

Opportunities and challenges of exporting green hydrogen to Europe (Case of Algeria)

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Abstract:

This study aims primarily to highlight the possibilities of producing green hydrogen in Algeria, and the opportunities for exporting it to Europe. The study shows that there will be a promising market for the production and export of green hydrogen in Algeria, given its special competitive advantages such as: its enormous potential in renewable energy, its advanced export infrastructure and its strategic location. The study also confirms that Algeria has great technical potential to produce green hydrogen, especially in its south-east where the lowest levels of green hydrogen production costs are expected, particularly in Tamanrasset.

The important requirements presenting in this paper for penetrating European markets are the production of green hydrogen without greenhouse gas emissions, and at competitive costs. In addition to developing incentive policies to surpass the challenges affecting the development of green hydrogen along the value chain.

Keywords: Green hydrogen; Electrolyser; power-to-X; Renewable electricity; Algeria.

Jel Classification Codes : Q01; Q21; Q55; Q56; F21.

Résumé:

Cette étude vise à mettre en évidence principalement les possibilités de production d'hydrogène vert en Algérie, et les opportunités de l'exporter vers l'Europe. L'étude montre qu'il y aura un marché prometteur pour la production et l'exportation d'hydrogène vert en Algérie, compte tenu de ses avantages compétitifs particuliers tels que: son énorme potentiel en matière d'énergies renouvelables, ses infrastructures d'exportation avancées et son emplacement stratégique. L'étude confirme également que l'Algérie dispose d'un grand potentiel technique pour produire de l'hydrogène vert, notamment dans son sud-est où les niveaux les plus bas de coûts de production de l'hydrogène vert sont attendus, notamment à Tamanrasset.

Les exigences importantes présentées dans cette étude pour pénétrer les marchés européens sont la production d'hydrogène vert sans émissions de gaz à effet de serre et à des coûts compétitifs. En plus de développer des politiques incitatives pour surmonter les défis affectant le développement de l'hydrogène vert tout au long de la chaîne de valeur.

Mots clés: Hydrogène vert; Électrolyseur; Power-to-X; Electricité renouvelable; Algérie.

Jel Classification Codes : Q01; Q21; Q55; Q56; F21.

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I. Introduction

Green hydrogen in Europe is one of the top priorities in the energy transition, as it will help decarbonize European economies and reduce greenhouse gas emissions. Based on this vision, the European Union has adopted a green hydrogen strategy that aims to import half of its green hydrogen needs from neighboring countries, particularly North African countries and Ukraine.

In this context, Algeria - as an important and priority partner - is determined to benefit from the growing European demand for green hydrogen to become an important and strategic exporter of it. This issue has become one of the most important priorities of the President of the Republic, which he has repeatedly mentioned during several of his ministerial and governmental councils, given its competitive advantages that enable it to contribute to accelerating its role in the regional and global market.

I.1 Problematic of study

Based on the above, this study came to answer the following main question: **What are the possibilities of exporting green hydrogen from Algeria to the European Union in light of the challenges surrounding this opportunity?**

I.2 Sub-questions of study

To answer this problem, the following sub-questions should be answered:

- What are the possibilities of producing green hydrogen in Algeria?
- How possible is it to export Algerian green hydrogen to Europe?
- What are the most important problems facing the development of green hydrogen in Algeria?

I.3 Hypotheses of study

To answer the main question, the following hypotheses can be formulated:

- Algeria has great potential to produce green hydrogen at a competitive cost in the long term, which makes its export to Europe a promising opportunity.
- High investment costs, transport problems and water insufficiency...etc. are part of the challenges of producing green hydrogen in Algeria.

I.4 Objectives of study

This study aims to identify the potential and opportunities for green hydrogen production in Algeria and estimate its potential costs in the long term. It also aims to highlight the advantages that help Algeria to become a global

leader in the green hydrogen export market. Finally, it aims to present the important challenges that hinder the process of green hydrogen exporting.

1.5 Importance of study

This study derives its importance from the growing importance of green hydrogen that has emerged in recent years worldwide in the decarbonization sectors. In addition to the importance of Algeria's move towards investing in renewable energies in general and green hydrogen in particular, given its economic, social and environmental gains both in the medium and long term.

II. Theoretical background on green hydrogen

II.1 Colors of hydrogen

Hydrogen is produced through different processes and energy sources, and the hydrogen produced by all these methods remains the same. But it has been coded with colors (gray, blue, turquoise, green...etc.) to distinguish between these methods. (SANDALOW, MEIDAN, & ANDREWS-SPEED, 2022, p. 127)

Currently, more than 95% of the hydrogen produced is gray hydrogen. (REN21, 2021, p. 213) Black hydrogen, brown hydrogen and gray hydrogen are often under the term “gray hydrogen,” those are produced from hard coal, brown coal, and natural gas successively. (AIT BACHIR, 2021, p. 15) The (GHGs) emitted in these processes aren't captured, (Manna' & Saffouri, 2022, p. 11) making it unsuitable for a net-zero pathway. (IRENA, 2020, p. 09)

While green hydrogen is produced by electrolysis of water using energy generated from renewable sources. (AIT BACHIR, 2021, p. 16) It is produced without generating GHGs. (Manna' & Saffouri, 2022, p. 11)

II.2 Hydrogen production and climate change

Hydrogen is not a GHG (heat trapping); therefore, it can contribute significantly to combating climate change, (SANDALOW, MEIDAN, & ANDREWS-SPEED, 2022, p. 126) and to achieving net zero goals, by surpassing two challenges: its production must be significantly increased, and simultaneously it must be decarbonized. (Flis & Wakim, 2023, p. 04)

In upcoming years, for hydrogen to have an effective role in low-carbon energy systems, its production model must not generate negative effects on the environment and it must have an economic viability. (AIT BACHIR, 2021, p. 18)

II.3 Green hydrogen

The case in which hydrogen is produced without generating CO₂ emissions is the case of green hydrogen, which is produced completely from renewable electricity through the electrolysis of water. (Schwartzkopff, 2022, p. 30)

II.3.1 Benefits of green hydrogen

The benefits of clean hydrogen are diverse in addition to the benefits of hydrogen in general, as: (Kourkejian, 2021, p. 06)

- Its production is without a carbon footprint through the electrolysis process;
- The possibility of transporting it over long distances allows for the distribution of energy between countries;
- Also its suitable for long-term storage due to its high energy density;
- It is considered a multi-use carrier of clean energy and the diversity of applications in which it can be used.

II.3.2 Applications of green hydrogen

There are numerous applications of hydrogen in the energy sector, where it is principally used as a fuel for heating, electricity generation, or in transportation. (Manna' & Saffouri, 2022, p. 12) Additionally, its contribution to achieving energy security by providing additional energy carrier, (IRENA, 2020, p. 10) which diversifies the energy mix, giving more flexibility to balance networks and improving the resilience of the energy system. (IEA, 2021, p. 3)

In the industrial sector, hydrogen's uses are also multiple, where it can be used as an intermediate (raw material or feedstock) or directly in end uses. (Iea, Irena, Unsd, WB, & WHO, 2019, p. 109) These applications are generally represented in: oil refining, producing of ammonia in fertilizer, producing of methanol, iron and steel fabrication. (Matthes, Aruffo, & Retby-Pradeau, 2020, p. 24) It can also be used in food manufacturing. (Manna' & Saffouri, 2022, p. 14) It can contribute in decarbonizing industries, especially heavy industries, such as iron, steel, cement, and chemicals. (IRENA & ILO, 2021, p. 32)

While in the transportation it can be used and its related products as fuel, especially heavy-duty vehicles, (RaviKumar Bhagwat & Olczak, 2020, p. 13)

II.3.3 Electrolysis technology

Water electrolysis is a process in which water molecules are split into oxygen and hydrogen, using an electric current. (Flis & Wakim, 2023, p. 04) Currently, three kinds of electrolysis technologies are used: alkaline water electrolysis (AWE), proton exchange membrane (PEM) and solid oxide electrolysis cells (SOEC). (IRENA, 2019, p. 6)

AWE was used more than the rest technologies, as it constituted nearly 60% of the total installed capacity in 2022. (Hydrogen Council & McKinsey & Company, 2023, p. 17) As it is a developed commercial technology with low capital costs, (IEA, 2022, p. 112) and more working life exceeding 200.000 h

compared to the other technologies. (Tiar, Fadlallah, Benhadji Serradj, Graham, & Aagela, 2024, p. 784)

Water electrolysis has small share don't surpass 4% of global hydrogen production. On the end of 2022, the total installed capacity of water electrolyzers for producing green hydrogen estimated nearly 700 MW. (IEA, 2023, p. 68) In 2023, it increased to 1.1 GW. (Hydrogen Council & McKinsey & Company, 2023, p. 17) Which means that there is rapid growing in the deployment of electrolysis capacity in last years, reaching 20% in 2022, and 60% in 2023.

II.3.4 Cost of green hydrogen production

Currently, the global cost of green hydrogen production estimates two to three times higher than the cost of gray hydrogen, due mainly to the high capital and operating costs. (Manna' & Saffouri, 2022, p. 11) So that it is facing strong competition in terms of cost from other technologies.

When using electrolyser technology, the cost of generating renewable electricity constitutes a large part, reaching around 30% of the total cost of producing hydrogen LCOH, in some cases it may reach 60%. (IRENA, 2019, p. 15) Followed by the investment costs of the electrolyzer system, which differs relatively to the type of electrolyzer technology. While the cost of water ranges from 1% to 2%. (Matthes, Aruffo, & Retby-Pradeau, 2020, p. 13)

Falling both renewable electricity and Electrolysis capacity costs is likely to increase the economic attractive of green hydrogen. (RaviKumar Bhagwat & Olczak, 2020, p. 6) According to IRENA, the costs of electricity generated from solar PV and wind continue to fall. Also, the capital cost of electrolysis was declining by 60% between 2010 and 2020, as consequence, the cost of green hydrogen has fallen from USD10-15/kg to USD4-6/kg. (IRENA, 2020, p. 10)

Several studies have estimated that the cost of green hydrogen is still on the decline, and could fall below US\$1.5-2/kg by 2050. (Muhsen, Al-Mahmodi, Tarawneh, Alkhraibat, & Al-Halhouli, 2024, p. 02) Another important study estimates that LCOH is expected to fall rapidly by 85% from its current level to 2050, potentially bringing costs below US\$1/kg H₂. (AIT BACHIR, 2021, p. 19) Giving it more economic viability to alternate gray hydrogen.

II.4 Decarbonization with « Power-to-X » technologies

Power-to-X technologies refer to various processes in which electricity from renewable energy sources (such as solar) is converted into products like heat, hydrogen, synthetic energy, fuels or chemicals. Thus, water electrolysis is a power-to-hydrogen (PtX) technology, where electricity produces hydrogen (green) and oxygen. (Manna' & Saffouri, 2022, pp. 10,18)

III. Algeria's opportunities of exporting green hydrogen to Europe

III.1 European green hydrogen strategy

In Europe, the construction of the hydrogen economy began with the launch of the "Green Deal" by the new European Commission since 2019. The European Union set a 2020's commitment to become the primary carbon-neutral continent by 2050. (Matthes, Aruffo, & Retby-Pradeau, 2020, p. 10)

It aims to produce 54% of its final energy demand by 2050, and import 46% from North Africa. (Wijk, Wouters, Rachidi, & Ikken, 2019, pp. 17,20)

In the European energy transition, green hydrogen is an important priority, (Matthes, Aruffo, & Retby-Pradeau, 2020, p. 10) and one of the most prominent frameworks for cooperation between Europe and North Africa. It has adopted a joint hydrogen strategy, which aim to build a new European energy system based on a 50%-50% share of renewable electricity and green hydrogen by 2050. (Wijk, Wouters, Rachidi, & Ikken, 2019, p. 3)

The strategy foresees the installation of 40 GW of electrolyzed capacity in North Africa and Ukraine,(IRENA, 2020, p. 24) where 32.5GW will be produced for export to Europe, (van Wijk & Chatzimarkaki, 2020, p. 03) the rest will be directed to local markets, primarily for green ammonia production, which will be exported to Europe too. (Schwartzkopff, 2022, p. 37) As shown in table (01)

Table (01): Electrolyser capacity in North Africa and Ukraine by 2030

Electrolyser capacity	2023	2024	2025	2026	2027	2028	2029	2030	Total 2030
Domestic market (MW)									7500
Ammonia North Africa	75	125	250	500	750	1000	1250	1500	5450
Ammonia Ukraine		50	100	200	250	300	400	500	1800
Other (steel, refineries)				10	20	30	40	50	150
Hydrogen refueling stations					10	20	30	40	100
Export Market (MW)									32500
Hydrogen North Africa		500	1000	2000	3000	4000	6000	8000	24500
Hydrogen Ukraine			500	700	1000	1400	1900	2500	8000
Total (MW)	75	675	1850	3410	5030	6750	9620	12590	40000

Source: (van Wijk & Chatzimarkaki, 2020, p. 27)

It is noted that 75% of hydrogen exports will be from North Africa, which

enhances Algeria's opportunity in the field of exporting green hydrogen.

Due to recent events in Ukraine, and the urgent need to reduce dependence on Russian gas, Europe has creased its import goals to 10 million tons yearly by 2030. (Barnard, 2022, p. 1) This indicates that Ukraine's ability to export green hydrogen is less expected, and North Africa's opportunity to produce it is greater.

III.2 The competitive advantages of producing green hydrogen in Algeria

Algeria has competitive advantages that enable it to play an important role at the global market, the most important of which are the following:

III.2.1 Richness of renewable energy (particularly solar)

Within the Maghreb countries, Algeria is the most riche country in terms of energy resources, particularly solar energy. (AFDB, 2016, p. 83) It has one of the highest levels of solar radiation worldwide, especially in its south where insolation rates surpass 2,650 kwh /km². (Oxford Business Group, 2017, p. 85) Since GW of solar energy is supposed to produce 2,190 GWh of electricity annually (with capacity factor of 25%), this will produce nearly 36,500 metric tons of hydrogen. (Barnard, 2022, p. 8) There is also a significant suitability conditions for producing green hydrogen from electricity generated by onshore wind. (Wiedemann, 2024), but the focus of this paper is on solar hydrogen.

The presence of enormous solar potential and the availability of areas for solar systems installation make Algeria an optimal space for solar hydrogen production. (Ziani , Mahmah, Ziari Kerboua, & Benzaoui, 2012, p. 417)

III.2.2 Strategic location close to European energy demand markets

Algeria's renewable energy resources are located near from European energy demand centers than the Europe's excellent renewable resources, (van Wijk & Chatzimarkaki, 2020, p. 11) which will play a major role in this field

III.2.3 Availability of financing

Algeria can reinvest its fuels revenues in green hydrogen deployment, especially after its increasing due to the natural gas price rising. (Barnard, 2022, p. 19)

III.2.4 Advanced distribution and export infrastructures

Algeria has a well-established transcontinental gas pipeline network. (AIT BACHIR, 2021, p. 30) Part of this current infrastructure could be transformed to transporting hydrogen. (van Wijk & Chatzimarkaki, 2020, p. 13)

III.2.5 Local competences

Algeria is a country rich in hydrocarbons and one of the world's leading exporters of fossil energy, (AFDB, 2016, p. 14) and has a qualified, specialized

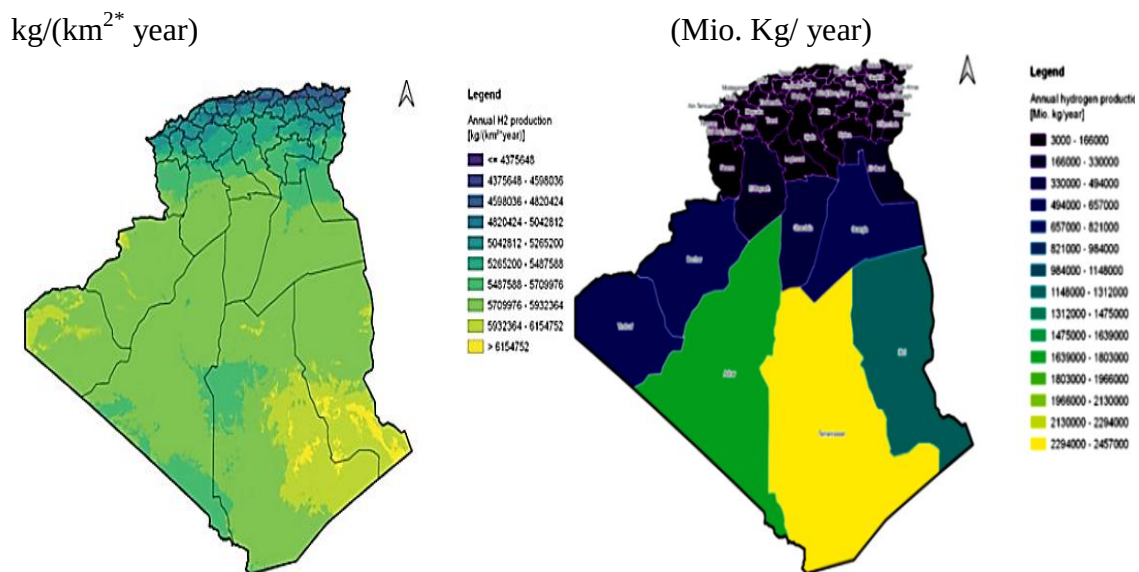
and experienced workforce can develop the hydrogen economy in the country.

III.3 Green hydrogen production potential from solar photovoltaic in Algeria

In Algeria, it has estimated the technical potential for producing green hydrogen from photovoltaic and wind energy at around 6,650 million tons /year in 2030, which is greater ten times than the potential for producing green hydrogen with wind energy. (Drenkard & Mirakyan, 2021, pp. 58-60)

Figure (01) shows the technical annual production potential in Algeria:

Fig.(01): Green hydrogen production potential from PV electricity (left), Green hydrogen production potential from PV electricity per region (right)



Source: (Drenkard & Mirakyan, 2021, pp. 58,59)

Regarding the left part of the figure, the greatest technical potential for green hydrogen production from photovoltaic is located in the southeastern region of the country, particularly in Hoggar and Tassili, Illizi and Tamanrasset. While the right part of the figure shows that the greatest production potential ranging between 0.52 and 0.66 million Mio. kg /(km²*year) can be observed principally in the Tadmait highlands (Tamanrasset), Tindouf and Adrar.

III.4 Estimated costs of producing green hydrogen using solar photovoltaic

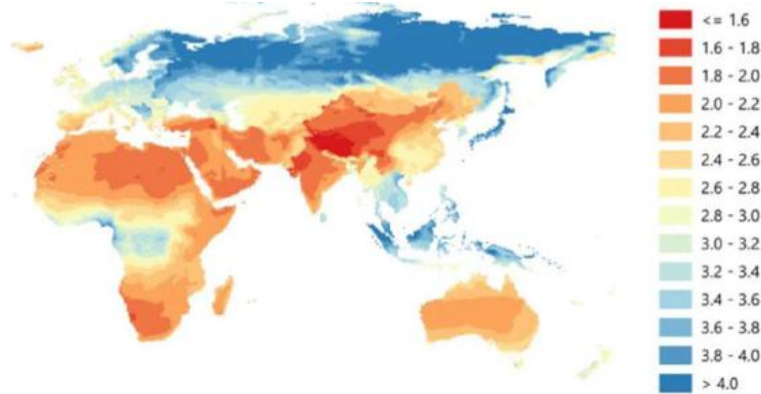
According to IEA, the Middle East and North Africa region has the double advantage to generate solar and wind energy at a cost level among the lowest worldwide, giving it the potential to produce green hydrogen for less than USD2/kg. (Matthes, Aruffo, & Retby-Pradeau, 2020, p. 14) While another study expects that the production of clean hydrogen in North Africa may cost about USD 1- 1.2 /kg by 2050. (Tiar, Fadlallah, Benhadji Serradj, Graham, & Aagela, 2024, p. 784)

According to IEA, Algeria is one of the most competitive countries in terms

of cost and capacity to produce green hydrogen:

Fig.(02): Potential long-term cost of green hydrogen based on solar photovoltaic energy and onshore wind energy

(USD/kg H₂)



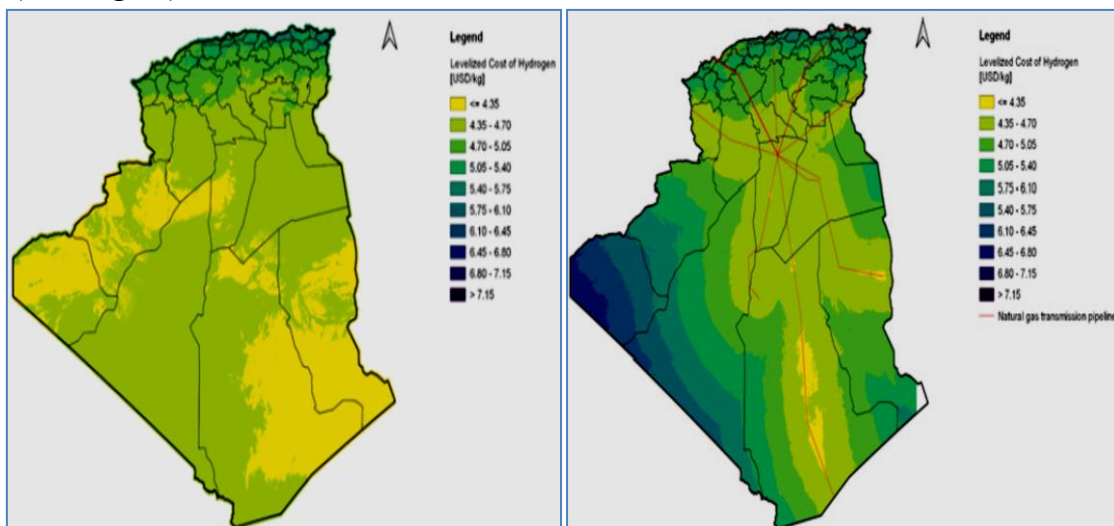
Source: (Kourkejian, 2021, p. 12)

It can observe from the figure that Algeria is capable of producing green hydrogen at a cost ranging between nearly USD 2 - 2.2 /kg.

In more detail, figure (03) shows an overview of the costs of producing green hydrogen from solar photovoltaic energy by 2030 in Algeria:

Fig.(03) : Green hydrogen production cost from PV electricity in Algeria horizons 2030 in the absence (left) and the presence (right) of transportation's costs

(USD/kg H₂)



Source: (Drenkard & Mirakyan, 2021, pp. 60-61)

Regarding the left part of the figure, the lowest level of (LCoH) is expected to be 4.35 USD/kg. This level is expected to be achieved in southwest of Tindouf, Bechar, north of Adrar, the Tadmit highlands, southeast of Tamanrasset and Illizi. While the estimating of transportation costs, there will be a significant increase in LCoH, especially in areas far from pipelines.

Since the cost of producing electricity from solar or wind energy in North Africa is lower than in Europe, the cost of hydrogen production is expected to be 0.5-1.0 euros/kg by 2030, and much lower than 1euro /kg by 2050, lower than the estimated cost in Europe which is expected to reach 1euro/kg. (Wijk, Wouters, Rachidi, & Ikken, 2019, p. 8) Which means that green hydrogen production in North Africa will remain more competitive than in Europe.

III.5 Exporting potential of green hydrogen from Algeria to Europe

Algeria seeks to benefit from the increasing European demand for green hydrogen in light of the shift towards the green hydrogen revolution. (Wiedemann, 2024) Especially that the Europe aims to import half of its green hydrogen needs from Ukraine and North Africa by 2030. (Schwartzkopff, 2022, p. 36) These three regions have an exceptional opportunity to become leaders in the global green hydrogen market, as: (van Wijk & Chatzimarkaki, 2020, p. 03)

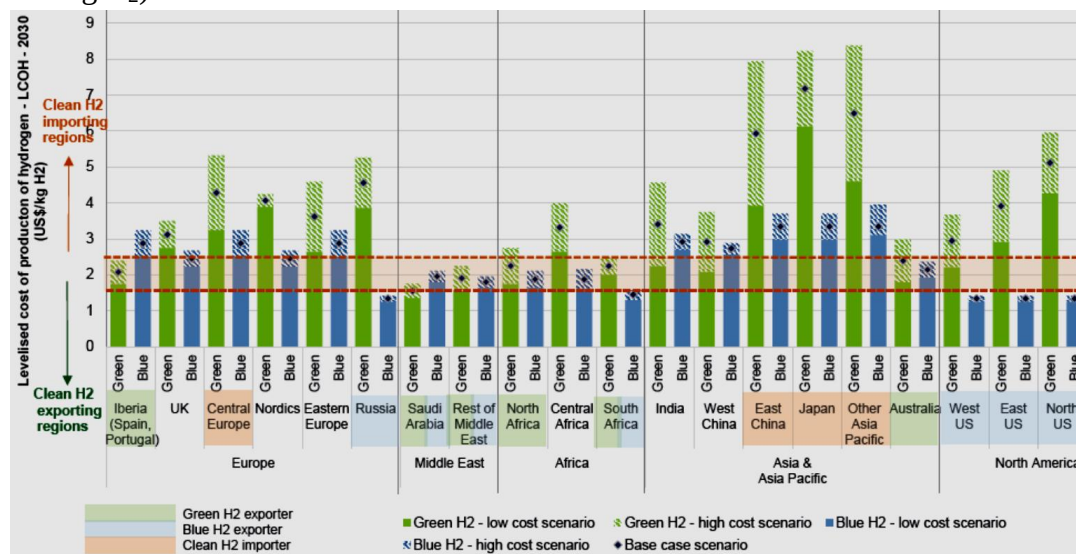
- North Africa is distinguished by their abundant renewable resources.
- The pipeline linking Europe and North Africa can be reused for hydrogen.
- Europe is a world leader in the electrolysis technologies industry.

Specialists have identified regions with significant potential to export clean hydrogen as having the availability of low-cost renewable energy resources or sites for storing both natural gas and carbon, and the ability to supply larger quantities of clean hydrogen than are required, to be directed to meet local demand. (Clarke, et al., 2022, p. 63)

Figure (04) shows North Africa's position in these two requirements:

Fig.(04): Levelized cost of green and blue hydrogen under 2030 assumptions

(USD/kg H₂)



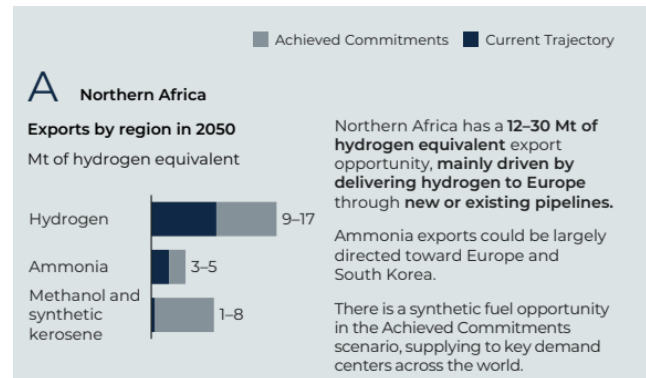
Source : (Clarke, et al., 2022, p. 62)

It can note that North Africa is expected to become an important region

exporting clean hydrogen, as it appears as a main region meet both requirements.

Figure (05) shows North Africa's export opportunities for hydrogen:

Fig.(05): North Africa's hydrogen exporting opportunities horizon 2050



Source: (AGHA & McKinsey & Company, 2022, p. 23)

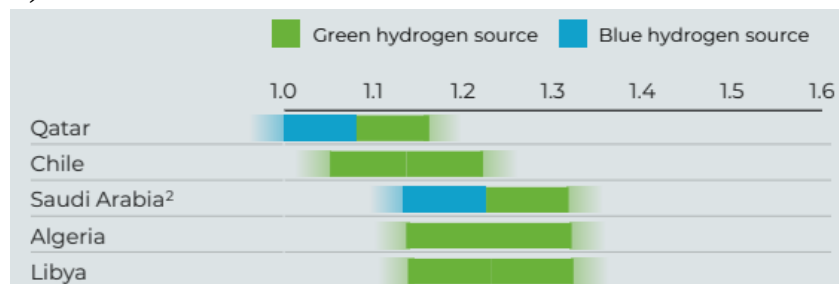
It is clear from the figure that North Africa has a great opportunity to export hydrogen and some related products, most notably ammonia and methanol, to Europe, ranging between 12-30 million tons by 2050.

Green molecule has also great benefit for North Africa. (Matthes, Aruffo, & Retby-Pradeau, 2020, p. 15) Ammonia is at the forefront of these products, as Europe is expected to import 5 - 10 Mt of hydrogen-equivalent ammonia by 2050. Algeria, as a major consumer and exporter of ammonia made from gray hydrogen, can manufacture green ammonia by substituting gray hydrogen with local green hydrogen. (Barnard, 2022, p. 20) Which can export it later.

Algeria can be competitive in exporting green ammonia to Central Europe as shown in Figure (06):

Fig.(06): Expected landed costs¹ of exporting green and blue ammonia to Central Europe, without support, horizons 2050

(USD/ kg H₂)



1: Lower bound: weighted average cost of capital + 1%; upper bound: weighted average cost of capital - 1%.
2 : Assuming 60% blue, 40% green

Source: (AGHA & McKinsey & Company, 2022, p. 18)

The figure shows that Algeria ranks fourth in the world in terms of the possibility of exporting green ammonia to Central Europe, at a very competitive cost ranging between USD1.15/kg and USD1.3/kg.

Importing hydrogen from North Africa is more cost-effective via pipelines than using ships. (Wijk & Wouters, 2021, p. 92) Estimates have shown that transporting green hydrogen from North Africa to Europe by pipeline will cost about USD 0.22/kg. (RaviKumar Bhagwat & Olczak, 2020, p. 7) By 2030, it is estimated that transporting hydrogen via pipelines will add about 0.2 euros /kg H₂. However, hydrogen exported from North Africa to Europe will remain more competitive than the local hydrogen. (van Wijk & Chatzimarkaki, 2020, p. 28)

III.6 The potential of Power-to-X (green hydrogen) for Algeria

In 2021, an exploratory study on the Power-to-X (energy-to-green hydrogen) potential in Algeria was published, within the framework of the Algeria-Germany energy partnership. Its aim is to provide a preliminary draft for a roadmap to the feasibility and needs of establishing a comprehensive PtX (green hydrogen) industry in Algeria over the coming years (time horizon: 2030 and 2050. The study showed that: (Loucif, 2022)

- Algeria has a great potential for green hydrogen production, and its development is technically and economically feasible.
- The costs of hydrogen production vary depending on the costs of solar photovoltaic or wind energy production.
- There is a possibility of using partially the infrastructure of fossil energy (gas) with success in the industry of green hydrogen.

IV. The shift to the hydrogen economy in Algeria

The transition to a hydrogen economy is well underway; this transition began in 2005 with the presentation of the Maghreb-European cooperation project (MedHySol), where a project was declared to develop the production and export of solar hydrogen on a large scale. The successful implementation of this project goes through two stages: (AIT BACHIR, 2021, p. 24)

- The first stage: in which a technical platform must be created, that contributes to the evaluation of all new technologies for generating solar hydrogen on a large scale (10-100 kW) and developing intermittent energy technologies.
- The second stage: in which the most cost-effective and efficient technology would be used for large-scale station models (1-1000 MW).

In 2021, Algeria issued a multi-billion-dinar hydrogen plan, of which 100 million dinars were allocated to research and development in the field of “green” hydrogen. (Boudghene Stambouli, Kitamura, Benmessaoud, & Yassaa, 2024)

The government expressed its commitment to include hydrogen in its energy export mix by 2030, as part from strategy of green hydrogen, which seeks to fully exploit all available potential. (AIT BACHIR, 2021, p. 25)

Algeria has established a Green Hydrogen Strategy 2050, which aims to create an encouraging environment that enables to develop the green hydrogen

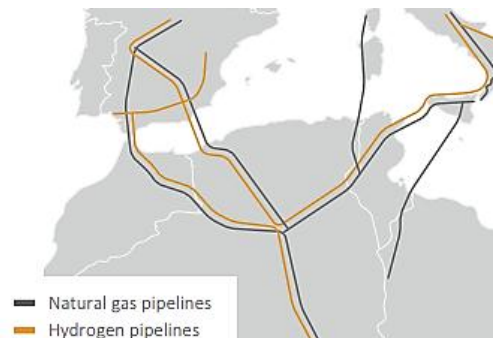
sector. As part of these efforts, the government has supported hydrogen research activities through research and development centers. (Boudghene Stambouli, Kitamura, Benmessaoud, & Yassaa, 2024)

The Algerian government has set a priority target of meeting about 10% of European hydrogen demand. (Wiedemann, 2024) And it may be able to achieve more after the events in Ukraine. In addition to the interest of many countries about the Algerian green hydrogen, such as Germany, Italy, the Netherlands and France. (Boudghene Stambouli, Kitamura, Benmessaoud, & Yassaa, 2024)

Through its plan, Algeria aimed to producing and exporting nearly 30-40 TWh of hydrogen (based fuels) by 2040. Focusing on initial projects until 2030, to developing the hydrogen sector. (IEA, 2023, p. 148) It intends to add liquefied natural gas (LNG) first, then replace it with blue hydrogen and finally with green hydrogen. by 2050 seeks to generate 25 GW of power from green and blue hydrogen as a primary goal in its energy transition plan. (Barnard, 2022, p. 15)

Since Algeria previously has a network of pipelines to Europe, this will increase the attractiveness of the hydrogen export opportunity. The shorter pipeline (Medgaz) goes to Spain, while the longer pipeline (Transmed) passes through Tunisia to Italy. (Wiedemann, 2024) Experts suggest that Algeria should, in the first phase, use existing natural gas pipelines to transport hydrogen by mixing no more than 20% of hydrogen with natural gas. (Barnard, 2022, p. 17) Figure (07) shows a schematic of the southern corridor linked Europe and Africa:

Fig.(07): Europe-North Africa hydrogen backbone infrastructure



Source: (Wijk, Wouters, Rachidi, & Ikken, 2019, p. 13)

In the first phase of the North Africa-Europe partnership, which runs from 2030 to 2035, the existing gas infrastructure from Algeria to Europe could be converted to a hydrogen transport infrastructure, as shown by the gray and orange lines. (Wijk & Wouters, 2021, p. 101)

According to the head of the research department at the Ministry of Energy and Mines, the ministry is expected to launch four pilot projects to produce green hydrogen before 2024. Three of them are being developed by the national energy company "Sonatrach", while the other project is likely to be

implemented with German partnership. The goal of these projects is primarily to include the use of green hydrogen in gas turbines, in addition to testing the hydrogen transporting via pipelines for export to Europe. (Ivanova, 2023)

From the prominent projects in this context is the partnership between Sonatrach and the Italian multinational oil and gas company (Eni), (AIT BACHIR, 2021, p. 25) which has large investment holdings in this North African country, where the two companies have actually signed several memoranda of understanding on hydrogen production filed. (Barnard, 2022, p. 16) They framed a roadmap to assess technically and financially the feasibility of an experimental project of green hydrogen manufacturing, using the electrolysis of water produced from oil fields after its treatment. (AIT BACHIR, 2021, p. 25)

In practice, Eni plans to produce green solar hydrogen in Algeria by building a gigawatt (GW) of solar energy. It will rely entirely on solar energy alone, which will reduce the use rate of the electrolyzer to 20-25%, due to the station being idle nightly and at evening. In this case, hydrogen production from solar energy is expected to cost between 4 US dollars/kg and 4.40 US dollars/kg, excluding storage, transportation and loss costs. (Barnard, 2022, p. 16)

Algeria also seeks to become an important supplier of green hydrogen to Germany, which intends to import 90% of its hydrogen needs by 2030. (RaviKumar Bhagwat & Olczak, 2020, p. 24) Many studies have confirmed that the best choice for Germany to meet its hydrogen needs by 2050 is to import it from Algeria, as the cost of a kg of Algerian green hydrogen and its exporting to Germany via pipelines was estimated at USD 1.6/kg, which is less than the cost of producing it in Germany, which is estimated at about USD1.7/kg. (Tiar, Fadlallah, Benhadji Serradj, Graham, & Aagela, 2024, p. 784)

V. Challenges of producing and exporting green hydrogen in Algeria and needful recommendations

V.1 Challenges of exporting the Algerian green hydrogen to Europe

V.1.1 Obstacles to foreign investment and lengthy regulatory procedures

According to the German Trade and Invest GTAI website, one of the obstacles to foreign investment in Algeria is prolonged procedures or regulatory complexities. (Wiedemann, 2024) However, recently, laws have been issued to improve the climate for foreign investment in Algeria, especially in solar and wind energy projects, most notably the exemption of renewable energy projects from some laws that do not encourage foreign investment, most notably the investment law that limits foreign capital ownership of projects to about 49% or less. (Behrsin, O'Malia, Prasad, Hinh, & Abdallah, 2022, p. 13)

V.1.2 Water insufficiency

Water is a basic necessity for the production of green hydrogen through electrolysis technology, (Clarke, et al., 2022, p. 70) as producing one MW of electrolysis requires about 4 m³ of pure water per day or 6 M³ of impure water per day. (Matthes, Aruffo, & Retby-Pradeau, 2020, p. 12)

Although it was previously recognized that water's cost doesn't surpass 2% of the cost of producing green hydrogen by water electrolyser, but Algeria's location in a region with water insufficiency makes it face serious challenges in managing its water resources. In this context, there is the choice of using desalinated water, especially since Algeria ranks second in the Arab world in the field of seawater desalination, (AFED, 2017, p. 87) where desalinated water or the remaining water from this process can be used in the electrolysis process.

V.1.3 Hydrogen transport problems

There are many problems when using existing natural gas pipelines for hydrogen. The pressure change can cause micro-fractures in the welded areas of pipelines which leads to hydrogen leakage. The second is the increasing costs because the three-fold increase in the energy required pushing hydrogen to move the same volume of natural gas over the same distance, because it is more widespread than NG. This raise of hydrogen transportation costs will increase the delivering price, which could reach 5 to 11 times what Europe was paying to import natural gas in 2021 without carbon pricing. (Barnard, 2022, pp. 17-18)

V.1.4 High cost of green hydrogen production

It was previously identified that the cost of green hydrogen is high due to the high costs of both electricity generated from solar or wind energy, and secondarily the high costs of water electrolysis systems. The first and the most important part of the cost don't represent a major problem for Algeria, because the cost of producing renewable electricity is low in Algeria. However, there is a challenge related to the high costs of electrolysis, which will negatively affect the cost of producing green hydrogen in Algeria. However, Algerian-European cooperation in the green hydrogen field and the exchange of related expertise is likely to reduce these costs, given that Europe is one of the world's leaders in the market of electrolysis technologies. (van Wijk & Chatzimarkaki, 2020, p. 21)

V.1.5 Energy losses

There are significant energy losses along the green hydrogen value chain, depending on the end use of hydrogen and the conversion method of hydrogen to another carrier. For example, in the stage of water electrolysis there is energy losses between 30% - 35% of the energy used in this process. While in the hydrogen transportation there is additional energy needed, which is equivalent to

10% - 12% of the energy of the hydrogen itself. (IRENA, 2020, p. 13)

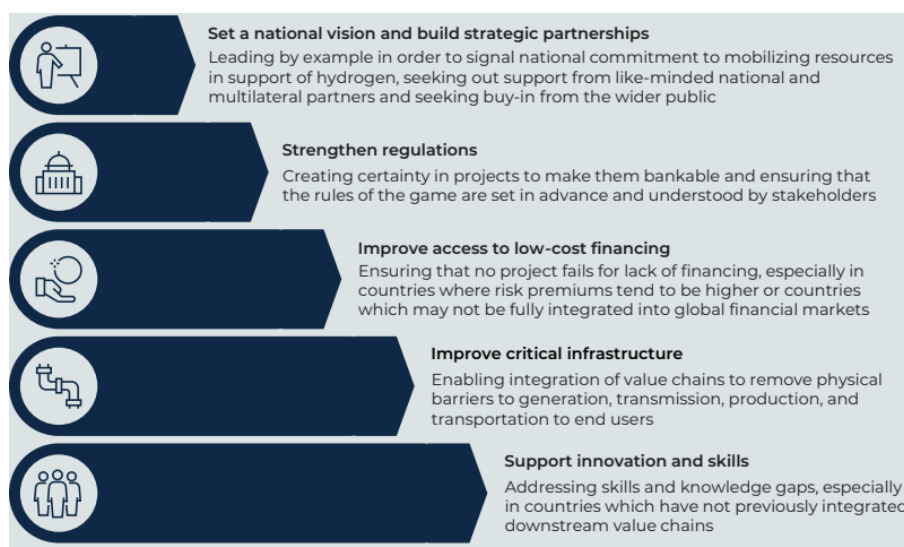
V.2 The most important recommendations submitted by the competent bodies to develop the green hydrogen economy

In order to design an environment for mutual cooperation for investment in Europe and North Africa, there are a number of considerations necessary for an action plan between North Africa and the European Union, the most important of which are: : (Wijk, Wouters, Rachidi, & Ikken, 2019, p. 27)

- The existence of a European political commitment supporting a hydrogen strategy with clear objectives, extending over successive decades.
- Consolidating the frameworks of partnership between the European public and private sectors in the field of clean energy industry, with the aim of establishing an ecosystem that supports a European clean energy industry capable of global leadership.
- Providing supporting regulatory environment and designing a market linked to it, in order to implement and develop the necessary investments.
- An integrated infrastructure for both electricity and hydrogen, and designing a policy frame for the system of its storage.
- Stimulating long-term shared cooperation between the European Union and North Africa, at the political, economic and societal levels alike.

The African Green Hydrogen Alliance (AGHA) in its side presented five keys that it sees as essential for developing the green hydrogen market in Africa, including Algeria, and they are summarized in Figure (08):

Fig.(08): key enablers to unlock North African countries green hydrogen potential



Source: (AGHA & McKinsey & Company, 2022, p. 32)

In 2020, the Hydrogen Council presented a set of requirements that must

be met in order to increase the competitiveness of green hydrogen, which Algeria could adopt, as an example of other countries, namely: (RaviKumar Bhagwat & Olczak, 2020, p. 28)

- Stimulating investment in the field of green hydrogen production, which will automatically improve its competitive cost with other types of hydrogen.
- Establishing a regulatory framework to appropriate policies, in order to create equal opportunities for clean and traditional technologies.
- Creating real market for green hydrogen and various related products.

VI. Conclusion

This research paper shows that Algeria has a valuable opportunity to become an international leader in the field of green hydrogen production especially solar hydrogen, through the efficient exploitation of its abundant renewable resources and the strengthening of international cooperation frameworks, which confirms the first hypotheses of this study.

Without forgetting the importance of developing serious policies to eviting the challenges standing the development of the green hydrogen production and exporting, most notably the problems of high production costs, transportation and storage infrastructure and energy losses, which confirms the second hypotheses of this study.

VI.1 Requirements

Success in developing green hydrogen in Algeria requires that it must:

- Establish and adopt a comprehensive and integrated strategic action plan to determine priorities,
- Stimulate and develop investments in the production, storage and transportation of green hydrogen using the most efficient water electrolysis technologies.
- Develop research and development efforts, honing skills and providing a qualified and experienced workforce cannot be overlooked.
- Develop well-thought-out policies to address the various challenges and obstacles that stand in the way of accelerating the development of the green hydrogen economy.

VI.2 Future prospects of the study

This research focused firstly on the potentials of green hydrogen production in Algeria, and the opportunities for exporting it to Europe, and secondly it presented the significant challenges that hinder these opportunities.

In the future studies, it can study and research in focusing of the real advance in green hydrogen infrastructures of production and transportation,

electrolyzer installations, costs estimation...etc. which will help the decision makers in Algeria to develop the green hydrogen sector.

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