

Green Hydrogen Export Projects from Algeria to European countries - Opportunities and Challenges-

مشاريع تصدير الهيدروجين الأخضر من الجزائر إلى أوروبا
- الفرص والتحديات -

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Abstract:

Green hydrogen is emerging as a sustainable and reliable energy source driven by international technological advancements and geopolitical developments. The world, including European countries, are striving to neutralize carbon dioxide emissions from fossil fuel consumption, which encourages the use of renewable energy sources, with green hydrogen becoming a key component of European energy policy.

Using a descriptive approach based on official data on Algeria's overall renewable energy potential, we found that Algeria possesses significant natural and human resources that will enable it, could soon enable the country, through partnerships with major European companies, to produce and export green hydrogen to European countries via direct and secure connections. This will provide it with additional sources of income and establish it as a reliable energy partner.

Keywords: Green hydrogen; Renewable energy; Hydrogen strategies; Algeria; European countries.

ملخص:

يتجه الهيدروجين الأخضر نحو التحول إلى مصدر مستدام وموثوق للطاقة بسبب التطورات التكنولوجية والجيوسياسية الدولية، حيث يتجه العالم بما فيه الدول الأوروبية نحو تحييد انبعاثات ثاني أكسيد الكربون بسبب استهلاك الوقود الأحفوري، وبالتالي تشجيع مصادر الطاقة المتجددة، بما في ذلك الهيدروجين الأخضر. والذي أصبح الاعتماد عليه سياسة أوروبية ملحة. باستخدام المنهج الوصفي وبناء على المعطيات الرسمية حول إجمالي الامكانيات من مصادر الطاقة المتجددة التي تمتلكها الجزائر، وجدنا أن الجزائر لديها إمكانيات طبيعية وبشرية هائلة ستمكنها في المستقبل القريب، من خلال الشراكة مع كبرى الشركات الأوروبية، من إنتاج وتصدير الهيدروجين الأخضر إلى الدول الأوروبية عبر روابط مباشرة ومضمونة، مما سيوفر لها مصادر دخل إضافية والاعتراف بها كدولة طاقة موثوقة.

الكلمات المفتاحية: هيدروجين أخضر؛ طاقات متجددة؛ استراتيجيات الهيدروجين؛ الجزائر؛ الدول الأوروبية.

JEL codes : O13 ; Q42 ; Q48.

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1. Introduction:

Algeria depends almost entirely on fossil fuels to meet its domestic energy needs, and it also relies on them as a primary source of income through exports. Over the past decades, hydrocarbon exports have accounted for more than 83 percent of the country's total exports (worldbank, 2025). At the same time, domestic demand for energy in all its forms—natural gas, petroleum products, and electricity—is increasing significantly. The annual growth rate of final consumption exceeds 5 percent and reaches up to 8 percent in some years (Ministry of Energy). This requires decision-makers to invest more in expanding reserves, increasing production, and developing infrastructure for production, transportation, and distribution.

Algeria covers a vast area of more than 2.3 million km², with a varied geography: the north has a Mediterranean climate, the center a continental climate, and the deep south a hot desert climate. This diversity makes it rich in renewable resources such as hydropower, wind, and solar energy.

Like many countries, Algeria aims to achieve sustainable energy security by investing in renewable energy sources, particularly solar power, which offers significant advantages due to prolonged sunlight exposure and high temperatures, especially in the far south.

Given the environmental challenges facing the world today and the global trend to reduce carbon dioxide emissions—mainly from fossil fuels—while imposing restrictions on hydrocarbon production and consumption, Algeria is adopting a new energy policy. This policy focuses on increasing reliance on and development of renewable energies, particularly solar and wind power. The country also has strong potential to generate energy from green hydrogen, and several projects have already been registered in this field.

Although European countries still rely heavily on fossil fuels, they are gradually transitioning to renewable energy sources at varying rates. Green hydrogen—produced using renewable sources such as solar, wind, and water electrolysis—has emerged as a promising future energy source, particularly if produced at competitive costs. This presents an opportunity for Algeria to produce green hydrogen and export it to Europe.

▪ **Problematic:** This paper explores a key issue: Algeria's potential to exploit green hydrogen technologies as a future energy source. We seek to answer several questions, including:

In light of new global trends toward innovative energy sources, can Algeria maintain its energy position and enter the global race for green hydrogen?

Does it possess the necessary capabilities to become a viable producer and exporter of this renewable energy?

Are there existing studies and projects that can be developed and implemented in this area?

▪ **Hypothesis:** This research is based on a central hypothesis: Algeria is theoretically rich in renewable energy sources that could enable the production of green hydrogen. In addition, its existing physical infrastructure—such as gas transport pipelines connecting it to Europe—gives it a strategic advantage for engaging in green hydrogen production and export partnerships.

▪ **Work Plan:** To explore this issue, the research is structured into several components. First, we address the economics of hydrogen and the rationale for adopting green hydrogen as an energy source. Second, we examine the potential and opportunities for green hydrogen within the context of the global and European energy mix. Finally, we discuss Algeria's green hydrogen strategies and highlight relevant partnership projects currently under development.

2. The Green hydrogen economy:

In this section, we explore the concept of hydrogen and its various types, with a focus on green hydrogen—its definition, significance, and the rationale behind developing a green hydrogen economy.

2.1. Hydrogen economy:

2.1.1. Hydrogen as an energy carrier:

Hydrogen is considered a secondary source of energy, meaning it stores and transports energy produced from other sources such as fossil fuels, water, and biomass. It is a clean fuel that, when consumed in a fuel cell, emits only water as a byproduct. Hydrogen can be produced from a variety of domestic sources, including natural gas, nuclear power, biomass, and renewable energy like solar and wind. These characteristics make hydrogen an attractive fuel option for various applications, including transportation, residential heating, portable power, and electricity generation (NREL).

Hydrogen functions as an energy carrier that enables the storage, transportation, and delivery of energy derived from other sources. Currently, it is produced using several methods, with the most common being natural gas reforming (a thermal process) and electrolysis. Other methods include solar-driven and biological processes (U.S. Department of Energy).

2.1.2. Hydrogen economy: Our heavy reliance on fossil fuels has resulted in numerous negative consequences, such as oil spills, the ozone layer depletion, global warming, and climate change. Ensuring energy security and price stability has become a top political priority. These factors are driving the global transition from a fossil fuel-based economy to a cleaner hydrogen-based future—commonly referred to as the hydrogen economy. This concept was first proposed in the early 1970s at the General Motors Technical Center by John Bockris and during the Miami Hydrogen Meeting (Abe, Popoola, Ajenifuja, & Popoola, 2019).

Academic literature indicates a growing interest in the hydrogen economy, with many studies and roadmaps published on its technological, economic, environmental, political, and social dimensions. The term “hydrogen economy,” originally coined by Bockris, envisioned a system where hydrogen is produced via water electrolysis and distributed through pipelines to homes, factories, and fueling stations, where it would be reconverted into electricity via fuel cells (Bockris, 1972).

Hydrogen can be generated using a wide range of sources, including fossil fuels, nuclear power, biomass, and renewables, through multiple production processes. It can be combusted directly or act as an energy carrier. When produced from renewable sources, it becomes a clean alternative to fossil fuel combustion (WorldForum, 2021).

2.1.3. Hydrogen Types:

- **Black, brown and grey hydrogen:** Grey hydrogen is the most common form and is generated from natural gas, or methane, through a process called “steam reforming”.
- **Blue hydrogen:** Hydrogen is labelled blue whenever the carbon generated from steam reforming is captured and stored underground through industrial carbon capture and storage (CSS).
- **Turquoise hydrogen:** Turquoise hydrogen combines the use of natural gas as feedstock with no CO₂ production. Through the process of pyrolysis, the carbon in the methane becomes solid carbon black.

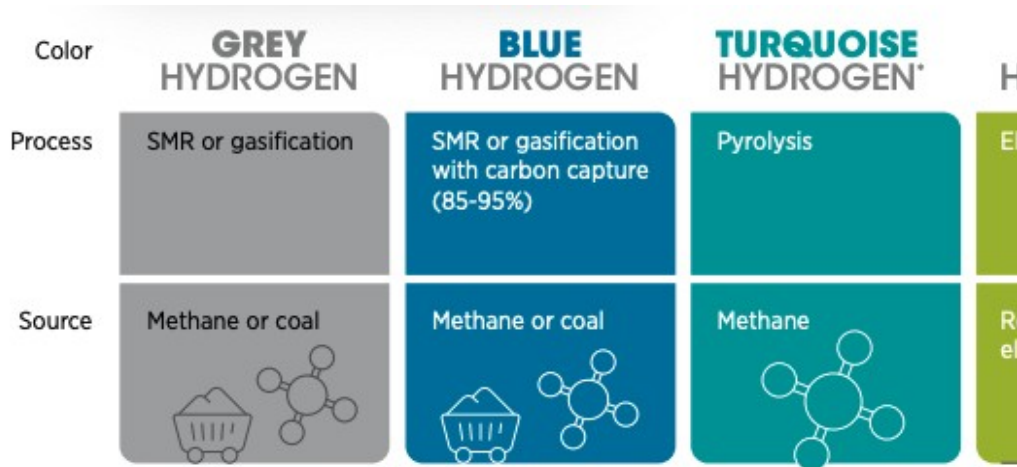
- Green hydrogen: Green hydrogen – also referred to as “clean hydrogen” – is produced by using clean energy from surplus renewable energy sources, such as solar or wind power, to split water into two hydrogen atoms and one oxygen atom through a process called electrolysis.

Renewables cannot always generate energy at all hours of the day and green.

hydrogen production could help use the excess generated during peak cycles. It currently makes up about 0.1% of overall hydrogen production, but this is expected to rise as the cost of renewable energy continues to fall.

Many sectors also now see green hydrogen as the best way of harmonizing the intermittency of renewables – storing excess energy at times of low demand to be fed back into the grid when demand rises – while decarbonizing the chemical, industrial and transportation sectors.

Fig. 1. Selected shades of hydrogen



Source: (IRENA, Green Hydrogen: A guide to policy making, 2020, p. 08)

According to the literature, hydrogen could meet up to 18% of global final energy demand, reduce CO₂ emissions by 6 Gt annually, and create 30 million jobs by 2050 (Uyar & Besikci, 2016). It is projected that hydrogen could power over 400 million cars, 15–20 million trucks, and approximately 5 million buses by 2050—comprising 20–25% of the global transport sector (Mostafaeipour et al., 2016). Hydrogen energy systems are also expected to become increasingly efficient (Nakamura et al., 2015). Scholars argue that hydrogen is a key enabler for sustainable growth and climate mitigation (Gonzalez et al., 2015).

Recent years have seen growing interest in hydrogen as a preferred energy carrier due to the following advantages (Angel et al., 2019):

- ✓ High energy conversion efficiency
- ✓ Versatile production sources
- ✓ Higher heating value compared to most fossil fuels
- ✓ Water is the only emission at the point of use (especially for green hydrogen)

Another key benefit is hydrogen’s potential to use existing natural gas infrastructure for distribution in residential areas (Gong et al., 2016). Studies suggest that hydrogen could meet about 10% of the global building heating demand by 2050 (Valente, Iribarren, & Dufour, 2018). In industrial applications that require medium to high-temperature heat, where electricity is inefficient, hydrogen presents a viable alternative (Maroufmashat et al., 2015).

Moreover, ongoing advances in hydrogen production technology are making the process more efficient, cost-effective, and less dependent on fossil fuels. Apart from serving as a sustainable energy carrier and heat source, hydrogen is a critical industrial raw material, especially in the production of methanol, ammonia, and steel (Acar & Dincer, 2014).

2.2. Green hydrogen as an alternative to fossil fuel:

2.2.1. Green Hydrogen:

Green hydrogen represents a promising alternative to fossil fuels. It is produced through the electrolysis of water, a process that uses electric current to split water molecules into hydrogen and oxygen. When powered entirely by renewable energy sources, this method results in zero greenhouse gas emissions (Al-Breiki & Bicer, 2020).

2.2.2. Hydrogen Production by Electrolysis.

Electrolysis is a carbon-free method of hydrogen production using renewable or nuclear energy sources. This process takes place in a device called an electrolyzer, which splits water (H_2O) into hydrogen (H_2) and oxygen (O_2) using electricity. Electrolyzers vary in size—from small, appliance-scale units for decentralized production to large, industrial-scale facilities connected directly to renewable power sources or other low-emission electricity supplies (U.S. Department of Energy).

Structurally, electrolyzers are similar to fuel cells, consisting of an anode, a cathode, and an electrolyte. Their function varies depending on the type of electrolyte material and the ionic species it transports. The three main types of electrolyzers include:

- Polymer Electrolyte Membrane (PEM) Electrolyzers
- Alkaline Electrolyzers
- Solid Oxide Electrolyzers

Hydrogen's high energy density, lightweight, and ability to be electrochemically converted make it an ideal energy carrier for long-distance transportation, whether through pipelines or in liquid form—such as ammonia—for global shipping (Al-Breiki & Bicer, 2020). It is also highly versatile: it can serve as a chemical feedstock, be burned for heat, act as a reagent in synthetic fuel production, or be reconverted to electricity via fuel cells. Its ability to store energy for long periods—either in tanks or underground caverns (Tarkowski, 2019)—makes it one of the few renewable technologies capable of seasonal energy storage (Oliveira, Beswick, & Yan, 2021).

According to recent data, global hydrogen demand continued to grow in 2023, reaching an all-time high of over 97 million tonnes (Mt)—a 2.5% increase from 2022. Demand has steadily increased over recent decades, with the exception of 2020, when the COVID-19 pandemic caused a temporary economic slowdown. Forecasts suggest that demand will reach nearly 100 Mt in 2024. The regional distribution of demand remained stable: China was the largest consumer, accounting for almost one-third of global use (approximately 28 Mt), more than twice the amount used by the second-largest consumer, the United States (13 Mt or 14% of global demand). Hydrogen consumption grew modestly across most regions, with notable exceptions such as the Middle East (over 6% year-on-year growth, driven by refining and methanol production) and India (over 5% growth, mainly in refining and the steel industry).

2.2.3. Why Green Hydrogen?

In 2023, global energy-related CO_2 emissions reached approximately 35.1 billion metric tonnes (BP, 2024). This continued growth trajectory threatens to raise Earth's temperature by several

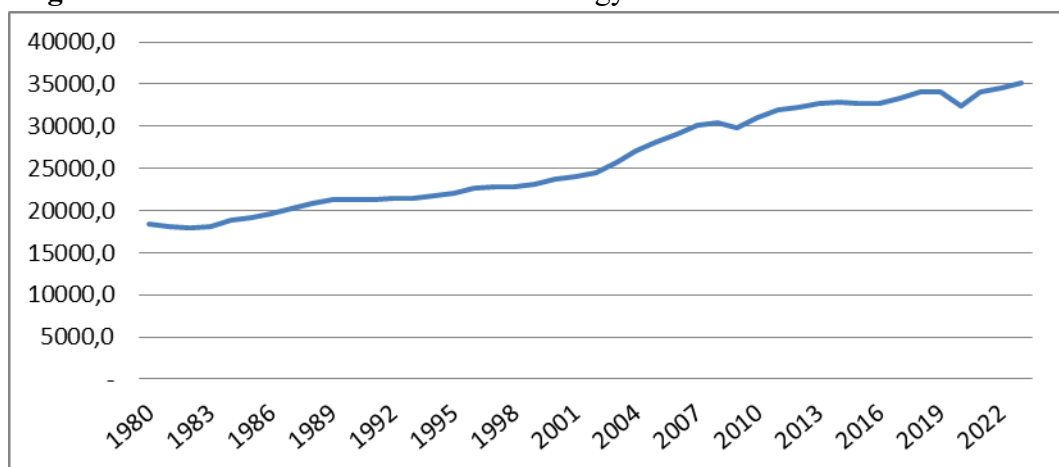
degrees in the absence of meaningful intervention. Reducing emissions in energy-related sectors remains particularly difficult due to the world's continued reliance on fossil fuels, especially in the electricity, transportation, industry, buildings, and heating sectors.

In response, many countries are implementing renewable energy technologies, enabling the electrification of various end-use processes with power generated from clean sources. However, the versatility of fossil fuels means that some sectors remain challenging to decarbonize through electricity alone.

Currently, around 120 million tonnes of hydrogen are produced annually. Approximately 96% of this volume is generated via fossil-based methods such as steam methane reforming (SMR) and coal gasification. Hydrogen is widely used in the chemical industry (e.g., for ammonia and methanol), oil refineries, steel production (as part of syngas), and energy generation. Of the total production, about 75 Mt/year is pure hydrogen, and an additional 45 Mt/year is produced as part of a mixed gas stream. Together, these represent around 3% of global final energy demand, equivalent to the annual energy consumption of Germany (IRENA, 2024).

Green hydrogen has the potential to become the sustainable energy carrier of the future. Unlike fossil-derived hydrogen, it is produced with minimal environmental impact and can be stored and transported over long distances. Green hydrogen can complement other energy carriers—such as electricity—to facilitate deep decarbonization of the energy system and the electrification of hard-to-abate sectors like transport, buildings, and industry (RaviKumar & Olczak, 2020).

Fig. 2. Carbon Dioxide Emissions from Energy Million tonnes of carbon dioxide



Source : Statistical Review of World Energy 2024 (BP, 2024)

This figure shows the significant development in the volume of carbon dioxide emissions, mainly emitted from the combustion of fossil fuels, as the volume of emissions increased from 18,373 million tons in 1980 to 35,129 million tons in 2023, at an average annual growth rate estimated at 19.45%, which is a large rate that reflects the development in the volume of fossil fuel consumption.

Three countries contribute mainly to these emissions: the United States of America, China and India, and the contribution of these countries in 2023 amounted to 13.2%, 31.9% and 08% respectively. These percentages are due to the size of the economic growth of these countries, which is accompanied by strong consumption of energy sources and fossil fuels in particular.

Table 1. Primary Energy: Consumption by fuel Exajoules

	2022							2023						
	Oil	Natural Gas	Coal	Nuclear energy	Hydro electric	Renewables	Total	Oil	Natural Gas	Coal	Nuclear energy	Hydro electric	Renewables	Total
US	35,75	31,67	9,91	7,31	2,36	8,42	95,42	35,86	31,91	8,20	7,32	2,21	8,78	94,28
China	29,51	13,60	87,83	3,76	12,18	13,37	160,26	32,73	14,57	91,94	3,90	11,46	16,13	170,74
India	10,10	2,10	20,03	0,42	1,64	2,09	36,37	10,57	2,25	21,98	0,43	1,39	2,38	39,02
Total World	191,62	144,31	161,53	24,13	40,58	45,18	607,35	196,43	144,37	164,03	24,57	39,651	50,58	619,63
of which: OECD	87,43	64,56	28,88	16,12	13,09	23,47	233,55	87,15	63,25	25,15	16,44	12,96	24,96	229,90
Non-OECD	104,19	79,75	132,65	8,01	27,49	21,71	373,80	109,29	81,11	138,88	8,13	26,69	25,62	389,73
European Union	21,88	12,38	6,89	5,49	2,57	8,64	57,85	21,45	11,50	5,48	5,56	3,05	9,35	56,38

Source : Statistical Review of World Energy 2024 (BP, 2024)

In 2023, fossil fuels (including oil, coal, natural gas and nuclear energy) contributed more than 85% of total primary energy consumption, which is almost the same percentage in all the major countries mentioned above, except for India, where the percentage exceeds 90%.

This confirms the significant impact of fossil fuels on carbon dioxide emissions, especially from large consuming countries.

2.2.4. Challenges Facing Green Hydrogen.

Despite its promising potential, the green hydrogen industry faces several technical, economic, and infrastructural challenges that must be addressed to ensure its large-scale deployment and sustainability:

- **High Production Costs :** Green hydrogen remains significantly more expensive to produce compared to conventional fossil fuels. Electrolysis technologies often rely on rare and costly catalysts—such as platinum—which elevate overall production costs. Consequently, there is a pressing need to develop more cost-effective and efficient water-splitting technologies and explore alternative catalysts to lower the economic barrier to widespread adoption.

- **Infrastructure Limitations :** The establishment of a comprehensive hydrogen economy requires an extensive and integrated infrastructure. This includes the construction of hydrogen production plants, storage systems, distribution pipelines, and refueling stations. Such infrastructure development demands substantial capital investment and coordinated efforts between the public and private sectors to ensure safety, scalability, and efficiency (Imam, 2023).

- **Storage and Transportation Challenges :** Hydrogen's physical properties present unique challenges in terms of safe storage and transportation. Its flammability, low density, and explosive potential necessitate advanced technologies for high-pressure or cryogenic storage, as well as secure and efficient transportation systems. Developing robust safety protocols and investing in innovative storage materials is essential to overcome these barriers.

- **Energy Carrier Limitations :** Hydrogen is not a primary energy source, but rather an energy carrier that must be produced from other sources such as renewable electricity or nuclear energy. In many cases, converting electricity to hydrogen and back into usable energy can involve energy losses, raising questions about overall efficiency. When feasible, direct electrification—for

example, through battery electric vehicles or grid-connected systems—remains a more efficient use of renewable energy.

- **Sector-Specific Applications :** Given current technological limitations and cost considerations, hydrogen is unlikely to replace fossil fuels across all sectors in the short term. However, it holds strong potential as a complementary fuel, especially in hard-to-abate sectors such as heavy industry, high-temperature processes, long-haul freight, and aviation. Its lightweight nature and high energy density make it particularly attractive for aerospace and maritime applications.

- **Technological Maturity and Innovation Needs :** Hydrogen technologies are still in the early stages of development and require further research and innovation to improve performance, reduce costs, and enhance sustainability. Key areas for technological advancement include:

- Improving the durability and efficiency of fuel cells and hydrogen converters.
- Developing novel materials and cost-effective catalysts.
- Enhancing storage systems and hydrogen delivery infrastructure.
- Establishing international safety standards and regulatory frameworks.

- **Competition with Other Low-Carbon Technologies :** For hydrogen to gain a competitive edge, it must become cost-competitive with other clean energy solutions, such as batteries, biofuels, synthetic fuels, nuclear power, and carbon capture technologies (e.g., CCS and CCU). Ensuring cost parity with these alternatives will be crucial for green hydrogen to gain traction in global energy markets (Al-Naimi, 2023).

2.2.5. The global hydrogen market and its development prospects:

Driven by strategic, economic, and environmental imperatives—particularly concerns over energy security and climate change mitigation—many countries have developed comprehensive roadmaps to decarbonize their economies and achieve carbon neutrality by 2050 or later. Within this framework, over 350 green hydrogen projects have been announced globally, spanning the entire value chain. These initiatives are supported by mature investment plans, including both public and private financing, with a total committed investment exceeding USD 80 billion.

The European Union, in particular, has positioned itself at the forefront of global hydrogen development through an ambitious strategy embedded in its Green Deal (also known as the Green Climate Pact). This strategy aims to bolster energy independence while simultaneously advancing climate goals by promoting carbon-free hydrogen technologies as a central pillar of the region's clean energy transition.

Significant progress has already been made in expanding global electrolyzer capacity for green hydrogen production. As of the end of 2021, installed electrolyzer capacity had doubled over five years, reaching approximately 500 megawatts (MW) worldwide (IEA, *Energy Technology Outlook*, 2023). Projections indicate that this deployment is set to accelerate significantly, with expected capacity reaching between 134 gigawatts (GW) and 240 GW by 2030.

Looking further ahead, all major energy scenario models anticipate a growing share of hydrogen in final energy consumption by 2050. This growth reflects not only technological advancements and decreasing costs but also the role of hydrogen as a versatile energy carrier in achieving deep decarbonization across sectors such as transport, industry, and power generation.

2.3. European Green Hydrogen Strategy.

This section outlines the European Union's strategic roadmap for the development and deployment of green hydrogen as a key enabler in achieving climate neutrality by 2050, based on the communication titled *A Hydrogen Strategy for a Climate-Neutral Europe* (European Union, 2020).

2.3.1. Towards a Hydrogen Ecosystem in Europe: A Roadmap to 2050.

Hydrogen can be produced through multiple pathways, each with varying levels of emissions, costs, and material requirements, depending on the energy sources and technologies employed. Currently, neither renewable hydrogen nor low-carbon hydrogen (such as fossil-based hydrogen with carbon capture) is cost-competitive compared to conventional fossil-based hydrogen.

- The cost of fossil-based hydrogen in the EU is approximately €1.5/kg, heavily dependent on natural gas prices and excluding the cost of CO₂ emissions.
- Fossil-based hydrogen with carbon capture and storage (CCS) costs about €2/kg.
- Renewable hydrogen production ranges between €2.5 and €5.5/kg.

Carbon pricing between €55 and €90 per tonne of CO₂ would be required to make low-carbon hydrogen competitive. However, the cost of electrolyzers has already decreased by 60% in the past decade, and is expected to halve again by 2030 due to economies of scale and technological improvements. In regions with low-cost renewable electricity, renewable hydrogen is projected to become cost-competitive by 2030.

2.3.2. A roadmap for the European Union.

The EU prioritizes the development of renewable hydrogen produced primarily from wind and solar energy, as it aligns best with the EU's long-term climate neutrality and zero-pollution objectives. This strategy builds on the EU's industrial leadership in electrolyzer production, while fostering job creation and economic growth.

The roadmap is structured into three key phases:

Phase 1: 2020–2024

- Install at least 6 GW of renewable hydrogen electrolyzers.
- Produce up to 1 million tonnes of renewable hydrogen.
- Focus on decarbonizing existing hydrogen production, particularly in chemical industries.
- Support the initial uptake in industrial applications and heavy-duty transport.
- Scale up electrolyzer manufacturing and connect them to local renewable energy sources.
- Deploy initial hydrogen refuelling stations for buses and trucks.
- Retrofit existing plants with CCS technologies.

Phase 2: 2025–2030

- Install at least 40 GW of renewable electrolyzers.
- Achieve production of up to 10 million tonnes of renewable hydrogen.
- Make hydrogen a key part of an integrated energy system.
- Expand applications to steel-making, rail, maritime transport, and seasonal energy storage.
- Improve flexibility and resilience of energy supply.

Phase 3: 2030–2050

- Achieve technological maturity for renewable hydrogen.

- Scale up deployment across all hard-to-decarbonize sectors (e.g., heavy industry, aviation).
- Increase renewable electricity production, as up to 25% of it may be dedicated to hydrogen production by 2050.

2.3.3. An Investment Agenda for the European Union.

To meet the 2024 and 2030 goals, a comprehensive investment agenda is required, involving synergies between EU funds, European Investment Bank (EIB) financing, and private capital.

Key investment estimates include:

- €24–42 billion for electrolyzer capacity by 2030.
- €220–340 billion to connect 80–120 GW of new solar and wind capacity to electrolyzers.
- €11 billion to retrofit half of the existing hydrogen production plants with CCS.
- €65 billion for hydrogen transport, distribution, storage, and refuelling infrastructure.
- €180–470 billion for hydrogen production capacity by 2050.
- Sector-specific adaptation costs include:
- €160–200 million to convert a single steel plant to hydrogen.
- €850–1000 million to deploy 400 additional small-scale hydrogen refuelling stations (up from the current 100). (european union, 2020)

3. Green hydrogen in Algeria:

To understand Algeria's energy landscape as a major exporter of oil and natural gas with a significant position on the global energy map, it is essential to examine trends in production and domestic demand. This analysis enables anticipation of future developments and the potential to sustain Algeria's current energy status, particularly in light of the global energy transition and the increasing shift towards clean energy. We will then explore Algeria's potential in the field of green hydrogen, along with current and future projects in this domain.

3.1. Drivers for Developing the Hydrogen Sector in Algeria:

Algeria possesses several comparative advantages that position it as a potential regional and global leader in the development of hydrogen, particularly green hydrogen. These include:

- Strategic Geographical Location and Abundant Renewable Energy Resources.

Algeria enjoys an exceptional solar energy potential due to its geographical location, with one of the highest solar irradiance levels globally. Vast land availability, particularly in the southern regions, provides ample space for large-scale solar power facilities.

The country experiences over 2,000 hours of sunshine annually across most of its territory, reaching up to 3,900 hours in the high plateaus and desert areas. Global Horizontal Irradiance (GHI) ranges from approximately 1,700 kWh/m²/year in the north to 2,263 kWh/m²/year in the south.

Additionally, Algeria possesses significant wind energy potential, which could contribute to reducing the cost of green hydrogen production.

Its proximity to Europe, extensive port infrastructure, and over 1,200 km of coastline offer strategic advantages for exporting hydrogen and its derivatives, strengthening Algeria's role as a future clean hydrogen hub in the Mediterranean. However, considerable efforts are needed to

upgrade and modernize existing infrastructure—or build new systems—to optimize operational efficiency and costs.

- *Robust and Expanding Power Grid.*

Algeria operates three main electricity networks:

- ▶ The Adrar-Ain Salah-Timimoun (PIAT) network
- ▶ The isolated deep-south networks (RIGS)
- ▶ The Northern Interconnected Network (RIN), a large-scale system covering much of the national territory, with cross-border connections.

The RIN spans 33,533 km and includes 387 substations with a transformation capacity of 69,898 MVA. Total distribution lines amount to 367,576 km.

- *Extensive Gas Pipeline Network with Cross-Border Links*

Algeria's national and international pipeline systems, operated by Sonatrach, include 22 networks spanning 20,705 km, transporting crude oil, condensates, natural gas, and LPG. In 2022:

- Total transport capacity: 406 MTOE
- Reserved capacity: 230 MTOE (57%)
- Available capacity: 175 MTOE

The system includes key export routes such as the MEDGAZ and Enrico Mattei pipelines. Additional export capacity could be developed through new pipeline infrastructure.

- *Abundant Water Resources*

Algeria possesses significant underground water reserves, such as the Alpine aquifer in the Sahara, with specific flow rates around 250 liters/second and relatively shallow reservoir depths (1,000–2,000 meters). Moreover, Algeria's desalination capacity is growing, currently reaching 2.1 million m³/day.

Treated wastewater from over 200 treatment plants, with a national treatment capacity exceeding 480 million m³/year (one-third used in agriculture), could also serve as a reliable water source for electrolysis. Prioritizing non-groundwater sources, such as treated wastewater and desalinated seawater, is recommended to preserve aquifers for future generations.

- *Active Research and Academic Ecosystem*

Algeria has a strong educational and research infrastructure with 109 higher education institutions, including 54 universities, 9 university centers, 11 national schools, and 35 graduate schools. Numerous research centers are dedicated to energy, agriculture, industry, and telecommunications, creating favorable conditions for innovation in hydrogen technologies.

- *Developing Industrial Base*

The national industrial base includes SMEs, family-owned enterprises, and startups. Algeria has long-standing experience in natural gas production, liquefaction, and gray hydrogen generation for Sonatrach's facilities.

International firms operating in Algeria, such as Linde Gas, Air Products, and Siemens, contribute their expertise in electrolyzer manufacturing and hydrogen supply.

An emerging value chain in renewable energy is also forming, including photovoltaic panel manufacturing plants (up to 500 MWh/year), cable production units, and structural metal fabrication facilities.

- Geostrategic Positioning

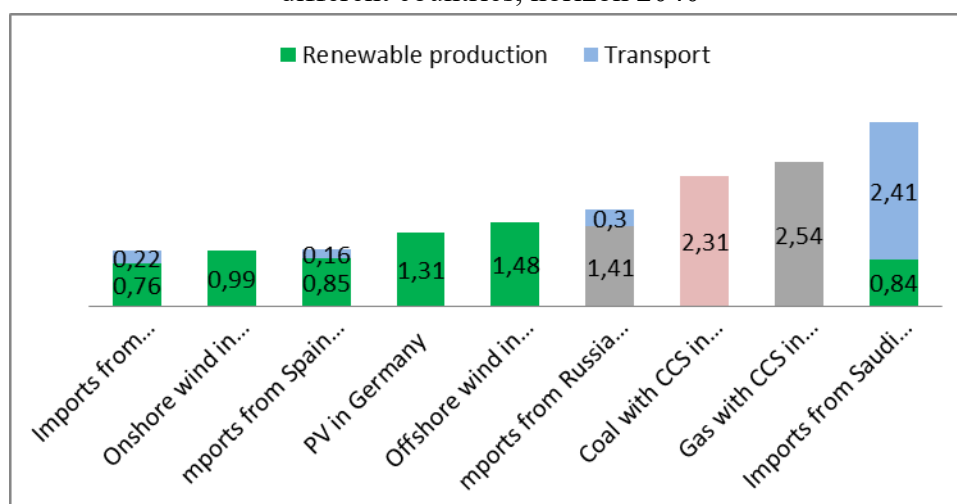
Algeria's reputation as a reliable energy supplier and its geographic proximity to Europe enable it to negotiate strategic partnerships for clean hydrogen exports. Multiple hydrogen production pathways are viable in Algeria, including:

- Steam Methane Reforming (SMR)
- SMR combined with Carbon Capture and Storage (CCS) or Carbon Capture, Utilization, and Storage (CCUS)
- Electrolysis using renewable energy
- Hybrid methods combining biomass, electrolysis, and SMR with CCS/CCUS
- Recovery of flare gases

- Competitive Hydrogen Production Costs

Algeria's unique assets—abundant renewable energy, geographic proximity to key markets, and existing infrastructure—enable it to produce and deliver green hydrogen at highly competitive costs, as illustrated in Figure 3

Fig. 3. Comparison of the cost of hydrogen delivered to Germany (production + transport) from different countries, horizon 2040



Source : Global Gas Report 2020, SNAM, IGU, BloombergNEF p65 (Bloomberg, 2020).

3.2. Green Hydrogen Production Prospects in Algeria :

Algeria aims to produce about 40 terawatt hours of energy using green hydrogen, by 2040. To this end, the authorities conducted an evaluation study of various hypotheses, including:

3.2.1. Assumptions : As for the assumptions related to the potential energy or the energy expected to be reached through the plans prepared by the relevant authorities, the volume of production, investment, and production sources can be summarized as follows:

a. Hydrogen production expectations :

Given the goal of achieving green hydrogen production with a capacity of 40 terawatt hours by 2040 and starting from 2030, the development will be gradual depending on the maturity of the technology and the penetration rate of renewable energy sources in the national energy mix.

Fig. 4. Hydrogen production development, prospects 2040

Source : National Strategy for the Development of Hydrogen in Algeria. (CEREFEE, 2023)

b. Green electricity production :

For the production of green hydrogen, only solar photovoltaic and wind power plants were considered to generate the necessary green electricity, allowing the production of more than (01) million tons of green hydrogen starting from 2040.

Furthermore, in accordance with the renewable energy development strategy, decided by the public authorities and given the complementary nature of the photovoltaic and wind energy load profiles, it was decided to use a calculation assumption for the production of green electricity with a ratio of 70% for solar photovoltaic and 30% for wind energy.

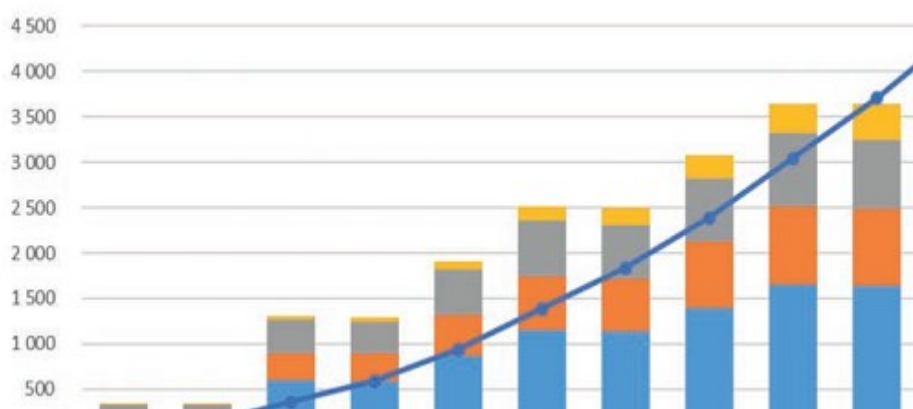
c. Electrolyzer capabilities :

As for the electrolysis technology chosen, only PEM electrolyzers were chosen for this evaluation, because among the technologies currently on the market that have proven their technological maturity, PEM electrolyzers are the most suitable due to their compatibility and adaptability to the intermittency of renewable energies. They offer better flexibility and higher efficiency, making it possible to achieve the lowest weighted average cost of hydrogen production (LCOH), although their current acquisition cost is considered high.

d. Investment amounts :

Investment levels are evolving and depend on the development of the market and electrolysis technologies. The expected investment volume for cumulative hydrogen production by 2040 (40 TWh), without taking into account the cost of storage (electricity and hydrogen), is estimated at 24.8 billion dollars.

Fig. 5. Evolution of investments for green hydrogen production, horizon 2040 (in millions of dollars).



Source : National Strategy for the Development of Hydrogen in Algeria. (CEREF, 2023)

3.2.2. Algeria's Strategy for Green Hydrogen Development:

Algeria's strategy to develop green hydrogen is fundamentally built upon its geographic proximity to European markets, the availability of adequate infrastructure such as pipelines, and its immense potential for generating renewable energy, particularly solar power (Independent Arabia, 2024). The country aspires to become a global hub for hydrogen production and export, with a strategic focus on the European market. According to the Algerian Ministry of Energy, expected revenues from the hydrogen sector could reach \$10 billion annually by 2040.

Estimates suggest that investment intentions in Algeria's green hydrogen sector range between \$25 and \$30 billion, with actual investment levels contingent on the evolution of international hydrogen markets, the development of local production capabilities, the acquisition of necessary technologies, and the creation of an investment-friendly environment. These factors are expected to be clarified through ongoing feasibility studies and partnerships with both domestic and international stakeholders interested in hydrogen importation.

Algeria's national roadmap for hydrogen development consists of three main phases:

- Start-up and Training Phase (2023–2030): Focused on acquiring technology, developing human capital, and conducting pilot projects.
- Expansion and Market Consolidation Phase (2030–2040): Emphasis on scaling production and establishing Algeria as a key market player.
- Manufacturing and Export Phase (2040–2050): Full-scale production and export, particularly targeting the European market (Asharq, 2023).

The Algerian government has designated hydrogen as a national strategic priority, aligning with its climate commitments and broader energy transition objectives. Policymakers believe that Algeria holds significant advantages enabling it to become a leading regional actor, especially given its solar energy potential and well-developed electricity and gas transmission infrastructure (Attaqa, 2024).

To advance its strategy, the Algerian government has initiated several key actions:

✓ Signed Memoranda of Understanding (MoUs) to conduct feasibility studies for the “SouthH₂ Corridor”, a hydrogen pipeline project that will connect Algeria to Europe via Tunisia, reaching Germany, Italy, and Austria.

✓ Partnership with Spain’s Cepsa to evaluate the technical and economic viability of a 200 MW green hydrogen production project, including potential exports to Spain using existing infrastructure.

Furthermore, Algeria aims to balance resource exploitation with environmental protection. Innovation is a cornerstone of its sustainable energy future, exemplified by its national renewable energy program, which targets 15,000 MW of solar energy capacity by 2035.

Algeria seeks to position itself as a regional energy hub through ambitious mega-projects, such as connecting the Southern and Northern electricity grids, with investments exceeding \$3 billion. Over the next five years, the country is expected to launch several large-scale hydrogen projects aimed at producing 1.2 million tons of green hydrogen, primarily for export. Approximately 300,000 tons will be allocated to the domestic market, particularly to decarbonize key sectors such as petrochemicals (Elkhabar, 2024).

a. The SouthH₂ Corridor: Linking Algeria to Europe :

On October 14, 2024, during the 12th Africa and Mediterranean Energy and Hydrogen Exhibition (NABEC 2024), Algeria signed a memorandum of understanding to initiate joint feasibility studies for the SouthH₂ Corridor, a strategic hydrogen transport route connecting Algeria to Germany via Italy and Austria. Partners include VNG (Germany), Snam and Corridor (Italy), and Verbund (Austria).

This MoU outlines plans to develop an integrated hydrogen value chain, aiming to transport approximately 4 million tons of green hydrogen annually from Algeria to European markets, using existing and/or new infrastructure. The corridor is of regional significance, representing a vital energy interconnection between Europe and Africa. The pipeline is expected to span 3,300 kilometers and provide up to 40% of the EU’s hydrogen import target, which seeks 10 million tons of imports annually by 2050 (Attaqa, 2024; OffshoreEnergy, 2024).

Algeria plans to produce and export between 30–40 billion kWh of hydrogen (equivalent to up to 1 million tons) in various forms, including gaseous, liquid, and derivative hydrogen. The corridor will also help decarbonize industries across Italy, Central Europe, and Germany (EHB, 2022).

Fig. 6. SouthH₂ Corridor.



Source : Offshore Energy, 2024 (OffshoreEnergy, 2024),

b. Algeria–Spain Green Hydrogen Partnership:

As part of its broader strategy, Algeria is working to strengthen its role as a key energy supplier to Europe, both in traditional fossil fuels and clean energy. Many European countries, including Spain, view North Africa as a strategic source for future green hydrogen imports. Enagas, the operator of Spain’s energy network, has expressed readiness to receive green hydrogen supplies from North Africa by 2030.

According to Deloitte, by 2050, North Africa could generate \$110 billion annually in green hydrogen exports, making it the world’s leading exporter, followed by North America (\$63 billion), Australia (\$39 billion), and the Middle East (\$20 billion) (Skynewsarabia, 2023).

On the same day as the SouthH₂ Corridor MoU, Sonatrach and Cepsa signed another agreement to conduct joint feasibility studies for an integrated green hydrogen and derivative production project in Algeria. The project entails:

- Construction of an electrolysis plant (50–200 MW) to produce green hydrogen.
- Establishment of wind and solar power facilities to supply renewable energy.
- Development of infrastructure to produce and store green methanol and green ammonia.
- Construction of storage and port facilities for transportation and export.
- Selection of an optimal site for project execution and commercial operation (APS, 2024; OffshoreEnergy, 2024).

4. Discussion:

In the 21st century, the world is increasingly moving toward carbon neutrality and the reduction of polluting emissions, driven by the growing threat of global warming and other environmental challenges. At the same time, the rising global demand for energy in all its forms has prompted nations to seek energy security and develop sustainable sources. Like other regions, European countries—whether acting collectively within the European Union or individually—are pursuing this objective by turning to various renewable energy sources, particularly green hydrogen.

Supplying green hydrogen at competitive economic prices requires Europe to source it from countries capable of sustainable and low-cost production—North African nations, and Algeria in particular, are well-positioned to meet this need.

According to available technical studies, Algeria can produce green hydrogen at an estimated cost of only \$0.98 per kilogram, one of the lowest production costs globally. The country is already

physically connected to Europe through natural gas pipelines, which, with modifications or through the construction of new pipelines, can be adapted to transport green hydrogen safely and efficiently.

As part of its transition toward renewable energy, Algeria has launched large-scale investment programs, funded both by the government and through partnerships with European companies. These investments are expected to total around \$25 billion by 2040. If implemented successfully, the strategy could yield over one million tons of green hydrogen during the same period.

Algeria holds significant potential due to its vast geographic area, favorable climate for both solar and wind energy generation, and strategic proximity to European markets. These advantages position the country as a promising large-scale producer of green hydrogen capable of meeting European demand.

Italy and Spain, being geographically closest to Algeria and already linked via existing gas infrastructure, are expected to remain key partners in this transition. This is reflected in both the eastern hydrogen corridor (linking Algeria to Italy, Germany, and Austria) and the western corridor toward Spain. By developing its hydrogen export capacity, Algeria aims to diversify its sources of national income. Currently, fossil fuels account for more than 95% of export volume and approximately 45% of GDP. Green hydrogen thus presents a strategic opportunity to replace fossil fuels as a primary export, especially in light of growing domestic energy demand, which could otherwise reduce exportable fuel volumes and revenues.

5. Conclusion:

This paper has highlighted the strategic importance of green hydrogen as a promising renewable energy source that can contribute not only to reducing carbon dioxide emissions but also to enhancing energy security and facilitating a smooth energy transition.

While green hydrogen is often referred to as the fuel of the future, its development still faces several challenges, including high production costs, limited transportation and storage infrastructure, and the need for continued investment in research and development.

Amid rising energy consumption in Europe and growing concerns over energy security—particularly in the wake of the Russian invasion of Ukraine and subsequent efforts by European countries to reduce reliance on Russian natural gas—green hydrogen has emerged as a viable and relatively affordable alternative energy source.

The European Union has adopted a phased strategy for green hydrogen development extending to 2050. The first phase involves the installation of at least 6 gigawatts of renewable hydrogen electrolyzers and the production of up to one million tons of renewable hydrogen. By 2030, the goal is to scale up to 40 gigawatts of electrolyzers and 10 million tons of production. The final phase, projected for 2050, envisions mature hydrogen technologies widely deployed across all sectors, including those that are traditionally hard to decarbonize.

Algeria, with its vast renewable energy potential—particularly in solar and wind power—and access to significant groundwater reserves, is well-positioned to become a competitive producer of green hydrogen. The cost of production in Algeria is among the lowest globally, making the European market a natural target for its hydrogen exports. Existing physical infrastructure, such as natural gas pipelines that can be repurposed for hydrogen transport, further strengthens this strategic alignment.

Moreover, the global shift toward clean energy may adversely affect Algeria's hydrocarbon export revenues, which currently form the backbone of its economy. This potential decline underscores the urgency of diversifying income sources. Joint green hydrogen projects with European partners therefore represent a mutually beneficial strategy that supports the energy transition objectives of both Algeria and Europe, while also offering Algeria a sustainable path toward long-term economic resilience.

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