source: Author's elaboration based on IEA (2019).

Production, Storage, Transport, and End-use. The integration of these stages is a prerequisite for making hydrogen economically competitive. These studies also emphasize the impact of the regulatory framework and government support on the success of each stage.

3.2 Comparative Country Studies

Studies by Fraunhofer (2024) and BMWK (2024) highlight German leadership in infrastructure and regulatory models, contrasting it with North African countries that possess high production potential but lack robust legal frameworks and technical expertise. These studies show that Algeria has strong initial endowments in solar energy and gas infrastructure but requires significant technological upgrades to export green hydrogen.

3.3 Economics and Investment in Green Hydrogen

Reports by ESMAP (2024) and the World Bank (2024) have analyzed investment costs and price scenarios (4-6 USD/kg in Algeria versus ~7.3 EUR/kg in Europe), emphasizing the importance of local industrial demand in improving economic feasibility. Literature on Important Projects of Common European Interest (IPCEI) and H2Global also indicates that investment in infrastructure represents the key turning point towards a sustainable investment model.

3.4 Industrial Applications and End-Use

Studies by CEREFÉ (2024) and the Hydrogen Council (2024) highlight that the industrial use of hydrogen, particularly in iron and steel and ammonia production, is the largest factor in creating added value. German literature indicates that diversifying end-uses, including heavy transport, power generation, and chemicals, is a primary driver for attracting investment.

3.5 Research Gaps

The analysis of the literature reveals two primary gaps that have not been addressed in depth by previous studies:

1. The absence of a systematic comparative study between Algeria and Germany across all stages of the value chain.
2. The absence of an applied investment model based on the value chain and tailored for countries with high solar potential.

4. Methodology

4.1 Type of Study

This article adopts a comparative analytical approach, combining an analysis of the green hydrogen value chain in Algeria with a comparison to the German model. The objective is to propose an integrated investment model capable of addressing structural and regulatory gaps in the Algerian context. The methodological foundation integrates qualitative analysis of policies and official documents with recent global literature on green hydrogen.

4.2 Data Collection Methodology

The study relies on document analysis of official sources, including reports from international agencies (IEA, IRENA, EIB, World Bank), Algerian national strategies (PNEREE 2023), German reports (BMWK, Fraunhofer, Hydrogen Council), and published papers in peer-reviewed journals. Data was classified according to four main value chain axes:

- Renewable electricity production
- Storage
- Transport and infrastructure

- End-use

4.3 Analysis Methodology

The study employs structural gap analysis to identify regulatory, technical, and financial gaps in the Algerian context, utilizing benchmarking to measure differences with the German experience. This methodological integration enabled the construction of an investment model that combines: investment attractiveness factors, financing mechanisms, risk mitigation strategies, and short-, medium-, and long-term performance indicators.

4.4 Study Limitations

The study focuses on qualitative analysis without incorporating precise financial models, given its strategic development nature. The results depend on the availability of recent data, with some limitations concerning data on Algerian projects still under development. The comparison is also limited to Germany as a global benchmark.

Germany was selected as a benchmark case due to its advanced hydrogen governance framework, mature infrastructure, and strong industrial demand, making it a relevant reference for assessing the transferability of value-chain-based investment models to emerging economies such as Algeria.

4.5 Research Ethics

The research adhered to the use of reliable, published, and open sources, with respect for intellectual property rights.

The goal of this methodological framework is not only to provide a descriptive analysis but to develop an applicable investment model suited to international market conditions and national needs, aligning with methodologies recommended in contemporary energy studies.

5. The Green Hydrogen Value Chain in Algeria in Light of the German Experience

The green hydrogen value chain refers to the integrated stages a sustainable energy carrier undergoes, from electricity production from renewable sources, through electrolysis, to storage and transport, and finally to domestic end-use or international export. This comprehensive view is essential for assessing the economic and technical potential of green hydrogen and for recognizing its role not as a standalone project, but as a strategic lever for investment, industrial development, and clean energy.

At the European level, this chain is a central focus of Germany's National Hydrogen Strategy. The German government has allocated €4.6 billion to support 23 projects covering all value chain stages (Enerdata, 2024). In Algeria, the country has adopted a national roadmap to

establish an integrated green hydrogen system encompassing production, storage, transport, and end-use or export, leveraging its vast natural resources and Germany's pioneering experience in this field (Fraunhofer, 2024).

5.1 Renewable Power Generation

Renewable electricity is the backbone of the green hydrogen value chain, accounting for over half of total production costs. Algeria's abundant solar resources, particularly in the south, allow for low-cost electricity generation (0.025–0.035 USD/kWh), whereas Germany compensates lower solar potential with a mature regulatory framework and a diversified renewable energy mix with higher costs (0.06–0.08 USD/kWh). Renewable electricity prices are a primary driver of green hydrogen production costs, as lower LCOE directly reduces the levelized cost of hydrogen; IRENA indicates that with sufficiently low renewable power costs (e.g., solar PV at around US \$20/MWh), green hydrogen production costs could fall below USD 2/kg over time, making it more competitive with other low-carbon pathways (IRENA, 2025) (Bank & ESMAP, 2024) (CEREFEE, 2024).

between southern production areas and northern industrial consumption zones, limited infrastructure for large-scale electrolysis projects, and the absence of an incentivizing regulatory system capable of mitigating long-term investment risks. The National Program for Renewable Energies and Energy Efficiency (PNEREE) is expected to increase renewable capacity to 22 GW by 2030, with a significant portion of solar capacity allocated to hydrogen projects, enhancing local production capacity and supporting the emergence of an integrated local industrial value chain (Mines, 2024) (Fraunhofer, 2024).

In contrast, Germany, despite its lower solar irradiation of 900–1,300 kWh/m² annually, has successfully built an advanced renewable energy system based on a mix of wind and solar power, supported by strong financial policies including feed-in tariffs and competitive auctions. The share of renewable electricity in Germany has risen to over 52% of national production, enabling the country to develop industrial electrolysis projects despite high initial costs (BMWK, 2023) (Fraunhofer, 2024).

The comparison between the two countries clearly shows that Algeria's advantage lies in low solar electricity costs, while Germany's strength is its regulatory and technological maturity. From an investment perspective, combining the strengths of both parties—cost, technology, and regulation—provides a foundation for a mutually beneficial partnership model. This would enable Algeria to transition from a mere supplier of raw energy to an industrial actor

capable of creating added value through the localization of electrolyzer component manufacturing and the development of hydrogen transport networks for export.

Table 1: Comparative Renewable Electricity Costs (LCOE)

Country / Context	Typical Renewable LCOE (USD/kWh)	Source
Algeria (solar-rich regions)	0.025 – 0.035	World Bank & ESMAP, 2024; CEREFÉ, 2024
Germany	0.06 – 0.08	IEA Renewable Energy Report, 2024; Agora Energiewende, 2025
Global Solar PV (benchmark)	~0.043	IRENA, 2025
Global Onshore Wind (benchmark)	~0.034	IRENA, 2025

Table 1 shows that Algeria benefits from significantly lower solar electricity costs compared to Germany, representing a strong competitive advantage for low-cost green hydrogen production. Germany, on the other hand, compensates for lower solar irradiation with a diversified renewable energy mix and a stable regulatory framework supporting industrial electrolysis projects. This directly links electricity costs to each country's competitiveness along the green hydrogen value chain and highlights Algeria's potential to leverage German experience in regulation and technology.

5.2 Storage

continuity, allowing surplus renewable generation to be retained and dispatched according to demand. Germany has committed significant resources toward large-scale hydrogen storage as part of its hydrogen infrastructure rollout under the IPCEI Hy2Infra initiative, which includes the development of hydrogen storage facilities with an aggregate capacity exceeding 370 GWh, contributing both seasonal and short-term balancing assets to the emerging European hydrogen network (Commission, 2024) (Enerdata, 2024).

Distributed projects such as Uniper's plans to develop up to 600 GWh of underground hydrogen storage by 2030 further underline Germany's strategic emphasis on scale and resilience in storage capacity (UniperSE, 2024) (Expo, 2024).

In contrast, Algeria's hydrogen storage infrastructure remains at an early stage of development, with potential geological storage capacities estimated in the range of 50–100 GWh but limited deployment of advanced technologies such as high-pressure tanks, liquid hydrogen, or LOHC systems (Mines, 2024) (CEREFÉ, 2024). While the country's subsurface geology offers promising conditions for future storage build-out, substantial investment and

technical transfer will be required to realize competitive storage capabilities that can support large-scale hydrogen production, industrial demand, and export logistics.

This quantitative disparity in storage readiness reflects broader capacity challenges: Germany's advanced storage projects position it to integrate hydrogen into energy and industrial systems with greater flexibility, while Algeria's storage potential remains largely untapped and a key target for future infrastructure investment.

Table2: Comparative Hydrogen Storage Capacity

Country	Estimated Storage Capacity (GWh)	Status & Notes	Sources
Germany	~370 GWh (IPCEI Hy2Infra baseline) Up to ~600 GWh planned by 2030	Large-scale hydrogen storage under IPCEI; pilot and commercial facilities	European Commission IPCEI (2024); Uniper (2024) (Competition Policy)
Algeria	50–100 GWh (potential)	Geological potential with early-stage infrastructure; advanced technology deployment limited	Ministry of Energy and Mines (2024); CEREFÉ (2024) (Enerdata)

Table 2 highlights that Germany has advanced storage projects allowing flexible integration of hydrogen into energy and industrial systems, whereas Algeria's storage potential remains largely untapped. Investing in storage infrastructure and technology transfer is critical for Algeria to support large-scale hydrogen production, industrial demand, and export logistics.

5.3 Transport and Infrastructure

The transport and infrastructure stage is a pivotal element in the green hydrogen value chain, enabling the delivery of hydrogen from production and storage sites to industrial users, heavy transport, and export facilities.

Germany has developed an advanced pipeline network of over 40,000 km, integrated with the European Hydrogen Backbone project, along with strategic ports such as Wilhelmshaven and Hamburg ready for hydrogen import/export. Advanced transport technologies, including liquefied hydrogen (LH₂) and Liquid Organic Hydrogen Carriers (LOHC), are actively deployed, supported by a robust regulatory framework based on ISO/TR 15916 and IEC standards (BMWK, 2024) (Europe, 2024).

In contrast, Algeria possesses a 32,000 km national gas pipeline network, with approximately 20–30% technically suitable for hydrogen transport after upgrades. Key ports, including Arzew and Skikda, provide export potential, but the country faces challenges such as lack of hydrogen-specific regulatory frameworks, limited experience with LH₂/LOHC

technologies, and port infrastructure not fully adapted for international safety standards (Fraunhofer, 2024) (Mines, 2024).

From an investment perspective, modernizing existing pipelines, developing port infrastructure, and transferring German technology offer Algeria the opportunity to create a regional hydrogen cluster. This stage is critical for linking production to industrial demand and export markets, ensuring cost-effective and safe transport while enabling the localization of industrial components such as pipeline materials, safety systems, and liquefaction units.

Table3: Comparative Hydrogen Transport Infrastructure

Country	Pipeline Length (km)	Port Readiness / Export Capacity	Advanced Transport Tech	Sources
Germany	40,000+	Wilhelmshaven, Hamburg fully equipped	LH ₂ , LOHC, regulatory ISO/IEC standards	BMWK, 2024; Hydrogen Europe, 2024
Algeria	32,000	Arzew, Skikda ports; limited readiness	LH ₂ /LOHC limited, requires tech transfer	Fraunhofer, 2024; Ministry of Energy and Mines, 2024

Table 3 illustrates that Germany has a mature transport network, enabling reliable hydrogen delivery to industrial users and export terminals. Algeria can leverage its existing gas pipelines and key ports but requires modernization and technology transfer to create a regional hydrogen cluster, linking production to industrial demand and export markets.

5.4 End-Use of Green Hydrogen

The end-use stage is the decisive pillar in the green hydrogen value chain, where production, storage, and transport converge into industrial, energy, and mobility applications. Germany has developed a diversified hydrogen consumption ecosystem, including industrial-scale green steel production, chemical plants powered by green hydrogen, and a growing network of hydrogen refueling stations for heavy-duty vehicles. Investments exceeding €10 billion between 2020 and 2024 under the IPCEI and H2Global programs have accelerated adoption, supported by a stable regulatory framework and long-term industrial planning (BMWK, 2024) (Fraunhofer, 2024).

In Algeria, industrial hydrogen demand is still nascent. Current applications rely primarily on grey hydrogen for fertilizers (e.g., ASMIDAL), methanol, and steel production. National estimates indicate a significant potential to shift toward green hydrogen, particularly in emission-intensive sectors and regions with abundant solar energy for hybrid electricity solutions (CEREFÉ, 2024).

Developing end-use infrastructure is critical for Algeria to create industrial demand, reduce emissions, attract investment, and enable integration with European export markets.

Table4: Comparative End-Use of Green Hydrogen

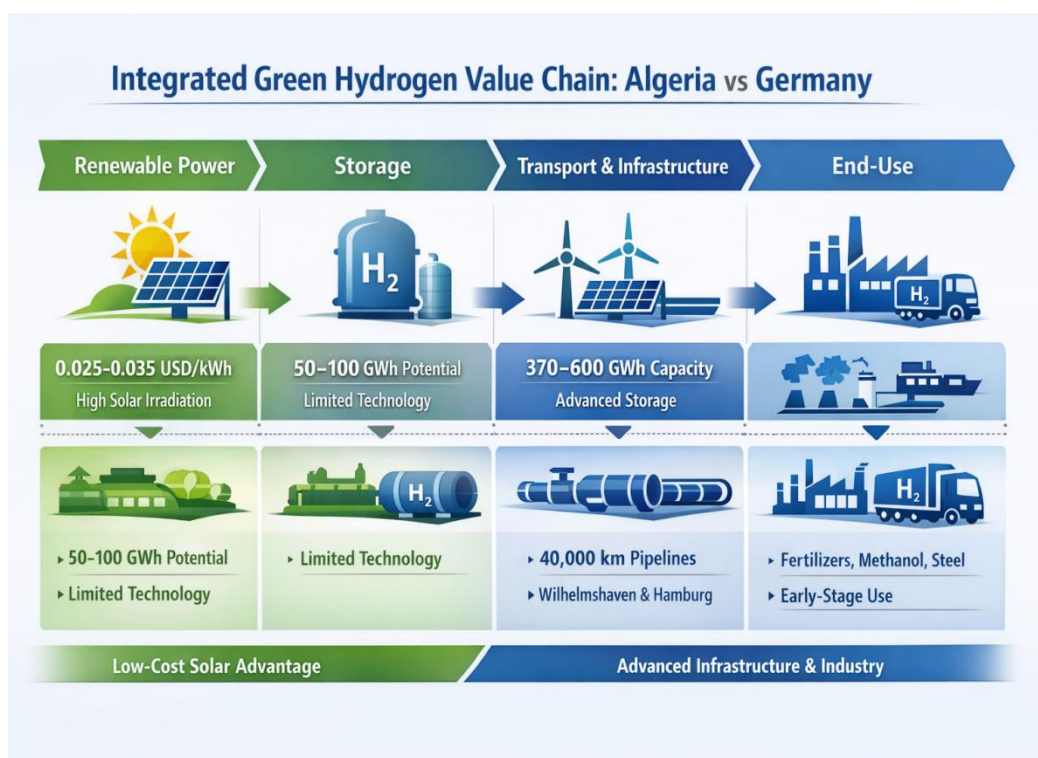
Country	Key End-Use Sectors	Industrial Scale & Readiness	Investments & Policy Support	Sources
Germany	Green steel, chemical plants, heavy transport, power & heating	Diversified, industrial-scale projects operational	>€10 B between 2020–2024; IPCEI, H2Global; regulatory stability	BMWK, 2024; Fraunhofer, 2024
Algeria	Fertilizers, methanol, steel (currently grey hydrogen)	Early-stage; green hydrogen adoption potential	PNEREE + planned industrial integration; nascent policies	CEREFÉ, 2024; ESMAP, 2024; Ministry of Energy and Mines, 2024

Table 4 shows Germany’s diversified green hydrogen consumption ecosystem, including industrial-scale applications and mobility infrastructure. Algeria’s industrial demand is still nascent, highlighting the need to develop end-use infrastructure to create domestic demand, reduce emissions, attract investment, and integrate with European export markets.

5.5 Comparative Complementarity along the Algerian–German Green Hydrogen Value Chain :

This study aims to provide a practical comparison between Algeria and Germany across the green hydrogen value chain stages. The forthcoming figure illustrates the differences and complementarities between the two countries at each stage, from renewable power generation to the final end-use of hydrogen, highlighting the main strengths of each nation.

Figure 2 : From Comparison to Complementarity: Algeria–Germany Integration across the Green Hydrogen Value Chain



Source: Adapted from Fraunhofer ISE (2024); BMWK (2024); Ministry of Energy and Mines, Algeria (2024).

6. The Integrated Investment Model for the Green Hydrogen Value Chain in Algeria

6.1 Structural Pillars of the Integrated Investment Model

Algerian national policies, notably the PNEREE 2023 program and laws supporting investment in renewable energies, demonstrate the country's intent to enhance low-carbon electricity production and link it to electrolysis for green hydrogen. The legislative framework also includes provisions for licensing industrial projects and incentives for international partnerships, alongside policies encouraging the localization of energy-intensive industries like fertilizers, methanol, and steel. However, significant gaps persist within the value chain (Bank & ESMAP, 2024).

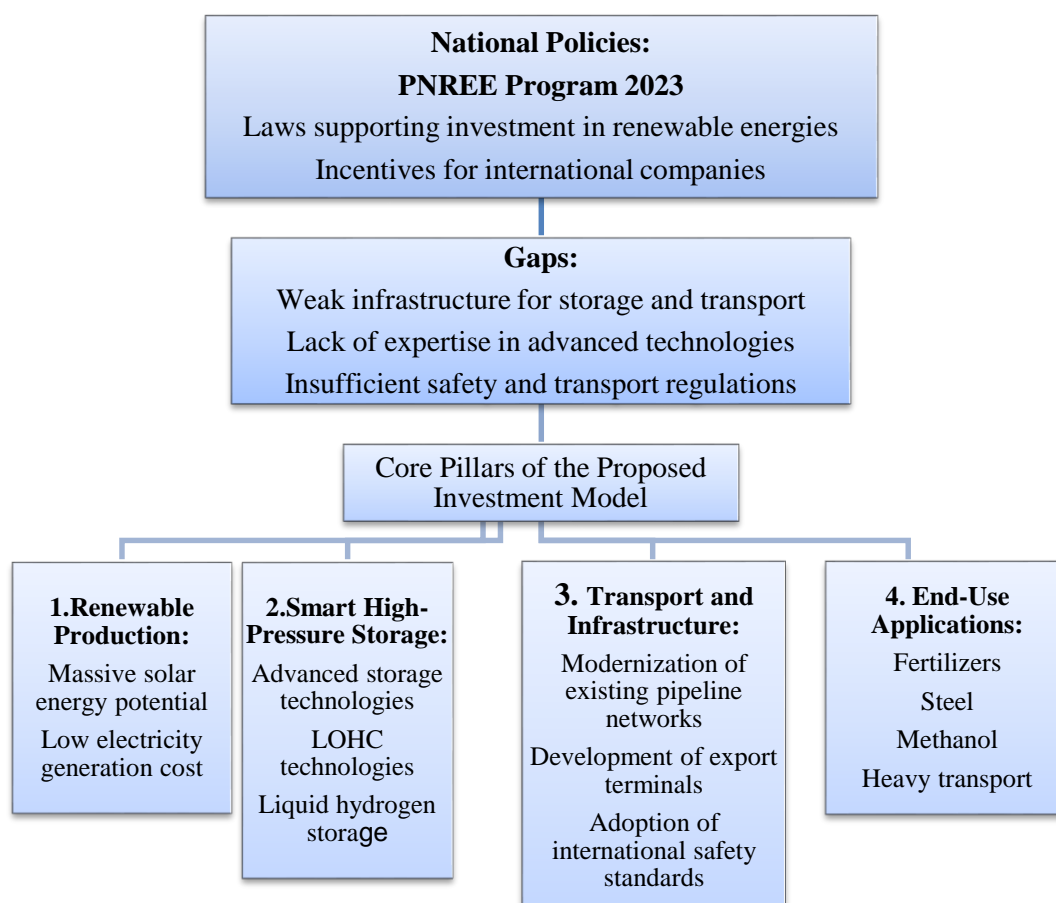
The proposed investment model is predicated on a detailed analysis of the value chain stages, where identified technical, regulatory, and financial gaps are translated into specific investment intervention areas. Gaps in electricity generation justify a focus on attracting foreign investment and technology transfer; storage and infrastructure needs support the establishment of Public-Private Partnerships (PPPs); market and manufacturing gaps necessitate local incentives to create industrial demand; and transport/export challenges require developing strategic infrastructure financed through multi-level mechanisms. Thus, the investment model

becomes a practical extension of the value chain, not a separate theoretical construct. It is founded on the following four structural pillars:

1. **Renewable Production:** Leveraging the immense solar energy potential in southern Algeria to supply low-cost electricity for electrolysis.
2. **Smart Storage:** Developing diverse storage technologies, including high-pressure, liquid storage, and LOHC, coupled with transferring German expertise and localizing these technologies.
3. **Transport and Infrastructure:** Modernizing existing pipeline networks, developing export terminals, and implementing international safety standards to ensure efficient connectivity between production, domestic consumption, and European exports.
4. **Industrial End-Use:** Supporting energy-intensive sectors with green hydrogen, including fertilizers, methanol, steel, and heavy transport, thereby enhancing national value addition and fostering industrial innovation.

This model seeks to bridge the regulatory and technical gaps between Algeria and Germany, drawing on German experience in managing investments, partnerships, and advanced technology. It also promotes synergy between national policies, natural capabilities, and investment opportunities, positioning Algeria to build a sustainable and scalable green hydrogen system capable of meeting domestic demand and penetrating European markets competitively. (IEA, 2023) (IRENA, 2022).

Figure 3. The Core Pillars of the Integrated Investment Model for the Green Hydrogen Value Chain



Source: Author's elaboration based on IEA (2023), IRENA (2024), PNREE (2023), and EIB (2024).

6.2 Presentation of the Proposed Integrated Investment Model

Transforming available resources and potential into an integrated green hydrogen value chain requires a clear investment model that addresses technical and regulatory gaps, defines investment priorities, and ensures sustainable financing and effective partnerships. This model is derived from an analysis of Algeria's green hydrogen value chain, a comparison with Germany, and international best practices (EIB, 2024) (IEA, 2023).

6.2.1 Addressing Structural and Regulatory Gaps

The analysis of Algeria's green hydrogen value chain reveals structural and regulatory gaps that hinder the sector's ability to attract investment and build international competitiveness. Addressing these gaps is a prerequisite for the success of any investment model and the feasibility of projects in the short to medium term. These gaps are as follows:

A. Regulatory Gaps: Algeria lacks a specialized legislative framework for hydrogen. Measures to address this include defining green hydrogen legally, streamlining licensing for production,

transport, and export, adopting ISO/IEC standards, and setting incentivized electricity tariffs for electrolysis (IEA, 2023).

B. Market Gaps: Weak domestic demand limits industrial uptake. Stimulating the market requires creating initial demand in fertilizers, methanol, iron & steel, and oil refining, alongside long-term off-take agreements with national and international partners (IRENA, 2024)

C. Infrastructure Gaps: Existing pipelines and ports are not fully prepared for hydrogen handling. Proposed solutions include upgrading convertible gas lines (20–30%), developing export terminals in Arzew and Skikda, and implementing advanced storage technologies such as high-pressure tanks and LOHC systems with German expertise (EIB, 2024).

D. Technology and Capacity Gaps: Local technical capabilities are limited in electrolysis, storage, and liquefaction. Strategies involve fostering university–industry partnerships, establishing R&D centers, and launching specialized vocational programs (IEA, 2023) (IRENA, 2024).

6.2.2 Strategic Axes of the Investment Model

The proposed model is built upon four interconnected strategic axes:

A. Attracting Foreign Direct Investment (FDI): Ensuring a stable, competitive environment with tax incentives, partial government guarantees, long-term off-take contracts, and dedicated industrial zones (EIB, 2024).

B. Enhancing National Investment: Leveraging Sonatrach and Sonelgaz for initial projects, supporting clean-tech startups, and building local manufacturing capacity for electrolyzers and storage systems (IEA, 2023).

C. Public–Private Partnerships (PPPs): Financing high-capital infrastructure projects, including large-scale electrolysis plants, hydrogen transport networks, and export terminals (IRENA, 2024).

D. Innovation, Research, and Development (R&D): Establishing a National Green Hydrogen Center, localizing advanced German technologies, supporting patents, and cost-reduction solutions (EIB, 2024).

6.2.3 Multi-Level Financing Mechanisms

Implementing the investment model requires adopting a hybrid financing system combining national, international, and private sources.

A. Sovereign Financing: Energy Transition Fund resources, government green bonds, and strategic projects (IEA, 2023).

B. International Financing: EU Global Gateway, H2Global, World Bank, EIB programs (EIB, 2024) (IRENA, 2024).

C. Private Financing: Green investment funds, venture capital, innovative instruments like Green Bonds and blended finance (IEA, 2023).

6.2.4 Key Performance Indicators (KPIs) for Measuring Progress

Performance indicators are essential for monitoring the implementation of the investment model and evaluating its effectiveness.

A. Short-Term (2025–2030): Number of implemented projects, total electrolyzer capacity, private sector contribution (IRENA, 2024).

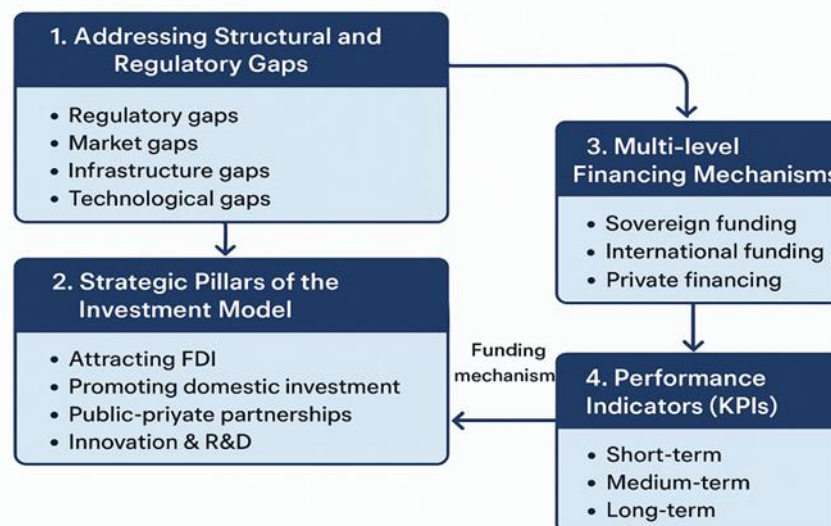
B. Medium-Term (2030–2040): Annual green hydrogen production, share of exports, industrial investments (IEA, 2023).

C. Long-Term (2040–2050): Emission reduction, sector GDP contribution, European market integration (IEA, 2024).

6.2.5 Risk Analysis and Mitigation Strategies

Green hydrogen projects face technical, financial, regulatory, market, and environmental risks. Mitigation includes gradual technology adoption, R&D partnerships, diversified funding, PPPs, legal stability, long-term purchase agreements, European off-take diversification, and sustainable water management (IEA, 2023) (EIB, 2024).

Figure 4: Integrated Investment Model for the Green Hydrogen Value Chain in Algeria



Source: Author's elaboration

Figure 4 presents the proposed Integrated Investment Model for the Green Hydrogen Value Chain in Algeria. The model, elaborated by the author, builds on an analysis of structural,

regulatory, market, infrastructure, and technological gaps, drawing on international best practices and lessons from Germany. It integrates four strategic axes—FDI attraction, national investment enhancement, PPPs, and R&D/innovation—supported by multi-level financing mechanisms and monitored through key performance indicators.

7. Discussion

resource potential and its current level of readiness to develop an integrated and competitive green hydrogen economy. While Algeria benefits from one of the lowest renewable electricity generation costs globally, the lack of a dedicated hydrogen regulatory framework significantly constrains large-scale investment and project bankability. Structural weaknesses remain evident, particularly in transport and storage infrastructure, safety and technical standards, and the absence of sufficient initial industrial demand capable of stimulating market formation. This imbalance reflects a gap between resource availability and economic absorption capacity along the value chain.

The comparative assessment with Germany demonstrates that the latter's competitive advantage does not stem from natural resource endowment, but rather from its ability to establish an integrated ecosystem combining legislation, financing instruments, infrastructure readiness, and strong industrial demand. The German case confirms that green hydrogen development is not driven solely by production capacity, but by the effective integration of all value chain stages, with industrial end-use representing the primary driver of investment attractiveness. Accordingly, Algeria's success in leveraging partnerships with Germany and the European Union depends on prioritizing domestic demand creation in strategic sectors such as fertilizers, iron and steel, methanol, and heavy transport.

Within this context, the proposed integrated investment model provides a coherent and operational framework for addressing the identified value chain gaps. By activating four interconnected axes—foreign direct investment, national investment mobilization, public-private partnerships, and innovation and research—the model links legislative, institutional, technical, and financial dimensions into a unified structure. Its added value lies in incorporating modern financing mechanisms, including green bonds, blended finance, and European support schemes such as H2Global, thereby enhancing project bankability and reducing investor risk.

Furthermore, the discussion highlights that Algeria's ability to develop a scalable and sustainable green hydrogen sector will depend on regulatory stability, timely infrastructure development, and effective management of environmental constraints, particularly water consumption associated with electrolysis. In light of Europe's decarbonization objectives for

the 2045–2050 horizon, the gradual integration of Algeria’s green hydrogen value chain could position the country as a strategic supplier and long-term partner within the European hydrogen market.

Beyond the Algerian case, the proposed investment model demonstrates a high degree of transferability to other solar-rich emerging economies seeking to enter the green hydrogen market. By systematically linking value chain stages with investment levers and risk mitigation mechanisms, the framework can be adapted to contexts in North Africa, the Middle East, and Sub-Saharan Africa, provided that national regulatory, institutional, and industrial specificities are appropriately integrated.

8. Conclusion and Recommendations

The findings of this study confirm that Algeria possesses significant structural advantages, including exceptional solar potential, a strategic geographic location, and an emerging industrial base, enabling it to become a future hub for green hydrogen in the Euro-Mediterranean region. However, the analysis reveals persistent gaps in regulation, infrastructure readiness, financing mechanisms, and technological capabilities.

By comparing Algeria's current trajectory with the German experience, the study demonstrates that the success of a hydrogen economy depends not only on natural resources but also on coherent governance, long-term policy stability, and integrated value chain planning.

Limitations and Future Research Directions:

Future research could extend this analysis by integrating quantitative financial modeling, scenario-based cost projections, and project-level feasibility assessments. Additionally, comparative analyses involving other European hydrogen import strategies could further refine the robustness of the proposed model.

The proposed investment model provides a structured roadmap that aligns national energy strategies with industrial development, international partnerships, and sustainable financing. If implemented gradually and supported by strong institutional coordination, Algeria can achieve competitive production costs, attract foreign investment, secure export markets, and develop a high-value industrial ecosystem based on green hydrogen.

Policy Recommendations:

1. **Establish a Dedicated Hydrogen Regulatory Framework:** Enact a national hydrogen law defining green hydrogen standards, licensing procedures, safety protocols, and tariff mechanisms for renewable electricity used in electrolysis.

2. **Activate Public-Private Partnerships (PPPs):** Leverage PPPs to finance large-scale electrolysis projects, transport pipelines, and export terminals, thereby alleviating the state's financial burden.
3. **Develop Industrial Demand Drivers:** Stimulate domestic demand by integrating green hydrogen into priority sectors such as fertilizers, methanol, steel, and heavy transport, fostering a stable local market before scaling exports.
4. **Accelerate Infrastructure Development:** Modernize existing gas pipelines for hydrogen transport, develop storage facilities, and construct pilot hydrogen corridors linking production areas with industrial clusters.
5. **Promote Research, Innovation, and Workforce Development:** Establish national R&D centers in collaboration with universities and international partners to localize electrolyzer technology, storage solutions, and safety protocols.
6. **Diversify Financing Mechanisms:** Mobilize sovereign fund resources, issue green bonds, and participate in global programs like Global Gateway, H2Global, and the EIB's Clean Hydrogen Facility to enhance project bankability.
7. **Ensure Environmental Sustainability:** Prioritize water-efficient electrolysis by integrating seawater desalination, recycling, and circular water use strategies to minimize environmental impact.

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