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POLICY PAPER

The Case of Green Hydrogen in Morocco

Maintaining a competitive edge between domestic demands and international market pressures

ANALYSIS

Imprint

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Introduction: From Part of the Problem to Part of the Solution – Changing Hydrogen from Grey to Green

In 2021, around 70% of the world's energy requirements for dedicated hydrogen[1] production were met by methane (CH^4) as feedstock. This 'grey hydrogen' is produced using the Steam-Methane Reforming (SMR) method to separate hydrogen atoms from carbon atoms in methane. However, this is a highly endothermic reaction, which releases carbon dioxide (CO^2) into the atmosphere.

The remaining 30% of hydrogen production was met with coal (brown hydrogen). Electrolysis (i.e., the process of using electricity to split water (H^2O) into dihydrogen (H^2) and oxygen (O^2)) and biomass gasification barely met 0.2% of the total energy demand for hydrogen production. Less than 1% of the hydrogen produced with fossil fuels was from facilities equipped with carbon capture, utilization, and storage (CCUS) (blue hydrogen) (IEA, 2022).

The production cost of hydrogen from natural gas is influenced by a range of technical and economic factors, with gas prices and capital expenditures being the two most important. Fuel costs are the largest cost component, accounting for between 45% and 75% of production costs. Therefore, the production of hydrogen is emission intensive. It is responsible for around 830 million tons of CO^2 per year, equivalent to the CO^2 emissions of the United Kingdom and Indonesia combined.

Supplying hydrogen to industrial users is now a major business around the world. Demand for hydrogen, which has grown more than threefold since 1975, continues to rise – almost entirely supplied by fossil fuels, with 6% of global natural gas and 2% of global coal going to hydrogen production (IEA, 2019). With growing climate change awareness and governments net zero ambitions, demand for zero carbon hydrogen or green hydrogen (Green H2) is expected to grow exponentially in the future, reaching 20.000 TWh in 2050 (WEC, 2018).

Green H2 is commonly produced by electrolysis from renewable energy sources. As the cost of renewables continues to plummet and electrolysis technologies are expected to become more mature and competitive with conventional unabated fossil-based technologies, green H2 has the potential to take over the proportion of grey, brown, and blue production for chemical and industrial processes; (2) can reduce dependence on fossil fuels for deep decarbonization of the economy for hard-to-electrify sectors either by acting as a fuel burned in combustion engines or by producing electricity from hydrogen in a device known as hydrogen-powered fuel cells; and (3) is also seen as an enabling technology - enabling renewables through long-duration energy storage and offering flexibility through Power-to-X applications.

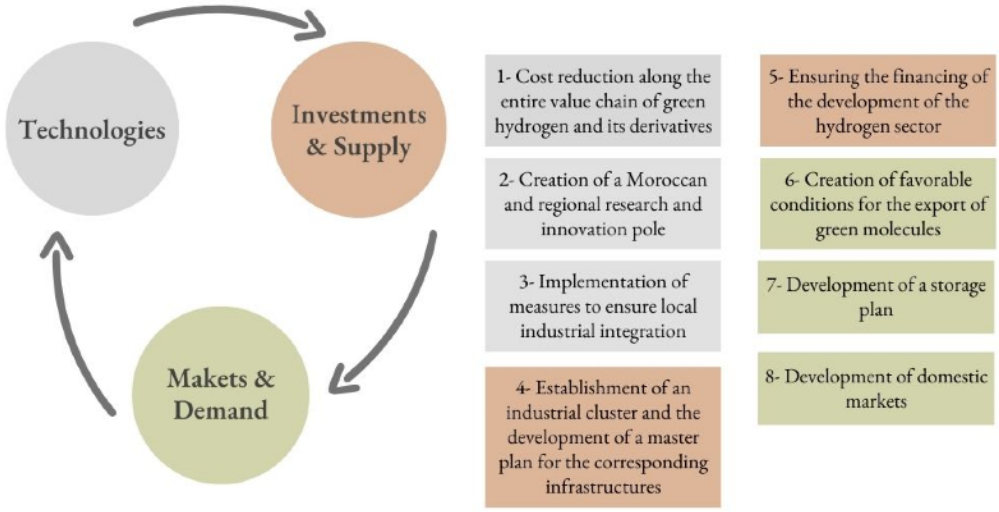
[1] Hydrogen (H) consists of a single proton and its atom has only one electron. The molecule of dihydrogen (H2) is made up of two hydrogen atoms joined by a single bond. Commonly, the term hydrogen is actually used to refer to dihydrogen.

1. Analysis: Ambitious Strategies and Investment in Renewables Provide Early-Adopter Advantages for Morocco in Green Hydrogen

Since 2009, the Kingdom of Morocco has adopted an ambitious energy strategy, which drove its energy transition by focusing primarily on developing renewable energy in the electricity sector. In 2020, nearly 20% of electricity is generated from renewable energy, and the share of the latter in the installed capacity is close to 37% (Ministry of Energy Transition and Sustainable Development, 2022).

Recently, Morocco has initiated a new process aimed at creating an economic and industrial sector around green molecules- namely hydrogen, ammonia, and methanol- to strengthen its transition in sectors that are difficult to decarbonize. Today, the world market for hydrogen is essentially industrial. It is mainly used in petroleum and chemical industry processes, notably for the desulfurization of petroleum fuels and the synthesis of ammonia for fertilizers.

Figure 1: Strategic areas of Morocco's Green Hydrogen Roadmap



According to the roadmap, Morocco intends to produce green H2 through electrolysis technology using green electricity. Hydrogen can also exist in its natural form in underground deposits. Studies have shown the availability of this potential in many countries, including Mali and the United States. In the case of Morocco, the National Office of Hydrocarbons (ONHYM) is currently studying the national potential in this field. An initial study has identified 8 areas of interest, including 2 areas with significant concentrations of surface infiltration of natural hydrogen. ONHYM plans to map, model, drill, and experimentally monitor the identified sites.

Hitting the right note: combining public investment and market forces in pilot programmes
As green H2 is at the crossroads of several sectors, many institutions and public companies could be involved at different levels in its market development. These institutions include the Ministry of Energy Transition and Sustainable Development, the Ministry of Economy and Finance, the Ministry of Industry, Investment, Trade, and Digital Economy, the Institute for Research on Solar and New Energies (IRESEN), the Moroccan Agency for Sustainable Energy (MASEN), the National Office of Water and Electricity (ONEE), the National Electricity Regulatory Authority (ANRE), and the National Office of Hydrocarbons and Mines.

Institutional and regulatory landscape

Morocco created new institutions dedicated explicitly to green H2. For instance, the National Hydrogen Commission aims to reinforce Morocco's strategy in renewable energy development, ensure its energy independence, and reduce greenhouse gases. It will also be responsible for guiding and monitoring the implementation of studies in the field of hydrogen, as well as examining the implementation of the roadmap to produce hydrogen and its derivatives.

In addition, Green H2 Morocco was created by the Ministry of Energy Transition and Sustainable Development in 2021. Its objective is to contribute to the emergence of a competitive green H2 sector, to strengthen the capacities of local actors in the production, use, and development of the green molecule and to stimulate collaborative innovation. Besides, the Moroccan Association for Hydrogen and Sustainable Development (AMHYD) brings together hydrogen and fuel cell actors, companies, laboratories, research institutes, competitiveness clusters, local authorities, and regional associations.

Pilots to test technology and markets

The green H2 industry is still in its infancy in Morocco. As such, there isn't a fully operational market for it yet. However, numerous pilot projects have sprung up as a first step in implementing the national "Green Hydrogen Roadmap," by acting as Proof of Concept, thus capitalizing on Morocco's renewable energy ecosystem- including research platforms, public agencies, energy service companies, clusters, and industry associations.

One example is the Power-to-X project, which is the first large-scale green H2 industrial project in Morocco, in collaboration between MASEN and the German government. It consists of building a 100 MW renewable energy plant to produce green H2 through electrolysis and is scheduled to be commissioned in 2025. Another example is the Hevo Ammonia Morocco Project, which aims to produce green ammonia and hydrogen with a Portuguese company, Fusion Fuel Green, and a global provider of engineering solutions, Consolidated Contractors (CCC). The project was expected to start in 2022 after the completion of the feasibility study.

In addition, a small-scale green ammonia production project is also being developed in partnership with the OCP Group (Morocco's state-owned enterprise producing phosphate and fertilizers), IRESEN, Mohammed VI Polytechnic University, and the Fraunhofer IMWS & IGB centers. This pilot project will have a capacity of 4 tons of green ammonia per day and will be equipped with an electrolysis capacity of 4MW.

More recently, the Moroccan company GAIA Energy signed an agreement with the Israeli company H2PRO on the sidelines of the COP 27 to implement a pilot project in Morocco to produce a large capacity of hydrogen and green ammonia, using H2PRO's electrolyzer technology, starting with a capacity of 10-20 megawatts.

The global hydrogen market – an incentive or a threat to competitiveness?

Morocco is thus multiplying agreements with partner countries on joint projects to develop value chains and R&D around green H2. However, many of these same countries- particularly in Europe- have also shown interest in other countries of the Mediterranean region as well, suggesting that Morocco should carefully consider the potential drawbacks of developing its green H2 industry in the coming years.

In doing so, the country risks being exposed to the high risk and volatility of the international market, which will require continued assurance of national competitiveness in many areas: cost, sustainable transportation, certificates of origin, etc. As far as public opinion is concerned, green H2 is seen as the future low-carbon technology that will revolutionize the energy transition, both for its environmental benefits and for strengthening the competitiveness of Morocco's industrial sector.
However, many experts are cautioning against this enthusiasm as the green H2 industry is still emerging and faces several technical limitations that must be overcome to achieve its potential. For instance, the cost of producing green H2 currently remains higher than that of grey hydrogen. In addition, the hydrogen molecule is particularly unstable, which raises the issue of its transportation and storage. Addressing these limitations will be critical to the pace of the development of the green H2 industry.

2. Future Potential for Green Hydrogen in Morocco

In its "Green Hydrogen Roadmap," Morocco assessed potential domestic demand and international market that it can capture and rolled out two scenarios: (1) The reference scenario, where national energy efficiency targets are achieved, but with less than 52% installed capacity of renewable energy sources by 2030; (2) The optimistic scenario, where Morocco achieves targets of 52% installed capacity of renewable energy sources (which includes rapid deployment of renewables), but without meeting energy efficiency targets.

For its domestic market, Moroccan-produced green H2 has three applications:

(1) As an input in industrial processes: the roadmap primarily sets on capitalizing on Power-to-X applications to improve the fertilizer industry integration rate; and may possibly use green H2 in the refinery industry, whereby green H2 can aid the desulfurization of crude oil without the output of CO_2 into the atmosphere.

(2) To a much lesser extent, as an alternative fuel in the transportation sector either in the form of green H2 or synthetic fuel and to a lesser extent in the residential sector to replace imported Liquefied Petroleum Gas (LPG) commonly used in Morocco for cooking and heating.

(3) As a storage and flexibility solution, which constitutes a real asset in mitigating the intermittency of renewable energy sources and safeguarding the national network.

Domestic applications: Leveraging green hydrogen competitiveness to explore wider applications

Green H2 to produce ammonia locally

Morocco is one of the world's most competitive fertilizer producers. It currently holds 72% of the world's phosphate reserves (estimated at 50,000,000 metric tons). It is also the second-largest phosphates producer worldwide (37,000 metric tons in 2020), after China (90,000 metric tons) and followed by the USA (24,000 metric tons). The OCP Group (OCP), Morocco's state-owned phosphate rock miner, phosphoric acid manufacturer, and phosphate fertilizer producer, therefore, has significant ammonia (NH_3) needs.

In fact, Morocco is the world's fifth-largest importer of ammonia, importing 1.59 million tons (Mt) and 1.44 Mt in 2019 and 2018, respectively, corresponding to OCP's needs. Morocco's leading supplier of ammonia is Russia, which has, on average, a carbon footprint of 2.4 tons of CO2 per ton of ammonia produced [2] (Berahab et al., 2021).

One way to produce green ammonia locally is by using green H2 and nitrogen. These are then fed into the Haber-Bosch process that artificially fixates molecular nitrogen (N_2) to dihydrogen (H_2) in order to convert it to ammonia (NH3). In the 'Green Hydrogen roadmap,' instead of remaining a net importer of ammonia, Morocco plans to produce upwards of 3.7 Mt of green ammonia annually by 2050.

Recently, OCP Group launched a 13-billion-dollar strategic program for 2023-2027, called its Green Investment Strategy devoted to raising fertilizer production, but also investing in new green fertilizers, renewable energy, and desalination units, thus marking a big leap from ambition and reality. The Group aims to produce 1 million tons (Mt) of green ammonia by 2027 and 3 Mt by 2032, 5 gigawatts (GW) of clean energy by 2027 and no less than 13GW by 2032 and a seawater desalination a capacity of 560 million m^3 (Mm^3) in 2026, of which 110 Mm3 should already be achieved in 2023 due to the commissioning of several new desalination stations (OCP, 2022). Through this large-scale project, OCP can improve its competitiveness by becoming a net exporter of green ammonia.

[2] Ammonia is commonly produced following these three steps: 1) SMR method to produce H2; 2) Separation of nitrogen of the air mostly via fractional distillation of air, a highly energy intensive method; 3) In addition to the Haber-Bosch process.

Green H2 as input for the refining industry

For the refining sector, a demand for hydrogen has been calculated in Morocco's 'Green Hydrogen roadmap' based on refineries that may emerge in Morocco. This demand should start at 5 Mt initially and reach 10 Mt in the long term. It is assumed that Green H_2 will cover 25% of its total demand for this fuel by 2030 and may reach 40% in 2050. It is worth mentioning that the only refinery in the country 'Société Anonyme Marocaine de l'Industrie du Raffinage '(SAMIR), initially a joint venture between the Moroccan state and the Italian giant ENI then privatized in 1997, closed in 2015 due to severe financial difficulties and management failure.

Green H2 as an alternative fuel for domestic transportation and residential sectors

Green hydrogen can accompany the decarbonization of hard-to-electrify sectors, such as transportation. While battery technology is adapted for urban cars, long-range trucks, vans, heavy-duty vehicles, return-to-base fleets, and aviation are moving towards hydrogen either as a fuel burned in hydrogen combustion engines or by producing electricity from hydrogen-powered fuel cells. Battery packs supported by hydrogen fuel cells are also an option.

The aviation sector presents significant potential for hydrogen fuel cells, but also for future fuels such as cryogenic hydrogen. The emergence of Power-to-X can also be beneficial for producing high-valued synthetic fuels such as gasoline, diesel, methane, or even kerosene through renewables-powered electrolytic routes and even partially substituting LPG used in cooking and heating. The production of synthetic fuels could replace some volumes of imported conventional fuels.

Storage Solutions for Green Hydrogen

Green hydrogen can serve as a medium to store green energy or used as a 'balancing load', but itself is hard to store and transport, owing to energy-intensive processes of compression or liquefaction and boil-off losses during transportation. Therefore, it represents a solution as an energy vector, but may require storage solutions in the form of hydrogen carriers.

For instance, in addition to the role of 'chemical commodity,' green ammonia can also be a flexible energy carrier since it is easier to store and transport than hydrogen or also used as a 'balancing load.' Synthetic methane can also potentially be a part of this circular hydrogen economy, acting as a source of hydrogen that can be transported over long distances for various applications.

International market: Morocco's green hydrogen roadmap, an export-oriented strategy

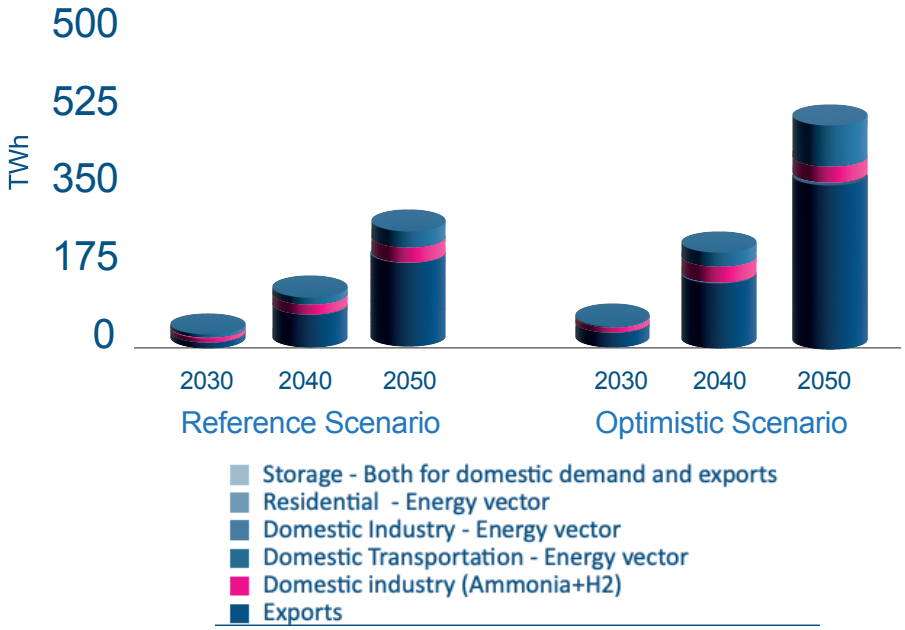
Morocco's share of the international market is estimated using a World Energy Council study called "international aspects of a power-to-x roadmap," which projected the global market for Green H2 at 20.000 TWh by 2050 (WEC, 2018). The Moroccan "Green Hydrogen roadmap" assumes that this global market will represent 600 TWh in 2030. A study published by the Fraunhofer Society titled "Study of the opportunities of Power-to-X in Morocco" has shown that the country may capture up to 4% of this global demand in 2030 and that the participation of Morocco in the world market would decrease to about 1% by 2050 when other countries accelerate the pace of development of this industry.

In Morocco's "Green Hydrogen roadmap," it is assumed that 75% of exports will correspond to hydrogen exported in the form of ammonia and 25% to synthetic liquid fuels. The production of synthetic fuels could replace imported conventional fuels to be used by local industries or to be transported by pipeline to Europe or West Africa [3], in case of proven economic profitability.

In this regard, Moroccan ports ranked at the top of Mediterranean ports and in the top 40 well-connected ports worldwide are ideal for serving as hydrogen hubs – aggregating both demands from their own operations, from maritime transport, land transport, and local industrial uses, in addition to serving as a storage production and global export asset.

[3] Planned Morocco-Nigeria pipeline.

Figure 2: Possible demand for green hydrogen according to Morocco's green hydrogen



3. Outlook: What Is Necessary for A Market for Green Hydrogen to Develop in Morocco

From what has been laid down in the preceding lines, Morocco's green H2 strategy is mostly exports oriented as exports will account for about 70% of the overall demand for Moroccan green H2 starting 2030 for both scenarios. To be a leader in the international market requires Morocco to continuously ensure national competitiveness in many areas: regulatory, technical, managerial, and financial [4], to name a few.

Fundamentally, Morocco's green H2 ambitions highlight the need for additional (1) renewable capacities, (2) industrial electrolyzers; (3) desalination plants given water scarcity in the country; (4) processing plant capacities – PtL; and finally (5) Haber Bosch processing plants capacities – PtA. These are all accounted for in the roadmap with projections about capacity requirements along with the CAPEX necessary for their development. Morocco plans a cumulative investment of 90 billion Moroccan Dirhams (MAD) by 2030 and 760 (MAD) by 2050 in the reference scenario (Tables 4 and 5 in the annex).

One of the main challenges for green H2 production anywhere is its cost, which is currently two to three times higher than that of grey hydrogen. This is owing more to the high cost of electrolyzers than to the cost of green energy. Indeed, the weighted average cost of energy (LCOE) of renewable energies has decreased considerably in recent years on a global scale. And while Morocco is currently lagging behind other countries, especially in solar energy, the country continues to reduce renewable energy production costs. For example, the sales contract signed between Nareva and ONEE in 2012 for the Tarfaya wind plant was Dh0.64/kWh, whereas the 850 MW wind power project signed between the two operators in 2015 was Dh0.30/kWh (CESE, 2020). In any case, Morocco possesses substantial experience and potential economies of scale in this area. Therefore, it is the cost of electrolyzers that must be addressed as it should drop by 80% in the long term to be competitive with grey hydrogen (Res4Africa, 2021). Incentives will thus be needed in the near term.

Additionally, considering water scarcity in Morocco, green H2 is dependent on desalination [5]. The required plants would have to produce an amount of water in the range of 50 to 70 Mm3 water, depending on the scenario [6]. This will not interfere with municipal water needs [7] (Bozier P. et al., 2022). However, it will generate constraints regarding the location of the green H2 production, which will therefore need to be close to the seaside.

This is advantageous to Morocco given the country's shorelines that span 3500 km, its proximity to end markets (Europe), and its significant maritime export experience: 34 ports, including 13 open to foreign trade, and its maritime transport infrastructure places the country at the top of the Mediterranean ports. In 2019, Morocco was ranked in the top 40 well-connected ports worldwide. The country's maritime infrastructure could also be a real asset for storage at ports and global exports while respecting safety measures, as green H2 is highly flammable, odorless, and colorless. Therefore, proper ventilation and leak detection are essential elements in the design of safe hydrogen systems.

In terms of export outlets, Morocco has two alternatives. It could either (i) export green H2 to the whole world, at the risk of losing part of the strategic advantage in terms of flexibility/reliability of supply to other competing countries (Middle East, Australia), or (ii) export to Europe, given the proximity to Morocco. It seems that this second option is the preferred one.
For Morocco to ship its green H2, it needs to invest in new sites in the south where the best sites for high-capacity factor for hydrogen production are located and then reload the green H2 produced by trucks to be shipped through the available ports. However, costly long-haul transportation may require additional investment in new infrastructure that must be secured and made available in time to meet the National Roadmap.

[4] Capital and operational expenditures, and soft costs such as financing, permitting, project management etc.)

[5] The draft National Water Plan 2020-2050, which constitutes a roadmap to face future challenges in the water sector, foresees the construction of seawater desalination plants to produce nearly 515 million cubic meters per year in 2030.

[6] For reference, in 2020, ONEE produced 1.25 bcm of water, representing about 85% of the country's water production.

[7] A 1 GW electrolysis plant would use less than 10 million litres per day of water, which is low by the standards of seawater desalination plants.

Therefore, developing a common market for green H2 between Morocco and Europe will require coordination in order to build or adapt the necessary infrastructure on both sides of the Mediterranean and investment in storage facilities for green H2 and derivatives in the form of salt caverns. In this sense, Morocco could leverage and adapt its gas and port infrastructure, which is well connected to the Atlantic and the Mediterranean.

In addition, given that transportation of green H2- either via trucks or by ship to destination markets- should become environmentally sustainable, it is essential for Morocco to ensure the traceability of the green H2 value chain, from production to final disposal, a process that involves different types of rules of origin. Hence the need to implement certifications or guarantees of origin that comply with the regulations and standards of exporting countries, in this case, Europe, and allow hydrogen to be labeled as "green" to ensure consumer transparency. For instance, the European Union is already working towards standardizing the hydrogen sector through a common low-carbon standard for hydrogen production based on lifecycle performance. It has come up with solutions like the CertifHy project, which is a Guarantee of origin scheme for green and low-carbon hydrogen (RES4Africa, 2021).

Morocco's vision for producing and exporting green H2 cannot be fulfilled without laying the foundation for a clear and transparent institutional and regulatory framework to send the right signals to investors and customers. In a rapidly advancing world with countries issuing laws and regulations in record time, being among the first to develop a regulatory and policy framework could become a strong competitive advantage.

To successfully create a green H2 market, one of the challenges is bringing academic and industrial skills, opening up internationally, organizing a technological watch, and patenting the results and findings. It is also important to integrate green H2 targets systematically into energy, climate, and economic policies to leverage synergies and avoid contradictory strategies. In addition to setting targets within the development of the green H2 sector, it is also important to finance the routes to market to these targets. In the case of green H2, evidence shows that massive investments along the value chain are needed. In addition, the sector's governance must be brought to the highest level of importance (highest state level) and promote the emergence of an ecosystem capable of carrying out the desired ambition for the sector and the market.

Conclusion

Morocco is committed to participating in global climate efforts. The country is pursuing ambitious CO2 emission reduction targets and actively participating in international climate negotiations. It has also embarked on an energy transition focused primarily on deploying renewable energy. Morocco has now added another ambitious goal to its energy policy agenda: to position itself in the global market for green H2 through exports. The prospects for this vision are promising: the production of green H2 in Morocco would promote its economic growth, contribute to the decarbonization of its industry and strengthen the security of its energy and non-energy input supply. It would also strengthen its position as a strategic partner for the European Union.

Achieving such a vision requires addressing several technical, financial and institutional limitations (high cost of the electrolysis process, need to increase the production of green electricity, important water requirements, substantial financing, the necessity of regulation etc.). Besides the production of green ammonia for domestic use, the green H2 strategy is mainly oriented towards exports to Europe.

In this scenario, it is important to consider the impact of this export orientation on Morocco's energy transition and on the country's own population. To date, Morocco's ambition has been strongly demand-driven to supply EU member states seeking to secure access to the "oil of the future." However, the focus on exports must not be at the expense of the local population. Morocco must ensure that its own population can benefit from the hydrogen boom as well.

Furthermore, what is needed now for Morocco is to complete the national hydrogen roadmap by setting ambitious but achievable quantified targets for the entire green hydrogen value chain from production and electrolysis capacity to desalination plants, necessary transportation infrastructure, operating costs, R&D, etc. Short- and medium-term targets should be set to facilitate monitoring and evaluation.

Morocco should also define the country’s priority in terms of green H2 and its place in the energy strategy relative to other energy sources (oil, RES, natural gas, etc.) and infrastructure. For example, lack of clarity on the priorities and objectives of the natural gas and infrastructure sector and other fossil fuels could result in duplication of costs and investments and may not be financially sustainable, especially in the long term.

Finally, given that the relationship with the natural gas sector is particularly tight, the relationship between the natural gas strategy and the national green hydrogen roadmap needs to be carefully assessed.

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