

Green hydrogen governance to achieve sustainable development of the Algerian economy

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Abstract:

In order to foster sustainable growth and establish a cleaner environment, Algeria is vigorously pursuing the diversification of its energy sources. In order to transition the nation's economy from one that was dependent on fossil fuels to one that powered by renewable energy, a number of energy-related laws and initiatives implemented. In an effort to surmount these challenges, it is necessary to implement advanced technologies and reduce the emission of pollutants. Additionally, it is necessary progressively replace energy sources that are dependent on fossil fuels. Algeria is addressing its circumstance and the challenges it faces in regulating the exploitation of green hydrogen energy by the establishment of regulations to achieve this objective.

Keywords: Clean energy governance; green hydrogen; sustainable development

Jel Classification Codes : Q20 ; Q56 ;

Résumé:

Pour promouvoir une croissance durable et instaurer un environnement plus sain, l'Algérie s'engage activement dans la diversification de ses sources d'énergie. Pour opérer la transition de l'économie nationale d'une dépendance aux combustibles fossiles à une économie basée sur les énergies renouvelables, diverses lois et initiatives en matière énergétique ont été instaurées. Pour relever ces défis, il est impératif de déployer des technologies de pointe et de diminuer les émissions de polluants. De plus, il est impératif de substituer de manière progressive les sources d'énergie basées sur les combustibles fossiles. L'Algérie doit faire face à sa situation actuelle et aux défis qui se posent en matière de réglementation de l'exploitation de l'énergie verte de l'hydrogène, en mettant en place des réglementations visant à atteindre cet objectif.

Mots clés : Gouvernance des énergies propres ; hydrogène vert ; développement durable

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I. Introduction

Algeria's government is prioritizing the promotion of an environmentally sustainable economy that is powered by renewable energy sources, such as geothermal and solar energy, and that substitutes coal with hydrogen. In this model, hydrogen utilized as fuel to operate fuel cell engines that generate electricity through a hydroelectric process. This electricity then utilized to power buses and automobiles. Even though economic decisions based on market indicators, the market frequently neglects to account for environmental costs, which leads to decreased product and service prices. As an illustration, electricity produced by wind energy, which is one of the most environmentally friendly renewable sources, can contrasted with electricity produced by fossil fuel-based power plants, which are among the most polluting energy sources. As the search for fossil fuel alternatives continues, scientists have developed and explored new energy sources. The Center for Renewable Energy in the US has developed a device that can simultaneously separate hydrogen from water and convert it into electrical power, capturing over 12.5% of solar radiation. Algeria has prioritized strategies to investigate new energy sources.

Algeria's excitement for renewable hydrogen and its efficient deployment are our focus. Henry Cavendish discovered hydrogen in 1766 by reacting mercury with acids. Antoine Lavoisier named it "hydrogen," proving that water is hydrogen and oxygen. Early hydrogen uses included balloons. The solar atmosphere, volcanic gases, and Earth's atmosphere contain one part per million free hydrogen. It comprises 0.9% of Earth's crust. Hydrogen has the potential to be a clean energy carrier, especially in the Arab world's energy transition, however there are still many challenges. Hydrogen combustion does not emit carbon dioxide, making it essential to a carbon-free global economy. Algeria wants to restrict hydrogen energy use for a longer future.

II. Literature Review

II.1 first study (Delia , Brot , & the Heinrich, 2022)

The study stressed the importance of green hydrogen in the worldwide transition to fossil-free, climate-resilient, and environmentally Future-proof energy. Countries that can export hydrogen or its derivatives (such as green methanol and green ammonia) are expected to lead the green hydrogen movement, while those that can produce cheap renewable energy will affect production costs. These findings highlight the potential benefits of international green hydrogen commerce. Despite North-South trade and investment's poor history, the study suggests that past experiences can impact future outcomes. The urgent need for global decarbonization has great potential to boost economic

growth and wellbeing in both consuming and producing nations. An industry with multibillion-dollar potential is still young. This study establishes criteria and measures to ensure that green hydrogen production and commerce thrive, benefiting local communities, exporting nations, and importing nations while protecting environmental integrity, social equality, and human rights. Criteria and policies cover:

- Green hydrogen policy should ensure that producing nations benefit from value creation along the production and trade value chain, not only exporting raw hydrogen. Countries should explore ways to capitalize on external demand, incomes, and expenditures on renewable energy and hydrogen in domestic consumption. Trade and investment agreements should follow this.
- Hydrogen production must adhere to social and sustainability standards, including human rights and the "not harm" principle for the environment and local communities.
- For environmental benefits, avoid hydrogen leakage, optimize water use, and undertake sustainable desalination. Facilities should strategically placed based on socioeconomic and environmental evaluations, in partnership with residents. Green hydrogen facilities should avoid biodiversity hotspots.

Well-structured incentive programs can help green hydrogen scale to profitability. To guarantee the exclusive production and trading of green hydrogen, relevant policies must implemented, notably those that bridge the fossil-based and green hydrogen price gap. The recent rise in fossil fuel prices has reduced the price gap, making green hydrogen more viable. Eliminating fossil fuel subsidies, stabilizing carbon pricing, giving targeted payments, and public purchase of green hydrogen and its derivatives (like green steel) can help achieve this goal. Additional measures may include quotas, mixing requirements to stabilize demand, and aligning national policies and goals with frameworks and laws that reassure firms and investors.

II.2 second study (Cornelius, Valeria, & Louis, 2020)

This study shows that national governments, regional organizations, and private sector firms are furthering climate change, international trade, labor markets, and sustainable industries. Europe has developed a green recovery strategy to ensure sustainability and inclusivity in the wake of the global pandemic and its socio-economic effects. "Next Generation EU" is a novel recovery instrument designed to generate employment and integrate climate

initiatives. The European Green Deal is the fundamental component of the recovery package, guaranteeing that Europe attains climate neutrality as the inaugural climate-neutral continent by 2050. Green hydrogen is called the “missing link of the energy transition” because it can decarbonize and integrate sectors where CO₂ reduction or electrification is impossible. A green hydrogen economy can also help integrate more renewable energy (RE) into the energy grid, provide seasonal storage, and boost sustainable growth and local employment. MENA has some of the world's best solar and wind resources, enabling a high combined capacity factor for solar photovoltaic and wind energy, which is essential for low-cost green hydrogen generation. Europe and the MENA region may benefit from generating green hydrogen in the region, which will boost local industrial, social, and economic development and create many jobs. As Europe's goal of zero emissions by 2050 is enshrined in national legislation across all nations, prospective buyers are already lining up. The steel and heavy transport sectors are considering mass procurement of green molecules via market mechanisms in the medium to long term. MENA is changing as a potential dominant force from the vast and energy-rich desert. Recent tactics of prominent organizations like ACWA Power include "green molecules", NEOM, Siemens, and Maasen, alongside "green electrons," to expedite the transition to a low-carbon economy in the Arab world. Global efforts have proliferated, emphasizing regional market advancements. Green hydrogen has the potential to establish a robust market with local employment and companies associated with the energy transition, thereby enhancing and maintaining prosperity and stability in the region.

This study demonstrates that the MENA region has the potential to develop into a major hub for green hydrogen, primarily benefiting regional populations while simultaneously supplying global markets. The advantages substantially surpass the dangers. We assert that meticulous evaluation of environmental difficulties, including land and water utilization, and notably, the eco-friendly and emission-free characteristics of hydrogen, will facilitate favorable progress. The developing green molecules can be likened to the success of renewable energy in the past decade, potentially at an expedited pace.

The global oil and gas industry is confronting a significant dilemma. Nonetheless, the positive aspect is that green hydrogen will incentivize leadership within this domain. Morocco has advanced in establishing a green hydrogen economy, whilst Oman is starting to see its potential. Saudi Arabia/NEOM announced the world's largest green hydrogen/ammonia project in July 2020. Two The UAE has initiated a minor pilot experiment. Nevertheless, minimal progress has occurred in the majority of other Middle Eastern nations. Collaborations with Europe and other geopolitical entities like China will facilitate expedited development. Policymakers in the MENA area possess a distinct opportunity, as well as a responsibility, to act swiftly for the advantage of their economies by reducing the

costs of green hydrogen projects through the formulation of ambitious national action plans with explicit milestones. A universal standard for verifying the environmental sustainability of hydrogen must be established as a requirement, which is essential for fostering trust and successfully entering worldwide markets.

II.3 The third study (Michael , 2020)

The 2020 European Commission Hydrogen Strategy promotes “green” hydrogen imports from North Africa and Ukraine. After the Ukraine invasion, Repowers EU reports that the EU would buy 10 million tons of gas by 2030 to reduce its dependence on Russia. Recently, three North African countries have prioritized hydrogen due to EU and partner attention. Morocco, Algeria, and Egypt plan to export green hydrogen and hydrogen-derived products by sea and pipeline to meet EU demand. Exporting green hydrogen at competitive prices is unlikely due to high manufacturing and transportation costs. Intermittent renewable energy for electrolyzer operation may increase costs, but grid connections may increase expenses and CO₂e emissions, weakening EU green hydrogen criteria. Green hydrogen transport costs three times the energy to liquefy compared to natural gas, and an equal-capacity tanker would deliver 27%. Daily, 0.2% hydrogen volatilizes in transit. Pipelines carrying hydrogen destroy pipes and electronics. Hydrogen takes three times more energy due to its density, and pipeline transportation costs would produce fugitive emissions. Without storage and transportation, green hydrogen may have cost 11 times more per energy unit than natural gas before the winter energy crisis and Ukraine invasion. High shipping and infrastructure costs make hydrogen largely produced at the consumption location. Claims of vast, expensive export markets for green hydrogen and its synthetic fuel derivatives should concern North African governments and businesses. Egyptian and Algerian oil and gas corporations are considering hydrogen projects using renewable energy (“green”) and natural gas with carbon capture (“blue”). Blue hydrogen costs twice as much as gray hydrogen and releases lots of CO₂, especially when recovering oil..

All three nations had large fertilizer businesses and manufactured or imported grey ammonia, which may boost local use. Morocco, Algeria, and Egypt are evaluating EU initiatives to import hydrogen from North Africa; the objectives of these three nations include:

Morocco

- Morocco intends to substitute ammonia imports with its own green fertilizer production.
- Aside from reducing elevated ammonia emissions, there are alternative applications for green hydrogen that lack rigorous validation.

Algeria

- Algeria intends progressively transition its European Union exports from natural gas to green and blue hydrogen, attracting interest from European partners.
- Eni's green hydrogen solar initiative projected to incur costs 11 times greater per energy unit than natural gas, prior to distribution expenses.
- Eni is also considering blue hydrogen, which would be more than twice as expensive as grey hydrogen.

It would be five times more expensive than natural gas per unit of energy, with significant methane emissions.

Egypt

- Green hydrogen see as a key path to economic development, the European Bank for Reconstruction and Development is a helper, while Egypt is already providing financial support measures.
- Maersk has been involved in a project to develop a hydrogen-based shipping fuel to solve the problem of bunker fuel pollution but they face challenges: green methanol is toxic, and has half the energy density of bunker and fuel oil.

II.4 The fourth study (Diego, João , José , John F, & Zita , 2023)

Hydrogen is promise as a sustainable secondary energy source and feedstock for greenhouse gas reduction and economic decarbonization. Many countries aim to build a hydrogen economy including governmental and commercial sectors. The European Green Deal inspired national hydrogen policies. To analyze Portugal's energy transition status and possibilities, this study considers green hydrogen generation. The analysis includes power generation, hydrogen production, CO₂ emissions, and permitted prices. A comparison of Egypt's transport and power generation targets in Portugal yields comprehensive simulation estimates of green hydrogen production related to renewable generating in two categories. Portugal's renewable energy matrix facilitates green hydrogen generation and meets European 2030-2050 ambitions. The results show that converting buses and vehicles to H₂-based fuels reduces CO₂. However, H₂-fueled thermoelectric plants are better for energy security.

III. Governance of Green Hydrogen Exploitation in Algeria

III.1 Algeria's plan to transport green hydrogen

Algeria intends to progressively transition EU exports from natural gas to green and blue hydrogen through pipelines and LNG initiatives. The green hydrogen project utilizing solar power projected to incur costs of approximately

\$4.40 per unit of energy derived from natural gas. Blue hydrogen from carbon capture and storage releases methane and costs twice as much as grey hydrogen and five times as much as natural gas. Algeria planned to boost oil extraction with CO₂ capture. The cost of transporting hydrogen via a conduit has increased by threefold. Algeria may replace natural gas and generate 27% of its electricity from renewable sources by 2030 with a \$7 billion investment. Algeria plans to add green and blue hydrogen to pipeline and LNG transport natural gas to Europe. Oil and gas multinational from Italy

Eni has large assets in Algeria and many hydrogen manufacturing memoranda of understanding with Sonatrach. The local energy transition plan calls for generating 25 megawatts of power from green and blue hydrogen by 2050. One megawatt of solar power would supply 0.2% of Algeria's 2018 natural gas exports. Algeria requires 500 gigawatts of solar power to convert 52 billion cubic meters to green hydrogen, 1,000 times its capacity. The vehicle is solar energy. (Observatory, 2020), but Algeria is exploring this energy through an announcement on the green hydrogen plan on Monday, April 19 in Algiers by the Minister of Energy Transition and Renewable Energies and the Minister of Higher Education and Scientific Research. In particular, the German partnership could support Algeria in developing the solar energy plan and in the production of green hydrogen. In another chapter, the national oil and gas company Sonatrach signed a memorandum of understanding with the Italian company ENI on hydrogen production, to intensify their efforts to reduce carbon emissions. Its efforts to respect the sustainable development goals and work to implement the National Climate Plan (PNC) allow Algeria to sort out the gradual dependence on hydrocarbons and ensure a healthy and sustainable environment while reducing gas emissions. The impact of (GES) provided by providing permanent technological solutions. To resume the energy transition, the Algerian government is looking to the green energy dynamic by launching an adaptive program for cre production of green ation of green energy energies with a capacity of 15,000 megawatts in the ice in 2035, in addition to putting the production of green hydrogen in reverse. The export, thanks to the great potential in renewable energies (solar and éolien notamment), linked to the regional situation and its expertise in seawater desalination technologies, the Algerian government is participating in the development of the seawater file "big-profile hydrogen." The national hydrogen strategy for Mars 2023 has published, in addition to several ongoing plans. (GIZ, 2023)

III.2 Dimensions of Exploiting Green Hydrogen in Algeria

Green hydrogen exploitation governance in Algeria has environmental, economic, and social sustainability implications. These dimensions require care.

Making sure green hydrogen helps the energy transition and economic diversification. Algeria might diversify its fossil fuel-dependent economy with green hydrogen generation. Main economic governance aspects are:

A-Economic dimensions of hydrogen: Renewable energies, notwithstanding their intermittent nature, have limitations, especially in meeting energy demand. Therefore, they must be stored in a high-density power source that allows long-term storage and long-distance transit with minimum loss. The future energy economy will use hydropower, wind, solar, and geothermal energy. Hydrogen is a highly efficient fuel that can store energy and generate electricity in power systems. (Observatory, 2020)

-Energy transition and export opportunities: Algeria can lead the area in green hydrogen production due to its renewable energy potential. This would boost economic growth by expanding export markets to Europe and beyond. A well-managed green hydrogen sector can create jobs in construction, renewable energy, hydrogen generation, and related services. Governance should provide local worker training and skills development.

- Investment attraction: Algeria will need major domestic and foreign investment to build green hydrogen production and transportation infrastructure. Governance measures should promote investment by providing clear legal frameworks, transparency, and green project incentives.

B. Environmental dimension: The generation of green hydrogen depends on renewable energy sources, such as solar and wind, to facilitate electrolysis, which separates water into hydrogen and oxygen, resulting in negligible greenhouse gas emissions. Essential elements of the environmental dimension in the administration of green hydrogen in Algeria are:

- Sustainable energy sources production capacity: Algeria possesses significant potential for solar and wind energy because to its extensive desert regions. Effective governance should prioritize the development of infrastructure for renewable energy to optimize its potential, essential for green hydrogen production.

- Water management: Significant water resources needed for electrolysis. Algeria, which is mostly dry, must carefully balance its water use to prevent making its water scarcity issues worse. In order, sustainably supply the required water, effective governance would promote the use of desalination plants driven by renewable energy.

- Land use and ecosystem protection: Biomes and ecological systems can be impacted by large-scale renewable sustainable energy projects, such as solar energy projects and solar-powered projects like Sun fields. Environmental

evaluations should be a part of green hydrogen governance to guarantee that local ecosystems are not negatively impacted.

- Global climate change and its effects: Green hydrogen is crucial to Algeria's climate mitigation efforts. It agreed to reduce carbon emissions under the Paris Agreement. Green hydrogen may reduce emissions from heavy industries and transport, which are challenging to decarbonize using electricity.

C. Social dimension: Green hydrogen development needs to take community involvement and social fairness into consideration in order to be sustainable. Important governance factors consist of:

- Inclusive development: Inclusive development: Algerians should share fairly in the economic advantages of green hydrogen, such as increased employment and easier access to energy. Rural and impoverished communities should receive special consideration as they stand to gain from better infrastructure and energy availability.

- Public engagement and awareness: Public consultation procedures and transparency should be guaranteed by governance structures so that local populations are aware of the potential advantages and impacts of green hydrogen initiatives. Joining these groups in civil society can increase support and acceptability from the public.

- Energy security and affordability: Green hydrogen has the potential to improve Algeria's domestic energy security by reducing the country's reliance on imported technologies in the energy sector. It is imperative to guarantee that the energy generated is affordable for all segments of society in order to achieve a more comprehensive level of social sustainability.

D. Institutional and governance frameworks: Sustainability principles should be integrated into all phases of policymaking, from planning to implementation, in Algeria's governance framework for green hydrogen. The primary institutional dimensions are as follows:

- Regulatory frameworks: Algeria will require all-encompassing regulations that precisely outline the guidelines for green hydrogen investment and production, environmental requirements, and export plans. Creating task groups or entities specifically for green hydrogen governance would facilitate the simplification of initiatives.

- International cooperation: Algeria can profit from relationships with international parties, such as the EU, which wants to employ hydrogen for green energy. Working with global corporations can provide technical expertise and money. Research and innovation: Schools, colleges, study centers, and private

enterprises must collaborate to develop local green hydrogen expertise and technology. Governance should promote innovation to boost production and cut costs.

Table 01: Environmental benefits of hydrogen in Algeria

		2021	2025	2030	2035	2040	2045	2045
Natural gas consumption	(10 ⁶ GJth)	788	819	874	874	874	874	874
Conversion rate	%	0%	0%	5%	5%	5%	5%	5%
Consumption to replaced by H2	(10 ⁶ GJth)	0	0	44	44	44	44	44
Amount of H2 required	(ktpa)	0	0	364	364	364	364	364

source : (Mirakyan, 2021)

Table 01 shows that most current natural gas turbines can handle a hydrogen share of 3-5% and some can handle 30% or more. If an increasing percentage (shown in Table 02) of natural gas consumption can be replaced by hydrogen from 2030, this amount of hydrogen will be necessary. The previous table shows an estimate of the amount of hydrogen to replace part of the natural gas consumption in Algerian power plants. If these shares of the energy inputs actually required be replaced by hydrogen, it is possible to save 2,500 million tons per year of carbon dioxide emissions in 2030 to 24,900 million tons per year in 2050. Algeria can also save the equivalent of its natural gas consumption for 10 years based on the current national gas consumption for electricity production.

III.3 Legal framework for the new energy strategy:

The legal framework for investment in the hydrocarbon sector created a favorable environment for foreign direct investment. The hydrocarbon law, enacted on August 19, 1986, served as the legislative framework until it was amended in 1991, introducing more flexible provisions regarding relations with foreign investors. The new hydrocarbon law, issued on December 3, 2002, and ratified on March 19, 2005, aligned with the country's evolving energy strategy in response to economic transformations and increasing global exchanges. As competition among producing countries to attract private capital in the petroleum sector intensified, the law opened up the sector to foreign investors through attractive institutional and tax incentives.

At the national level, Algeria continues to adopt laws and regulations to manage its natural resources without disturbing the environmental balance. Several laws and decrees have been issued, the most important of which are:

_ Law No. 99_9 dated July 15, 1999, relating to energy control;

_ Law No. 01_19 of December 12, 2001 on the management, control and elimination of toxic waste. (Raziq, 2004);

_ Executive Decree No. 04_409 of January 11, 2005, laying down the rules for energy efficiency applicable to machines powered by electricity, gas, and petroleum products;

- Executive Decree No. 19-280 of October 20, 2019, establishing, organizing, and operating a New energy sources and Energy Efficiency Conservation.

Article 2 of Executive Decree No. 19-280 establishing, organizing, and operating a governorate for renewable energies and energy efficiency stipulates the following: "A public institution in the field of energy shall be established under the Prime Minister called: "The governorate for renewable energies and energy efficiency";

Article 3 of the aforementioned Executive Decree No. 19-280 stipulates the following: "The governorate for renewable energies and energy efficiency, referred to in the text as "the governorate", shall enjoy legal personality and financial independence";

Article 10 of Executive Decree No. 19-280 stipulates that the governorate shall managed by a "governor";

Article 11 of Executive Decree No. 19-280 establishing, organizing and operating a governorate for renewable energies and energy efficiency stipulates the following: "The governor shall be appointed by presidential decree, and his duties shall be terminated in the same manner";

Paragraph 2 of Article 3 of Executive Decree No. 19-280 states that “the institution is subject in its relations with the State to the rules of public law, and is considered a trader in its relations with third parties” (Mohamed, 2022). Algeria intends to cut greenhouse gas emissions by 7% by 2030 under the Paris Agreement. This might reach 22% with international support. While renewable power sources account for less than 1% of Algeria's energy production, its wide geography and open space make it ideal for growing renewable energy capacities. Algeria aims to increase its solar capacity from 0.4 GW in 2021 to 16 GW by 2035, recognizing its potential. Algeria's September 2021 government agenda prioritizes fossil-free green hydrogen production for decarbonization. As a major oil and gas exporter, its hydrocarbon infrastructure offers an exciting peroxide potential foundation. Algeria's LNG transport capacity and proximity to Europe via a well-established gas pipeline network also influence future exports. The country's production and use of fossil fuel-based grey hydrogen for industrial usage suggest residential use of the green alternative. Since late 2021, a national hydrogen plan has developed. (<https://ptx-hub.org/algeria/>, 2024)

Financial and regulatory support for green hydrogen development in Algeria includes tax exemptions and financial incentives for companies investing in hydrogen projects, simplified hydrogen approval procedures, and funding Research on hydrogen technology project and development.

IV. Green Hydrogen Exploitation Strategy in Algeria

IV.1 Algeria's potential for investment in green hydrogen

By 2030, solar hydrogen production in Algeria projected to reach 5,100 kg/h per megawatt of solar energy, with an estimated temporal capacity of 224–280 MWh of electricity. This production level could power approximately 510,000 kilometers of driving for light vehicles (equivalent to 35 cars) and supply electricity to two cities the size of Bejaia and Jijel, with a combined population of over 700,000 people, as shown in Figure 01.

Figure 1: Solar hydrogen production levels in Algeria

	AEC		PEMEC		SOEC	
	2020–2030		2020–2030		2020–2030	
Product in the South (kg)	37 920	39 500	34 473	37 920	47 400	51 243
Product in the North (kg)	35 280	36 700	32 073	35 280	44 100	47 676
Regression (1000%/hour)	0.1	0.1	0.2	0.1	1.9	0.5
Annual production hourly volume (hour)	3 000	3 000	3 000	3 000	3 000	3 000
Electricity consumption (kWh/kg)	50	48	55	50	40	37

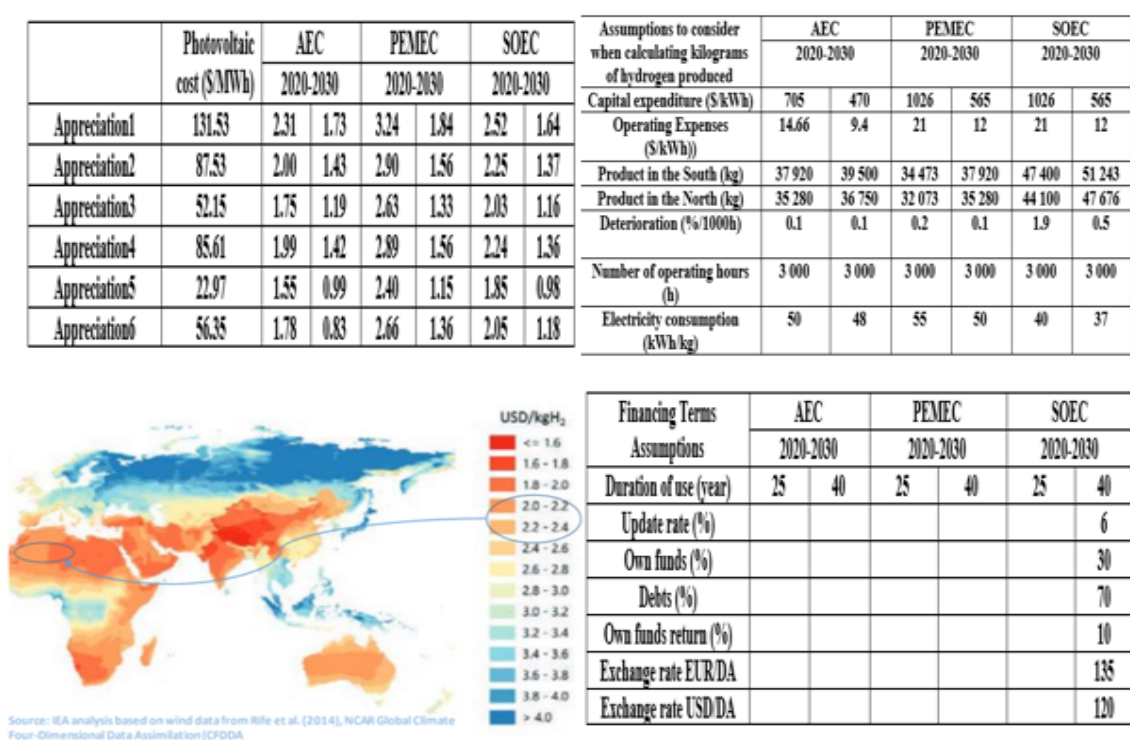


source : (Zitoot .2020)

The costs provided by the International Energy Agency (ranging from 3 to 7.5 USD for the renewable energy sector) can serve as a comparison, but it is difficult to make a precise determination as our calculations do not include the

costs of connecting photovoltaic power plants to electrolysis facilities or the cost of transporting hydrogen to distribution points. However, these costs appear promising, especially if existing gas networks are used for delivery. Calculating the export price (production costs plus handling/transportation costs) could be the focus of another study, which would provide better insight. For cost projections in 2030, the results indicate a reduction ranging from 0.83 to 1.84 USD per kg, representing a cost decrease of about 50%, which is significant for producing hydrogen from Algerian solar energy. However, analyzing the export market is another critical aspect that must be considered when assessing the feasibility of solar hydrogen as an alternative to hydrogen produced from natural gas. This is shown in Figure 02.

Figure 02: Solar Hydrogen in Algeria (Estimated Cost)

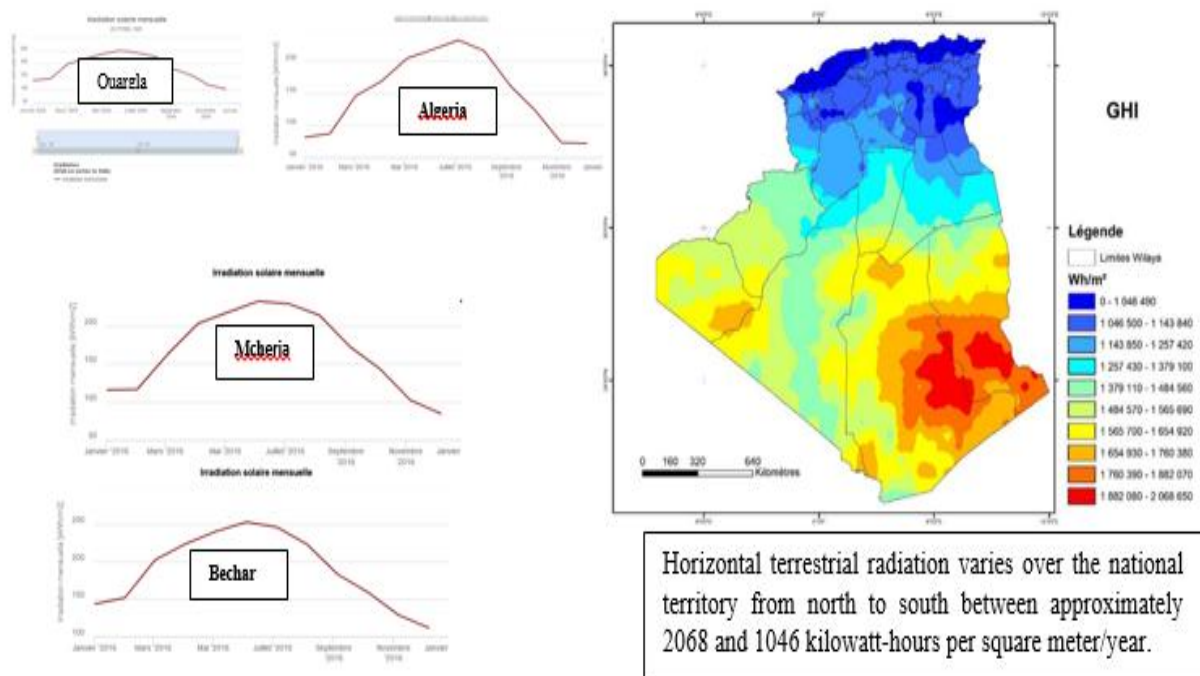


source : (Zitoot ,2020)

The solar radiation potential in Algeria, which naturally increases towards the equator, a north-south gradient observed for the specific hydrogen production potential. In the northern part of Algeria (Mediterranean coastal area, Tiliat Atlas Mountains, Saharan Atlas Mountains), north of 33°N latitude, the specific hydrogen production is between 29 and 39 million. kg / (km² * year). In the central part of Algeria (Sahara Desert, West / East of the Great Erg, Tademaït Plateau), between 27° and 33°N latitude, the specific hydrogen production increases to 40-41 million. kg / (km² * year). In the southern part of Algeria (Sahara Desert, Ahjar Mountains, Tassili-n-Ajjer Mountains), between 19° and

27°N latitude, the region can be divided into areas with high potential in the southeast of Ahjar Mountains with a specific hydrogen yield of 41 to 43 million. kg/(km²*yr) and areas with medium potential towards the Mauritanian border with specific hydrogen production of 39 to 40 million kg/(km²*yr). This is illustrated in Figure 03. The greatest potential for specific hydrogen production from photovoltaic energy found in the southeastern region of Algeria in the area of the Jebels El Hadjar and Tassili-N-Ajjer, specifically in the wilayas of Illizi and Tamanrasset. The lowest specific hydrogen production potential from photovoltaic energy found in the northeastern Mediterranean region between Bejaia and Annaba.

Figure 03: Solar energy potential in Algeria



source : (Zitoot .2020)

So incentives for the development of green hydrogen in Algeria, the country has proven experience in producing ammonia, ethanol, petrochemicals, and refining (Skikda and Arzew). The cost of producing hydrogen by electrolysis is still two to three times higher than that of natural gas. It will be necessary sharply reduce costs across the entire chain to start this industry.

Table 2: Annual hydrogen production potential (l/m²/d)

sites	Latitude (Nord)	Longitude	Insolation (kWh/m ² /jour)	Potentiel hydrogène (l/m ² /jour)
Adrar	27° 49'	00° 11'w	6,04	120,3772
Tam	22° 48'	05° 27'e	6,3	125,559
I-guezzem	19° 34'	05° 46'e	6,45	128,5485
Hassi-Mess	31° 40'	06° 8'e	5,71	113,8003
Biskra	34° 48'	05° 44 e	4,96	98,8528
I-Sefra	32° 45'	00° 36 w	5,35	106,6255
Timimoun	29° 15'	00° 17'e	5,84	116,3912
Laghouat	33° 48'	02° 53'e	5,23	104,2339
Illizzi	26° 30'	08° 28'e	6,04	120,3772
El Goléa	30° 34'	02° 52 e	5,78	115,1954
B.BMokhtar	21° 12'	00° 34'e	6,27	124,9611
Djanet	24° 16'	09° 28'e	6,25	124,5625
Tindouf	27° 40'	08° 09'	5,77	114,9961
Naama	33° 16'	00°18' w	5,13	102,2409
In Amenas	28° 03'	09° 38'e	5,99	119,3807
El oued	33° 30'	06° 47 e	5,29	105,4297
Béchar	31° 38'	02° 15' w	5,48	109,2164
Touggourt	33° 07	06° 08'e	5,29	105,4297
Ouargla	31° 55'	05° 24'e	5,7	113,601
In Salah	27° 12'	02° 28'e	5,98	119,1814
Ghardaia	32° 24'	03° 48'e	5,48	109,2164
Beni Abès	30° 08	02° 10' w	5,65	112,6045
Assekrem	23° 16'	05°34'e	6,21	123,7653

Source: (R. & A, 2003)

This table presents data on the annual hydrogen production potential of different sites in southern Algeria, where the hydrogen production potential: values range from 98.8528 to 128.5485 liters/m²/day.

The site with the highest potential is Ikzim (128.5485 liters/m²/day), which corresponds to its high level of sunshine, and the lowest potential is Biskra (98.8528 liters/m²/day), which corresponds to its low level of sunshine.

They show a clear positive correlation between sun exposure and hydrogen production potential. Sites with higher levels of sunshine generally have higher potential for hydrogen production.

The best-performing sites: Ikzim, Tam and B.B. Mokhtar show the highest potential for hydrogen production, these sites are generally located at low latitudes (19°-22°N).

The lowest-performing sites: Biskra, Laghouat and Naama have the lowest potential, which tend to be at higher latitudes (33°-34°N).

Data indicate that the southern regions of Algeria have better potential for solar

hydrogen production, likely due to the higher solar radiation levels near the equator. These data are useful in planning and implementing solar hydrogen production facilities in southern Algeria, focusing on the most promising locations to maximize the efficiency and economic exploitation of clean hydrogen energy.

IV.2 Supply and demand for hydrogen in Algeria:

Algeria exported US\$167 million of hydrogen in 2021, ranking 16th worldwide. Algeria shipped 9th most hydrogen that year. Algeria exports hydrogen principally to France (US\$76.5 million), Germany (US\$18 million), Spain (US\$12.1 million), Italy (US\$11.3 million), and Ireland (US\$9.25 million). Italy (\$10.2 million), Spain (\$4.24 million), and Switzerland (\$3.93 million) were Algeria's fastest-growing hydrogen export markets in 2020–2021. Algeria exported US\$193 million of hydrogen in 2022, 19th worldwide. Hydrogen was Algeria's 9th export that year. Algeria's top hydrogen export destinations are France (\$84.1 million), Germany (\$25.6 million), Spain (\$14.1 million), Italy (\$12 million), and Ireland (\$11.2 million). Between 2021 and 2022, Germany (\$7.63 million), France (\$7.56 million), and the United Kingdom (\$6 million) were Algeria's top export destinations for hydrogen. (<https://oec.world/en/profile/bilateral-product/hydrogen/reporter/dza>, 2024)

Algeria was the 107th greatest hydrogen importer in 2021, importing \$1.42 million. Hydrogen was Algeria's 704th main import that year. Algeria imports hydrogen mostly from France (\$953K), the UAE (\$128K), Spain (\$88.5K), Italy (\$78.9K), and Germany (\$65.5K). France was Algeria's fastest-growing hydrogen import market in 2020–2021.

Imports Algeria became the world's greatest importer of hydrogen in 2022, bringing in \$771K. Hydrogen was Algeria's 761st most imported product that year. Algeria mostly imports hydrogen from the United Arab Emirates (\$25.2K), Tunisia (\$28K), France (\$536K), China (\$84.6K), and Brazil (\$25K).

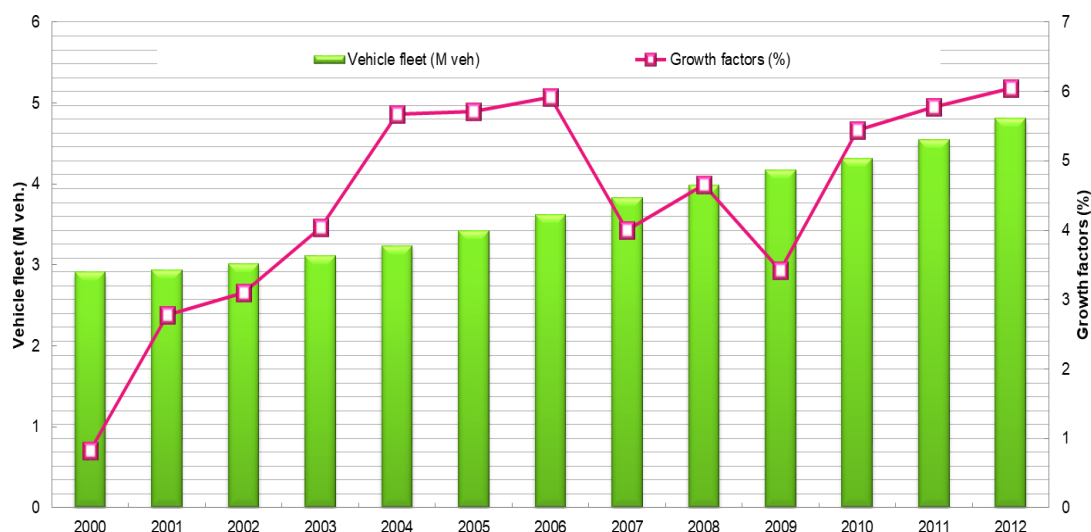
Algeria's fastest-growing hydrogen import markets during 2021 and 2022 were China (\$82.8K), Brazil (\$25K), Canada (\$2.45K), Spain (\$596K), and the UAE (\$58.6K)..

The fastest declining hydrogen export markets for Algeria (2021-22): (<https://isa-ghic.org/countries/algeria>, 2024)

- United States: -3.89M (-84%)
- Brazil: -3.51M (-100%)
- United Arab Emirates: -3.5M (-42%)
- The fastest-growing hydrogen export markets for Algeria in 2021-22 were:

- Germany: \$7.63M (42.4%)
- France: \$7.56M (9.88%)
- United Kingdom: \$6M (297%)

Figure N 04: Potential for hydrogen production relative to fuel consumption for road transportation sector in Algeria



Source: (Samia , Nourredine, Belkheir, & Abdelrahman , 2023)

This figure presents two key metrics relating to the transport sector in Algeria from 2000 to 2012:

Vehicle fleet (in millions of vehicles), represented by green bars, and growth factors (in percentages). There is a clear upward trend in the number of vehicles over the years. In 2000, the fleet was around 2.9 million vehicles. By 2012, it had grown to around 4.8 million vehicles. Growth appears to be relatively steady, with small increases each year. Growth factors show greater volatility compared to vehicle fleet figures. The lowest growth rate was in 2000, at about 0.7%. There was a sharp increase in the growth rate from 2000 to 2004, peaking at about 5.8%. The growth rate remained relatively high (5-6%) from 2004 to 2006. There was a significant decline in 2007 to about 3.5%. Another peak occurred in 2008 at about 4.7%. The growth rate fell sharply again in 2009 to its second lowest point, about 3%. From 2009 to 2012, there was a steady increase in the growth rate, reaching about 6% by 2012.

While the vehicle fleet shows steady growth, growth factors fluctuate significantly. The highest growth rates (2004-2006 and 2010-2012) correspond to increases in more acutely in the vehicle fleet, even during periods of low growth

rates, the total vehicle fleet continued to increase, but at a slower pace, the vehicle fleet's continued rise indicates a growing transportation demand in Algeria. Fluctuations in the growth rate may reflect economic conditions, policy changes, or other factors affecting vehicle acquisition, the overall trend suggests a significant expansion in Algeria's transportation sector over these 12 years. The growing vehicle fleet could represent a potential hydrogen fuel market if Algeria invests in this technology.

IV.3 Hydrogen policy in Algeria:

Algeria has significant potential for green hydrogen development, but the comprehensive regulatory framework for green hydrogen is still under development, and several existing measures and programs lay the foundation for the future regulatory landscape. Algeria is currently in the early stages of developing its hydrogen policy, but several key initiatives demonstrate its commitment to becoming a major player in the green hydrogen sector. Algeria has developed a national hydrogen roadmap, which was launched in March 2023, and outlines Algeria's plan to establish itself as a global leader in green hydrogen production and export by 2040. Key objectives include :(<https://isa-ghic.org/countries/algeria>, 2024)

- Reach 10 GW of electrolysis capacity by 2040.
- Provide 10% of Europe's hydrogen needs by 2040.
- Generate \$1 billion in revenue from hydrogen exports by 2030.

It also focused on the “Technology and Socio-Economic The Advancement of Sustainable Energy and Green Hydrogen in Algeria” project, which aims to develop the green power sector and support the project through a portfolio of green hydrogen, after minimizing gas emissions to the maximum, impacting Differences in the climate, enhancing synchronization, mobility, and the ability to operate at the local level.

Table 3: “Technology and Socio-Economic Development Growth of Renewable Energy Renewable Energy and Green Hydrogen in Algeria” project

Nom du projet	Technologie et développement socioéconomique des énergies renouvelables et l’hydrogène vert en Algérie
Sur mandat du	Ministère fédéral Allemand pour la Coopération Économique et le Développement (BMZ)
Partenaire politique	Ministère de l’Énergie et des Mines
Organe d’exécution	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
Durée	01.12.2022 – 30.11.2025

Source: (GIZ, 2003)

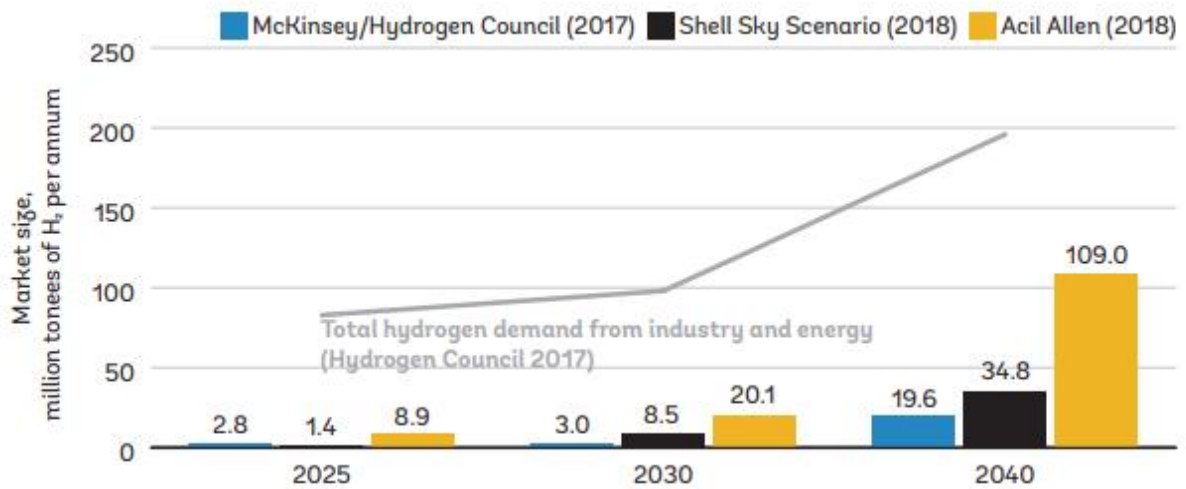
Algeria is aiming to establish a strong foundation for its hydrogen sector by 2050 through the Algerian Green Hydrogen Strategy 2050. This ambitious plan focuses on lowering emissions of greenhouse gases and lowering petroleum consumption. By 2040, Algeria intends to export 30-40 TWh of green hydrogen—both gaseous and liquefied—and its derivatives. To achieve this, the country is developing comprehensive strategies and policies, forming internal and external partnerships, and addressing current challenges to meet the needs of the green hydrogen economy. Algeria is also targeting the European market across the Mediterranean by securing land, tackling the shortage of water with desalination plants, and expanding its green energy resources through solar and wind strength. Furthermore, the country is exploring ways to lessen the effects on the environment of the blue hydrogen industry as it transitions to green hydrogen. Algeria is Working together with local energy groups to build a sustainable energy ecosystem. State-owned oil company Sonatrach has signed a Memorandum of Understanding (MoU) with Hecate Energy Global Renewables (HGR Energy) to explore renewable energy and green hydrogen projects. The Algerian Green Energy Group (GEC), a collaborative organization comprising industries, universities, research centers, institutes, and representatives from key government ministries, is essential to the development of collaboration among its members. Its primary objectives are to enhance competitiveness, provide specialized training, and build human resource capacity to support the development and knowledge transfer necessary for a hydrogen economy in Algeria. (Nadjib Drouiche ‘Alexander ‘ Wassila ‘2024)

IV.4 Global demand for investment in green hydrogen:

Although the precise numbers for amount of hydrogen produced vary, ranging from 55 million tons to 70 million tons yearly, Figure 05 projects that the

hydrogen industry will be worth about \$135.5 billion at a compound annual growth rate (CAGR) of 8% until 2023. Because of the many and varied applications of hydrogen (such as the creation of ammonia and its usage as a manufacturing agent in refining), we can see from the figure that the demand for hydrogen will rise significantly in the future, with an anticipated 109 million tons in 2040. In order to meet the demand for hydrogen in the worldwide market by 2050, it is also important to establish assumptions about the market's value for chemical and scientific applications. Figure 05 provides an illustration of this.

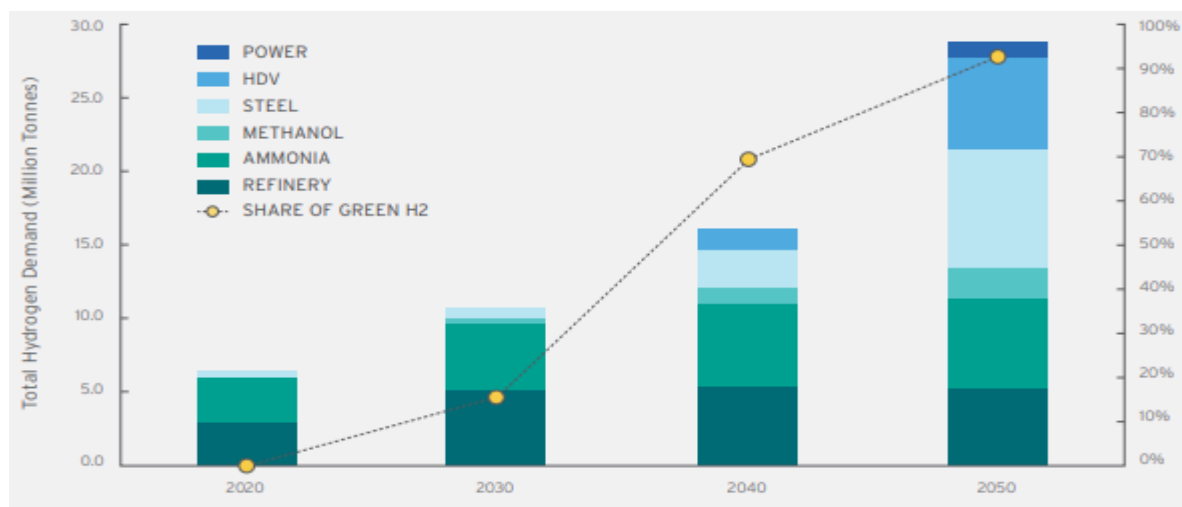
Figure 05: Global demand for hydrogen in the energy market



Source: (ESMAP. Washington ‘2020)

Additionally, Figure 06 demonstrates that cost-competitive green hydrogen has the potential to grow the market, particularly in industries that use gray hydrogen. The share of green hydrogen in the final product cost will be determined by the cost of production, as well as any short-term external efforts to create demand based on cost competitiveness. Around 94% of the need for hydrogen can be satisfied by 2050, hence it is anticipated that the demand for green hydrogen will dominate the 2020–2030 timeframe, particularly in new investments and existing industrial domains.

Figure 06: Hydrogen demand forecast and potential green hydrogen share



Source: (Aayog, 2022)

V. Conclusion

Interest in renewable clean power energy has become a major trend in developed countries, with investments in renewable power projects now accounting for over 50% of total global energy investments. In recent years, the demand for green energy has significantly increased, particularly in financing low-carbon energy projects, especially for industrial activities and consumption.

Algeria relies heavily on oil and natural gas in its exports a large extent by 96%. Therefore, its continued reliance on these resources at the same rate of consumption will result in elevated pressure on the rate of energy consumption in the future, which led to the search in favor of sustainable energy sources. Among the most important modern trends in Algeria, we find its attempt to delve into investing in hydrogen energy because of its capabilities that enable it to be a pioneer in this field.

It has become necessary for Algeria to highlight its position in exploiting renewable energy through what the study has reached, and the results we have reached were:

- Hydrogen energy can be produced from all renewable energies that generate electricity, but in Algeria, solar energy is one of the most prominent and important energies for producing hydrogen energy;
- Hydrogen energy considered one of the clean energies and it will greatly reduce carbon dioxide emissions;
- Algeria can be an exporter of electricity by effectively exploiting solar

energy as it has huge renewable energy reserves due to its strategic location;

The most important recommendations:

- In accordance with international hydrogen policies, a clear roadmap for the production, distribution, and use of hydrogen should be established, along with long-term objectives and benchmarks.
- To promote investment and innovation in hydrogen technology, put in place favorable laws, incentives, and regulatory frameworks.
- Work together to exchange knowledge, technology, and investment with global leaders in hydrogen technology, including the European Union, Japan, and South Korea.
- Use wind and sun power, especially in the Sahara Desert. Green hydrogen can be produced by electrolysis using these resources.
- To increase energy efficiency and cut expenses, combine hydrogen-manufacturing facilities with renewable energy plants.
- Modify natural gas infrastructure to repurpose Algeria's vast network of natural gas pipelines for the transportation of hydrogen both domestically and internationally.
- Construct hydrogen storage facilities in order to create cutting-edge hydrogen storage technologies, such as compressed and liquid hydrogen storage.
- Create hubs for the export of hydrogen, concentrating on ammonia and liquefied hydrogen as energy sources.
- Encourage the development of storage, hydrogen fuel cell, and sophisticated electrolysis technologies that are suited to Algerian circumstances.
- To establish competence and prove viability, small-scale hydrogen initiatives started in industries like transportation, manufacturing, and power generation.

VI. References:

Journal article :

1. Cornelius , M., Valeria, A., & Louis , R.-P. (2020). The Risks and Opportunities of Green Hydrogen Production and Export From the MENA Region to Europe. *Dii Desert Energy,immune,*.
2. Delia , V., Brot , f., & the Heinrich, B.-S. (2022). Green hydrogen: Key success criteria for sustainable trade & production.
3. Diego, B., João , S., José , A., John F, F., & Zita , V. (2023). Green Hydrogen and Energy Transition: Current State and Prospects in Portugal. *Energies*.
4. Michael , B. (2020). Morocco, Algeria, Egypt: Assessing EU plans to import hydrogen from North Africa.

5. Nadjib Drouiche, Alexander , A.-M., & Wassila , B. (2024). *Assessment of the economic viability, environmental, and social impacts of green hydrogen production: an Algerian case study.* Frontiers in Membrane Science and Technology

Reports

6. GIZ. (2003). *Technologie et développement socioéconomique des énergies renouvelables et l'hydrogène vert en Algérie.* Algérie: GIZ.
7. Mirakyan, D. A. (2021). *Étude exploratoire sur le potentiel du Power-to-X .* ALGER: Deutsche Gesellschaft für internationale Zusammenarbeit (GIZ) GmbH. ALGER.
8. Observatory, C. E. (2020). *Assessing EU plans to import hydrogen from North Africa.* Morocco, Algeria, Egypt.
9. R. , B.-K., & A, K. (2003). *Estimation de la Production de l'Hydrogène Solaire au Sud Algérien.* Algérien: Rev. Energ. Ren.: ICPWE (2003).
10. Samia , R., Nourredine, S., Belkheir, N., & Abdelrahman , G. (2023). *Estimates of the potential for hydrogen production from renewable resources in Algeria.* Algeria: University of Ouargla, Algeria.
11. Zitoot, A. (2020). *Solar hydrogen potential production in Algeria,* Algeria: Sonelgaz / Executive Directorate of Strategy and Foresight.
12. Aayog. *Harnessing GREEN HYDROGEN..* India: Rocky Mountain Institut. . join) 2022).
13. ESMAP. Washington. (2020). *Green Hydrogen in Developing Countries.* United States of America , World Bank.