*International Journal of Recent Technology and Applied Science*
*p-ISSN: 2721-2017, e-ISSN: 2721-7280*

Original Research Paper

# Technological and Economic Challenges of Green Hydrogen Production in Morocco for the European Market

**Bacaoui Mostafa[1*], Jazouli Taleb[1], Marwan Houssain[2]**

[1] *Faculty of Science and Technology, Sultan Moulay Slimane University. Morocco.*
[2] *Department of Innovate for Industry, Mohammed VI Polytechnic University. Morocco.*

**Article History**
**Received:**
02.01.2025

**Revised:**
29.01.2025

**Accepted:**
15.02.2025

***Corresponding Author:**
Bacaoui Mostafa
**Email:**
mostafa34@gmail.com



**Abstract:** This study explores Morocco's potential as a green hydrogen producer, focusing on its capacity to serve the European market. As the world shifts to sustainable energy, Morocco, with its abundant renewable energy resources, particularly solar and wind, is positioned to play a significant role in green hydrogen production. The study aims to assess Morocco's potential for large-scale hydrogen production, its economic and environmental benefits, implementation challenges, and export opportunities to Europe. A descriptive qualitative methodology was used, using a case study analysis of Morocco's energy policies, infrastructure, and potential. Data were collected through document analysis and semi-structured interviews with energy experts and policymakers. The study findings reveal that Morocco's strategic location, coupled with its renewable energy resources, make it an ideal candidate for green hydrogen production. However, technical challenges, such as inefficient electrolysis technology, and logistical issues associated with infrastructure development pose significant barriers. Despite these challenges, Morocco's growing role in the global green hydrogen market presents substantial economic benefits, including job creation and emission reductions. Future research should address specific technological barriers, including storage and transportation solutions, and further explore financial models to support large-scale green hydrogen projects. In addition, future research should investigate the regulatory framework needed to position Morocco as a competitive player in the global hydrogen market.

**Keywords:** Electrolysis Technology, Energy Policy, Green Hydrogen, Green Hydrogen Market, Renewable Energy.

## 1. Introduction

The global transition to green energy has become an urgent priority to mitigate the impacts of climate change and reduce greenhouse gas emissions. Increasing reliance on renewable energy corresponds with the objectives of the Paris Agreement, which seeks to limit the rise in global temperatures to well below 2°C compared to pre-industrial levels [1]. Among renewable energy technologies, green hydrogen has received growing attention as a versatile and sustainable energy carrier capable of aiding in the decarbonization of difficult sectors such as heavy industry and long-distance transport [2].

North Africa occupies a crucial position in the global renewable energy landscape due to its abundant solar and wind resources. These natural advantages present considerable chances for countries in the region to position themselves as leaders in renewable energy production, particularly in green hydrogen [3]. Among these countries, Morocco has demonstrated notable progress in developing renewable energy infrastructure by leveraging its geographical benefits and commitment to sustainability initiatives [4].

Morocco's proactive approach to green energy is evident in its substantial investments in solar and wind projects, establishing itself as a regional hub for renewable energy development [5] [6]. These investments meet local energy requirements and also create opportunities to export renewable energy to the European market, which is rapidly increasing its demand for low-carbon alternatives [2] [7] [8]. Nevertheless, despite its potential, Morocco faces numerous challenges in establishing a competitive green hydrogen sector, including technical inefficiencies in electrolysis technology, infrastructure issues, and regulatory barriers.

Although current studies have explored Morocco's renewable energy sector, there is still a lack of insight into the particular strategies required for incorporating green hydrogen into the worldwide energy market. Past research has not thoroughly examined how Morocco can address technological, economic, and policy challenges in the production and export of green hydrogen. Moreover, there has been minimal focus on Morocco's competitive standing compared to other emerging green hydrogen producers, especially within North Africa and the larger global market. Furthermore, the enduring economic effects, such as the generation of employment, enhancements in trade balance, and progress in technology, necessitate additional exploration.

This study aims to analyze Morocco’s potential as a major producer of green hydrogen in North Africa. It seeks to identify the key strategies needed to build a sustainable and competitive green hydrogen export market to Europe. Furthermore, it evaluates the economic impact of the initiative on the Moroccan economy, emphasizing job creation, technological innovation, and improving the trade balance. Another objective is to assess the challenges and opportunities associated with implementing Morocco’s green hydrogen initiative. This includes examining the technical, financial, and regulatory hurdles that must be overcome to achieve long-term success. By focusing on these objectives, the study provides a comprehensive understanding of Morocco’s position in the global green energy transition.

This study contributes to the growing literature on renewable energy development by highlighting Morocco’s important role in the global transition to green energy. It underlines the importance of green hydrogen in achieving a low-carbon economy and examines its potential to transform Morocco’s energy and economic landscape. In addition, the study offers valuable insights for policymakers, industry stakeholders, and researchers interested in sustainable energy development. By providing a detailed analysis of Morocco’s green hydrogen initiatives, the study supports the formulation of effective strategies to address existing challenges and maximize the benefits of renewable energy investments. The study discusses the broader implications of green hydrogen development for global energy markets, particularly in the context of North Africa-Europe energy cooperation. The study shows how Morocco’s progress in renewable energy can serve as a model for other countries seeking to achieve energy security and sustainability goals

## 2. Literature Review

### 2.1. Global Energy Transition and the Hydrogen Economy

The global energy transition is a significant shift from fossil-based energy systems to renewable sources, driven by the need to mitigate climate change and promote sustainable development. This transition is characterized by the rapid expansion of renewable energy technologies such as solar, wind, and hydropower, as countries seek to reduce greenhouse gas emissions and decarbonize their

energy sectors. Among the most promising alternatives in this transition is hydrogen, especially green hydrogen, which is produced using renewable energy sources such as wind and solar. Green hydrogen has been identified as an important solution for sectors that are difficult to electrify, such as heavy industry and long-haul transport [8].

Hydrogen's potential in the global energy landscape has attracted significant attention from governments and industry. As a versatile energy carrier, hydrogen can be used in a variety of applications, including energy storage, power generation, and transport. The global hydrogen economy is growing rapidly, with countries around the world setting ambitious targets for hydrogen production and consumption. The European Union, for example, has launched several initiatives to develop hydrogen infrastructure, including the European Hydrogen Backbone, which aims to create a hydrogen pipeline network to facilitate cross-border trade [9].

Developing countries play a key role in the emerging hydrogen economy. Many of these countries have abundant renewable energy resources, particularly solar and wind power, that can be harnessed for green hydrogen production. By harnessing their renewable potential, developing countries are becoming major players in the global hydrogen market, supplying clean energy to high-demand regions such as Europe. Countries such as Chile, Morocco and Australia are exploring the potential for green hydrogen production, with Morocco being a prominent example due to its abundant solar and wind power resources [10].

The growing demand for clean energy, particularly in Europe, creates significant opportunities for developing countries to enter the hydrogen market. The European Union is expected to become one of the largest importers of green hydrogen in the coming decades, with a projected market value of over €40 billion by 2030 [11]. This demand provides a strong incentive for countries with favorable renewable energy conditions to invest in hydrogen production. Furthermore, green hydrogen exports offer developing countries a pathway to economic growth, job creation and energy security, contributing to their overall development goals.

Recent research explores the potential of a green hydrogen economy in developing countries, focusing on production costs, infrastructure requirements, and the policy framework needed to support hydrogen initiatives. Research suggests that while initial investments in hydrogen production technologies can be high, the long-term benefits in terms of energy security, environmental sustainability, and economic development far outweigh the costs. The scalability of green hydrogen production, driven by technological advances and declining renewable energy costs, is expected to make hydrogen a competitive alternative to fossil fuels in the near future [12].

The role of international collaboration and technology transfer in the hydrogen economy is also a topic of growing interest. Many developing countries, despite their abundant renewable resources, face challenges in financing and implementing large-scale hydrogen projects. International partnerships and investment from developed countries help bridge this gap, providing the capital and expertise needed to support the growth of the green hydrogen sector. In addition, the establishment of a global hydrogen trading network, including the transportation of hydrogen via pipelines or ammonia, is critical to ensuring the success of the hydrogen economy [13].

As the hydrogen economy continues to develop, several studies examine the regulatory framework and potential policy mechanisms needed to foster its growth. The implementation of supportive policies, including subsidies for green hydrogen production, tax incentives for infrastructure development, and research grants for technological innovation, remain essential to accelerate the transition to a hydrogen-powered future. In addition, the development of international standards for hydrogen production, storage, and transportation ensures the safe and efficient use of hydrogen in the global energy system [14].

Despite the promising prospects for green hydrogen, challenges remain in scaling up production and building a global hydrogen market. Technical challenges associated with hydrogen production, storage, and distribution must be overcome to reduce costs and increase efficiency. Furthermore, political and regulatory uncertainties, particularly in developing countries, may hinder investment and slow the progress of hydrogen projects. Therefore, a comprehensive approach involving governments, industry stakeholders, and international organizations is needed to unlock the full potential of green hydrogen [15].

The global energy transition presents significant opportunities for hydrogen, particularly green hydrogen, to play a leading role in the future energy landscape. Developing countries, with their renewable energy resources, are well positioned to become major suppliers of green hydrogen to the

global market. However, challenges related to technology, policy, and financing must be overcome to ensure the successful integration of hydrogen into the global energy mix. Through international collaboration and supportive policies, the hydrogen economy can contribute to a sustainable and equitable energy future.

### 2.2. Renewable Energy in Morocco

Morocco has emerged as a leader in renewable energy development in Africa, with a strong commitment to achieving sustainable energy goals. The country has abundant renewable energy resources, especially solar and wind power, making it an ideal candidate for large-scale renewable energy projects. Morocco's strategic location in the MENA region, coupled with favorable climatic conditions, allows the country to harness its solar and wind power potential to meet its growing energy demand and reduce its dependence on imported fossil fuels [9].

One of Morocco's most notable renewable energy projects is the Noor Ouarzazate Solar Complex, which is one of the largest solar power plants in the world. The Noor project, with a total capacity of 580 MW, is a symbol of Morocco's commitment to renewable energy and sustainable development. The plant uses concentrated solar power (CSP) technology, which allows for energy storage and continuous electricity generation, even after the sun goes down. The project has not only helped Morocco achieve its renewable energy targets, but has also attracted international investment and positioned the country as a leader in solar energy development [10].

In addition to solar energy, Morocco has also made significant progress in developing wind energy. The country has several wind farms, including the Tarfaya Wind Farm, which has a capacity of 301 MW, making it one of the largest wind projects in Africa. Morocco's wind energy potential is enormous, with estimates suggesting that the country could generate more than 6,000 MW of wind energy by 2030. This would make a significant contribution to the country's renewable energy mix and help meet its energy security and sustainability goals [11].

The Moroccan government has set ambitious targets for renewable energy development under the Morocco Energy Strategy 2030, aiming to achieve 52% of total energy capacity from renewable sources by 2030. The strategy includes the development of solar, wind and hydropower projects, as well as the establishment of a robust energy infrastructure to support the integration of renewables into the national grid. This vision reflects Morocco's long-term commitment to becoming a regional hub for renewable energy production and export, particularly in the context of green hydrogen [12].

Morocco's renewable energy projects are also in line with its broader economic development goals. The expansion of renewable energy infrastructure creates thousands of jobs, attracts foreign investment, and contributes to the country's energy independence. In addition, the renewable energy sector has the potential to increase Morocco's export capacity, especially in the context of green hydrogen production, which can be exported to Europe and other global markets. This economic diversification is crucial for Morocco's development, as it reduces the country's dependence on fossil fuel exports and promotes a more sustainable energy economy [13].

Renewable energy development in Morocco is supported by several key policies and initiatives. The Moroccan Agency for Sustainable Energy (MASEN) plays a leading role in coordinating and implementing renewable energy projects in the country. The agency has been instrumental in promoting the Noor solar project and other renewable energy initiatives, working closely with international partners and stakeholders. In addition, the government has introduced several financial incentives and subsidies to attract private investment in renewable energy, including feed-in tariffs and tax exemptions [14].

Despite significant progress in renewable energy development, Morocco faces several challenges in scaling up its renewable energy sector. One of the main challenges is the integration of renewable energy into the national electricity grid, which requires significant investment in electricity grid infrastructure and energy storage systems. In addition, the country must address issues related to energy efficiency, grid stability, and financing to ensure the success of sustainable renewable energy projects [15].

As Morocco continues to expand its renewable energy capacity, the country is also exploring the potential for green hydrogen production. With its abundant renewable energy resources, Morocco has the potential to become a leading producer and exporter of green hydrogen, particularly to Europe, where demand for clean energy is expected to increase. The development of a hydrogen economy in

Morocco could provide significant economic and environmental benefits, contributing to the country's sustainable development goals and strengthening its position in the global energy market.

### 2.3. Challenges and Opportunities in Green Hydrogen Production

Green hydrogen production presents several technical challenges, including the need for efficient and cost-effective electrolysis technology. Electrolysis, which uses electricity to split water into hydrogen and oxygen, is currently the most widely used method for producing green hydrogen. However, this process requires large amounts of renewable energy and electricity, making it more expensive than traditional hydrogen production methods, such as steam methane reforming. Research is ongoing to improve electrolyzer efficiency and reduce the cost of green hydrogen production [17].

The high cost of green hydrogen production remains one of the main barriers to its widespread adoption. Although the cost of renewable energy has fallen significantly in recent years, the cost of electrolysis equipment and infrastructure remains a challenge. Several studies have suggested that economies of scale and technological advances will help reduce costs over time, but the initial investment required for green hydrogen production remains large. Governments and private sector actors need to develop innovative financing models and policy frameworks to support the growth of the green hydrogen sector [18].

Logistical challenges in hydrogen distribution and storage are also significant barriers to the growth of the green hydrogen economy. Hydrogen is a low-density gas that requires specialized storage and transportation infrastructure, including high-pressure tanks, pipelines, and liquefaction facilities. Developing an efficient and cost-effective hydrogen transportation network is essential to scale up green hydrogen production and facilitate international trade. Several projects are currently underway to develop hydrogen transportation solutions, including the construction of hydrogen pipelines and shipping routes [19].

In addition to technical and logistical challenges, the success of green hydrogen production depends on the development of a supportive regulatory environment. Governments need to implement policies that incentivize investment in hydrogen production, infrastructure development, and research and innovation. Several countries, including Germany, the Netherlands, and Japan, have introduced hydrogen-specific policies, such as subsidies, tax incentives, and research grants. These policies are essential to reduce the financial risks associated with green hydrogen production and accelerate the transition to a hydrogen-powered future [20].

Europe is a major market for green hydrogen, with several countries in the region setting ambitious hydrogen targets. The European Union has identified green hydrogen as a key component of its Green Deal and aims to become the world's first carbon-neutral continent by 2050. The European Commission has developed a Hydrogen Strategy for a Climate-Neutral Europe, which outlines a roadmap for the development of a hydrogen economy, including the establishment of hydrogen production, transport and distribution infrastructure [21]. Morocco, with its abundant renewable energy resources, is well-positioned to export green hydrogen to Europe, especially as demand for clean energy increases.

The European green hydrogen market presents significant opportunities for countries such as Morocco, which can leverage its renewable energy potential to produce green hydrogen at competitive prices. Several studies have suggested that Morocco could become a major exporter of green hydrogen to Europe, especially in the context of the EU's growing hydrogen demand. Morocco's proximity to Europe, combined with its renewable energy resources, makes it an ideal location for the production and export of green hydrogen [22].

Despite the promising market opportunities, challenges remain in developing the infrastructure needed to support international trade in green hydrogen. Long-distance transport and storage of hydrogen require significant investment in pipelines, ships and storage facilities. In addition, safety standards and regulations for hydrogen transport must be established to ensure the safe handling and distribution of hydrogen across borders [23].

## 3. Methodology

This research uses a descriptive qualitative design with a case study approach, focusing on energy policy and infrastructure in Morocco. The study examines Morocco's role in green hydrogen development and its potential to serve the European market.

Data collection was conducted throughout 2024 and involved multiple methods. First, document analysis was conducted by reviewing official Moroccan government reports, European energy policies, and global energy investment reports. Second, semi-structured interviews were conducted with 30 respondents, including energy experts, policymakers, and energy company representatives in Morocco. These respondents were selected from various cities, including Rabat, Casablanca, and Marrakesh, to ensure broad geographical representation.

Content analysis was applied to identify trends and patterns in Moroccan energy policy and the green hydrogen market. A comparative approach was used to assess Morocco's position in relation to other North African countries in the development of renewable energy and green hydrogen infrastructure.

## 4. Finding and Discussion

### 4.1. Morocco's Potential as a Green Hydrogen Producer

Morocco's strategic geographic location, coupled with its abundant solar and wind resources, make it a key player in green hydrogen production. With access to the Mediterranean Sea and its proximity to Europe, Morocco is ideally located to export green hydrogen to the European market. Renewable energy projects, particularly solar and wind, are actively used to produce hydrogen, contributing to Morocco's capacity for large-scale green hydrogen production.

Table 1. Geographical and Renewable Energy Advantages for Green Hydrogen Production in Morocco

| Factor | Details |
|---|---|
| Location | Proximity to Europe, access to the Mediterranean Sea |
| Solar Energy Potential | High solar radiation, especially in southern regions |
| Wind Energy Potential | Significant wind resources along the coast |
| Export Routes | Ports like Tangier Med, ideal for hydrogen transport to Europe |

Figure 1 shows the distribution of solar and wind energy resources across Morocco, highlighting the regions with the highest potential for green hydrogen production.

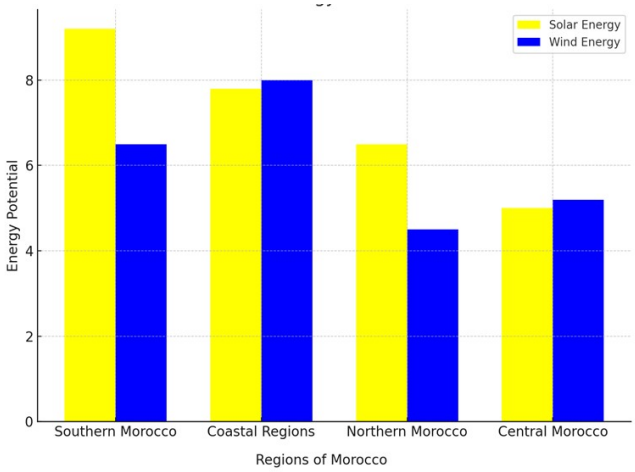


Figure 1. Solar and Wind Energy Resources in Morocco

### 4.2. Economic and Environmental Benefits

The development of green hydrogen in Morocco offers significant economic benefits, including job creation and economic diversification. Investment in renewable energy infrastructure generates employment opportunities in the construction, technology, and research sectors. In addition, the transition to green hydrogen contributes significantly to reducing Morocco's carbon footprint, while also aligning with global efforts to cut greenhouse gas emissions.

Table 2. Economic Impact of Green Hydrogen Development in Morocco

| Benefit | Description |
|---|---|
| Job Creation | Direct and indirect employment in energy, manufacturing, and research sectors |
| Economic Diversification | Reduced reliance on fossil fuels and increased exports |
| Technology Innovation | Development of new technologies in hydrogen production, storage, and transport |
| Carbon Emission Reduction | Significant reductions in emissions through clean hydrogen production |

Figure 2 illustrates the projected number of jobs created in various sectors as green hydrogen initiatives expand in Morocco.

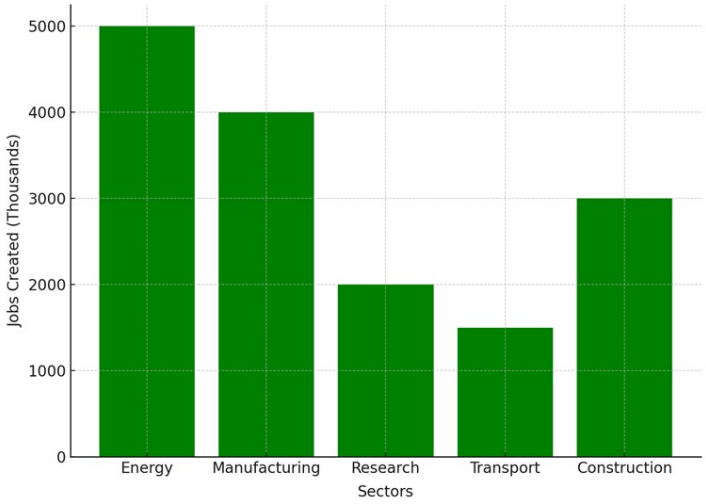


Figure 2. Job Creation Impact of Green Hydrogen Projects in Morocco

### 4.3. Implementation Challenges

Despite its significant potential, Morocco faces several challenges in implementing large-scale green hydrogen production. Technically, the country must overcome limitations in hydrogen electrolysis technology, which remains expensive and inefficient. In addition, the infrastructure needed to efficiently transport hydrogen to Europe is still under development, presenting logistical challenges. Financially, high production costs remain a barrier to scaling up the green hydrogen sector, and securing foreign investment is critical to bridging this gap.

International Journal of Recent Technology and Applied Science, vol 7, no. 1, pp. 44-54, March 2025. **DOI: 10.36079/lamintang.ijortas-0701.803**

Table 3. Technical and Financial Challenges in Green Hydrogen Production in Morocco

| Challenge | Description |
|---|---|
| Electrolysis Technology | High costs and energy inefficiency in water electrolysis for hydrogen production |
| Hydrogen Transport Infrastructure | Development of pipelines and shipping routes for hydrogen export |
| Production Costs | High initial investment and operational costs |
| Foreign Investment | Need for international investment and collaboration |

Figure 3 compares the costs of different hydrogen production technologies, including electrolysis and natural gas reforming, highlighting the higher costs associated with green hydrogen production in Morocco.

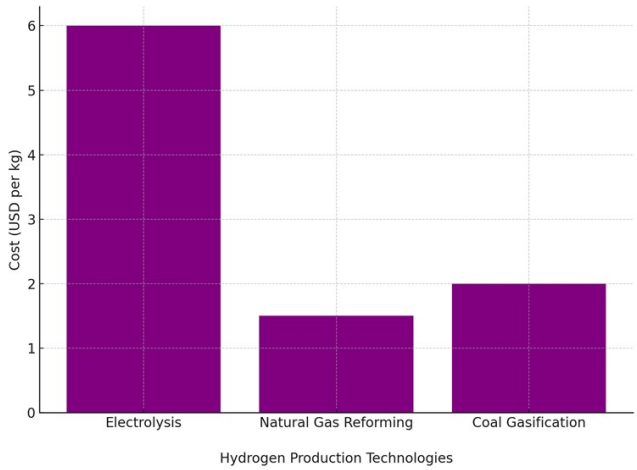


Figure 3. Comparison of Costs of Hydrogen Production Technologies

### 4.4. Export Opportunities to Europe

European demand for green hydrogen is growing rapidly as the continent seeks to meet its renewable energy targets. Morocco is well positioned to capitalize on this demand through strategic partnerships with European countries, especially Germany, which has been a key partner in promoting green hydrogen initiatives. Bilateral agreements, coupled with Morocco's renewable energy infrastructure, provide a strong foundation for future hydrogen exports to Europe.

Table 4. Major European Markets for Moroccan Green Hydrogen

| Country | Market Demand for Green Hydrogen | Partnership Opportunities |
|---|---|---|
| Germany | High demand for clean energy solutions | Collaborative projects on hydrogen production and export |
| Netherlands | Growing interest in low-carbon energy imports | Investment in infrastructure and transport routes |
| Spain | Regional demand for renewable hydrogen | Joint ventures for hydrogen export to Europe |

Figure 4 shows the projected increase in European demand for green hydrogen from 2023 to 2030, with a focus on Morocco's role as a major supplier.

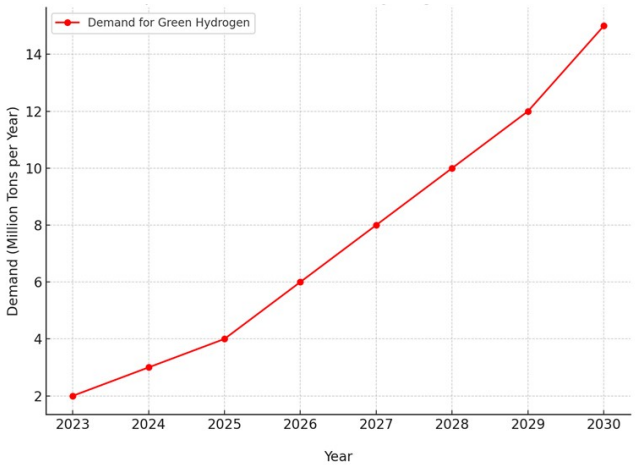


Figure 4. European Demand for Green Hydrogen (2023-2030)

Morocco has great potential to become a major producer of green hydrogen in North Africa, supported by its abundant renewable energy resources and strategic geographic location close to Europe. Morocco's solar and wind capacities position it as a major player in large-scale green hydrogen production, which is essential for decarbonizing industry and transport. With its proximity to European markets, particularly through ports such as Tangier Med, Morocco has a strategic advantage in exporting green hydrogen to Europe.

To harness Morocco's potential as a green hydrogen producer, several steps should be taken:

1) Invest in Research and Development
   Continued investment in R&D will be essential to advance hydrogen production technologies, particularly in electrolysis and storage. Innovation in these areas will reduce production costs and increase efficiency, making green hydrogen more competitive.
2) Foster International Cooperation
   Morocco should strengthen its partnerships with European countries to address technical challenges and secure the necessary foreign investment. Collaborative projects on infrastructure development, such as pipelines and shipping routes, will increase Morocco's capacity to export hydrogen to Europe.
3) Promote Incentive-Based Policies
   Policymakers should develop attractive incentives to encourage foreign investment in Morocco's renewable energy sector. These could include tax breaks, subsidies, or guarantees for investors involved in green hydrogen production and transportation infrastructure.

## 5. Conclusion

The development of green hydrogen in Morocco has significant implications for the national and global energy landscape. The green hydrogen sector can strengthen Morocco's position as a global player in the green energy transition, diversify its economy, reduce carbon emissions, and boost technological innovation. This study lays the groundwork for future energy policy development, guiding decision-makers to create more effective strategies for renewable energy and hydrogen production. The study emphasizes the need for technical progress and international collaboration to make Morocco a competitive player in the green hydrogen market.

To harness Morocco's potential as a green hydrogen producer, several key steps must be taken. First, investing in research and development is essential to advancing hydrogen production technologies, particularly improving electrolysis efficiency and developing innovative storage solutions. This will help reduce production costs and enhance Morocco's competitiveness in the

global market. Second, fostering international cooperation with European partners is crucial to address technical challenges and secure investments in infrastructure, such as hydrogen pipelines and shipping routes, to facilitate export. Lastly, promoting incentive-based policies, such as tax breaks, subsidies, and investment guarantees, will attract foreign investments and encourage the development of Morocco's green hydrogen sector, ensuring long-term growth and economic diversification.

While this study provides a broad overview of Morocco's green hydrogen potential, further research is needed to delve deeper into the technological barriers and specific financial models for scaling up production. Future studies should focus on cost-effective solutions for hydrogen storage and transportation, as well as the long-term impact of green hydrogen on Morocco's energy security and economy. Additionally, developing a regulatory framework in line with international standards for hydrogen trade could enhance Morocco's ability to compete in the global market.

## References

[1] J. Rogelj, M. den Elzen, N. Höhne, T. Fransen, H. Fekete, H. Winkler, W. Schaeffer, F. Sha, K. Riahi, and M. Meinshausen, "Paris Agreement climate proposals need a boost to keep warming well below 2 °C," Nature, vol. 534, no. 7609, pp. 631–639, 2020.

[2] Q. Hassan, S. Algburi, A. Z. Sameen, H. M. Salman, and M. Jaszczur, "Green hydrogen: A pathway to a sustainable energy future," *International Journal of Hydrogen Energy*, vol. 50, part B, pp. 310-333, 2024.

[3] J. Lilliestam, A. Patt, and G. Bersalli, "The effect of carbon pricing on technological change for full energy decarbonization: A review of empirical ex-post evidence," WIREs Climate Change, vol. 11, no. 1, 2020.

[4] B. E. Lebrouhi, B. Lamrani, Y. Zeraouli, and T. Kousksou, "Key challenges to ensure Morocco's sustainable transition to a green hydrogen economy," *International Journal of Hydrogen Energy*, vol. 49, pp. 488-508, 2024.

[5] M. Boulakhbar, "Towards a large-scale integration of renewable energies in Morocco," *J. Energy Storage*, 2020.

[6] Q. Hassan, A. M. Abdulateef, S. A. Hafedh, A. Al-samari, J. Abdulateef, A. Z. Sameen, H. M. Salman, A. K. Al-Jiboory, S. Wieteska, and M. Jaszczur, "Renewable energy-to-green hydrogen: A review of main resources, routes, processes and evaluation," *International Journal of Hydrogen Energy*, vol. 48, no. 46, pp. 17383-17408, 2023.

[7] Q. Hassan, P. Viktor, T. J. Al-Musawi, B. M. Ali, S. Algburi, H. M. Alzoubi, A. K. Al-Jiboory, A. Z. Sameen, H. M. Salman, and M. Jaszczur, "The renewable energy role in the global energy transformations," *Renewable Energy Focus*, vol. 48, 2024.

[8] C. E. Hoicka, J. Lowitzsch, M. C. Brisbois, A. Kumar, and L. R. Camargo, "Implementing a just renewable energy transition: Policy advice for transposing the new European rules for renewable energy communities," *Energy Policy*, vol. 156, 2021.

[9] P. Allen, H. Lyons, and J. C. Stephens, "Women's leadership in renewable transformation, energy justice and energy democracy: Redistributing power," *Energy Res. Soc. Sci.*, vol. 57, 2019.

[10] V. P. Müller and W. Eichhammer, "Economic complexity of green hydrogen production technologies - a trade data-based analysis of country-specific industrial preconditions," *Renewable and Sustainable Energy Reviews*, vol. 182, 2023.

[11] S. G. Nnabuife, K. A. Quainoo, A. K. Hamzat, C. K. Darko, and C. K. Agyemang, "Innovative strategies for combining solar and wind energy with green hydrogen systems," *Appl. Sci.*, vol. 14, no. 21, 2024.

[12] A. Elkhatat and S. A. Al-Muhtaseb, "Combined 'Renewable Energy–Thermal Energy Storage (RE–TES)' systems: A review," *Energies*, vol. 16, 2023.

[13] M. Stolte, F. D. Minuto, and A. Lanzini, "Optimizing green hydrogen production from wind and solar for hard-to-abate industrial sectors across multiple sites in Europe," *Int. J. Hydrogen Energy*, vol. 79, pp. 1201–1214, 2024.

[14] S. A. Nekrasov, "Reducing costs for integration of renewable energy sources: A way to making renewable energy more accessible," *Therm. Eng.*, vol. 68, pp. 593–603, 2021.

[15] A. Islam, T. Islam, H. Mahmud, O. Raihan, M. S. Islam, H. M. Marwani, M. M. Rahman, A. M. Asiri, M. M. Hasan, M. N. Hasan, M. S. Salman, K. T. Kubra, M. A. Shenashen, M. C. Sheikh,

and M. R. Awual, "Accelerating the green hydrogen revolution: A comprehensive analysis of technological advancements and policy interventions," *Int. J. Hydrogen Energy*, vol. 67, pp. 458–486, 2024.

[16] C. B. Hendricks and T. N. Walker, "Scaling up green hydrogen production: Policies and financial incentives," *Sustainable Energy Journal*, vol. 29, no. 2, pp. 210-225, 2024.

[17] K. Farhana, A. S. F. Mahamude, and K. Kadirgama, "Comparing hydrogen fuel cost of production from various sources - a competitive analysis," *Energy Convers. Manag.*, vol. 302, 2024.

[18] I. Marouani, T. Guesmi, B. M. Alshammari, K. Alqunun, A. Alzamil, M. Alturki, and H. H. Abdallah, "Integration of renewable-energy-based green hydrogen into the energy future," *Processes*, vol. 11, no. 9, 2023.

[19] F. Ueckerdt, C. Bauer, A. Dirnaichner, J. Everall, R. Sacchi, and G. Luderer, "Potential and risks of hydrogen-based e-fuels in climate change mitigation," *Nature Clim. Chang.*, vol. 11, pp. 384–393, 2021.

[20] S. G. Nnabuife, E. Oko, B. Kuang, A. Bello, A. P. Onwualu, S. Oyagha, and J. Whidborne, "The prospects of hydrogen in achieving net zero emissions by 2050: A critical review," *Sustainable Chemistry for Climate Action*, vol. 2, 2023.

[21] A. Aftab, A. Hassanpouryouzband, Q. Xie, L. L. Machuca, and M. Sarmadivaleh, "Toward a fundamental understanding of geological hydrogen storage," *Ind. Eng. Chem. Res.*, vol. 61, no. 9, pp. 3233–3253, 2022.

[22] S. Anwar, F. Khan, Y. Zhang, and A. Djire, "Recent development in electrocatalysts for hydrogen production through water electrolysis," *Int. J. Hydrogen Energy*, vol. 46, no. 63, 2021.

[23] C. Tsiklios, M. Hermesmann, and T. E. Müller, "Hydrogen transport in large-scale transmission pipeline networks: Thermodynamic and environmental assessment of repurposed and new pipeline configurations," *Appl. Energy*, vol. 327, 2022.