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Towards a Pan Arab Green Hydrogen Strategy

Assessment of green hydrogen opportunities in the Arab region

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Content

Acronyms

BAU	business-as-usual scenario
BMWK	German Federal Ministry for Economic Affairs and Climate Action
BF	Blast Furnace
EAF	Electric Arc Furnaces
EU	European Union
GHG	Greenhouse gases
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GW	Gigawatt
LAS	League of Arab States
LCOH	Levelized cost of hydrogen
(i)NDC	(Intended) Nationally Determined Contributions
NHS	National Hydrogen Strategy
MW	Megawatt
NZE	Net Zero Emissions
PtX	Power-to-X
RE	Renewable Energies
SDG	Sustainable Development Goal
UAE	United Arab Emirates
vRE	variable renewable energy

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Executive Summary

This study sets out a vision of how Arab Countries can turn green hydrogen into a viable solution to decarbonise and to strengthen the region's economies on the short, medium to long term, and how a joint strategy of Arab states can be used in achieving this vision. It is **aimed at government policymakers** in the Arab region. It is equally suited for other experts interested in formulating or influencing green hydrogen policy and programmes in the region.

The primary objective is to lay the ground for the development of a **Pan Arab Green Hydrogen Strategy**. The document hence identifies (i) current framework conditions, policy targets and plans for the deployment of green hydrogen in the region, (ii) the potential for the production and application of green hydrogen and its derivates, and (iii) potential scenarios for the development of a green hydrogen economy in Arab States.

The **policy framework conditions in LAS member states** are characterised by considerable commitment to combating climate change and increasing the share of (variable) renewable energy in the power sector. Several countries are also embarking on the implementation of strategies for the production and use of green hydrogen. Arab countries with existing infrastructure and potentially low costs of electricity generated from variable renewable energy (solar and wind) - such as Jordan, Morocco, Saudi Arabia and the United Arab Emirates - offer a key comparative advantage in the production of green hydrogen. There has been substantial progress in the deployment of renewable energy-based power sources during the past years. Total installed renewable energy capacities have increased from 18.3 GW in 2018 to 25.3 GW in 2022 in Arab states.

Main challenges for the production and export of green hydrogen relate to environmental and social concerns, high production and transport costs, as well as limited political and economic stability in several countries. With continued technological advancements, expansion and decreasing costs of renewable energy and electrolysers, this is expected change in the coming decades. Blue hydrogen - the production from natural gas with carbon capture – is currently considered more economic and explored by several Arab countries with vast natural gas resources.

With national strategies under development in a growing number of member states and the first mega-projects for the production of green hydrogen, substantial efforts have been made for the deployment of green hydrogen in the region. Bundling of these efforts will be essential for the sustainable **development of a green hydrogen economy in the region**. Ramping up green hydrogen industries in member countries will not only help to achieve the national greenhouse gas emissions targets according to Nationally Determined Commitments (NDC), but also align investment needs with policies for attracting possible green loans from international financial institutions and contribute to energy security and availability.

Against this background, this study advocates for the development of a **Pan Arab Green Hydrogen Strategy for the League of Arab States**. A harmonised approach can support knowledge transfer and research & development, the alignment of national strategies and plans, the joint exploration of feasible options for the production and regional application of hydrogen, as well as common ground in the initiation of interregional trade agreements.

The study presents a draft **green hydrogen roadmap** for the Arab region, which shall help to achieve a common commitment to green hydrogen development. To reflect the evaluation of the industry maturity and the expected increased deployment of green hydrogen, three development stages have been defined: Piloting, demonstration phase (2023-2030), market creation & scale-up phase (2030-2040), and mass-market/competition phase (2040-2050).

As a **first step towards the development of a regional strategy**, the development and alignment of national strategies and roadmaps for green hydrogen shall be encouraged. By identifying the potential for production, application and export of green hydrogen as well as related investment needs in Member States, common interests and opportunities can be identified and the planned actions harmonised across the region. The League of Arab States can play a central role in facilitating this knowledge transfer. As a second step, LAS can catalyse and coordinate the joint development of a Pan Arab Green Hydrogen Strategy.

Introduction

Background

Climate change and global conflicts impose risks on global energy security, threatening the reliable supply of fuels and resources.[1] Combatting climate change and its adverse effects on humanity and the environment requires a global energy transition, reducing the dependence on fossil fuels. Diversifying the energy mix is a key aspect of this energy transition. In addition to accelerating the deployment of renewable energy and energy efficiency, alternative energy carriers need to be investigated, including hydrogen and its derivatives.

The **economy of most Arab States** is highly dependent on fossil fuels. This has resulted in growing Greenhouse Gas (GHG) emissions over the past decades with some Arab States ranking among the highest per capita emitters of CO_2.[2] To enable decarbonisation of the energy sector and open up opportunities for an economic diversification in the region, measures to accelerate the energy transition towards a modern, sustainable energy supply is required.

These measures include an increase in the use of renewable energy sources and the improvement of energy efficiency across all sectors. The **deployment of green hydrogen** - hydrogen generated by renewable energy sources - can play a key role in mitigating climate change, leveraging the region's vast renewable energy potential and promoting international trade and energy partnerships. Hydrogen can fulfil the role as a vector for renewable energy storage, alongside batteries, and transport, ensuring back up for seasonal variations and connecting production locations to distant demand centres. Hydrogen and its derivates can replace fossil fuels in carbon intensive industry - such as in the steel or chemical sectors – and transport sector.[3] Green hydrogen is also seen as an engine for employment creation: IRENA (2021) estimates that investment in electrolysers and other green hydrogen infrastructure could create about 2 million jobs worldwide between 2030 and 2050.[4]

Efforts in Arab States are already underway to combating climate change and promoting the energy transition. Most member states have ratified the Paris Agreement, and many have clear targets towards the acceleration of renewable energy in the coming decades[5]. The development of production capacities for green hydrogen and its derivates is also envisaged in the region: Several countries are currently preparing **national hydrogen strategies** or planning substantial increases in their electrolyser capacities. Most of these ambitions are however still in their early development phase limited to only some States[6].

Against this background, it is crucial that concerted efforts are made to enable the coordinated, effective, and sustainable development of a green hydrogen economy in the region. This may include, but is not limited to transregional technology transfer, joint mobilisation of private investment, and the establishment of international partnerships for the export of green hydrogen. This document sets out a vision of how the League of Arab States **can turn green hydrogen into a viable solution** to decarbonise different sectors and to strengthen the region's economy on the short, medium to long term, and how a joint strategy of member states can be used in achieving this vision.

About this document

This document is **aimed at government policymakers** in Arab States. It is equally suited for other experts interested in formulating or influencing green hydrogen policy and programmes in the region.

The **primary objective of this document** is to lay the ground for the development of a Pan Arab Green Hydrogen Strategy for the League of Arab States. The document hence identifies (i) current framework conditions, policy targets and plans for the deployment of green hydrogen in the region, (ii) the potential for the production and application of green hydrogen and its derivates, and (iii) potential scenarios for the development of a green hydrogen economy in the League of Arab States. This analysis is complemented by recommendations for next steps in developing Pan Arab Green Hydrogen Strategy for the League of Arab States on the short, medium, and long term.

This document shows that the potentials to produce green hydrogen and the opportunities for its exploitation **vary substantially across the region**. The Arab League Member States are characterized by different political systems and economies, financial and natural resources, populations, geographic and climate conditions. The pathways for the production, transportation and storage of green hydrogen may hence differ from country to country. Achieving Sustainable Development Goal (SDG) 7 - ensure access to affordable, reliable, sustainable and modern energy for all, and SDG 13 - take urgent action to combat climate change and its impacts - however requires ambitious and well-coordinated policies at national and Pan-Arab levels, as well as a uniform approach in reaching out to prospective international partners. With this document, the ground for the development of a Pan-Arab green hydrogen strategy for the League of Arab states, is established hoping to contribute to a coordinated effort towards the development of a green hydrogen economy in the region.

This **document was elaborated** based on a meta-analysis of existing studies and outlooks on green hydrogen in the region, as well as the consolidation of existing policies, plans and ambitions at national and regional levels. The document was developed jointly by the Energy Department of the League of Arab States and the bilateral energy partnerships programme commissioned by the German Federal Ministry for Economic Affairs and Climate Action (BMWK). The document is structured into three parts:

i. Policy framework for green hydrogen in Members States, identifying advances and ambitions across the region
ii. Assessment of green hydrogen potential in the Arab States, analysing opportunities for the production and application of green hydrogen and its derivates
iii. Towards a Pan Arab Green Hydrogen Strategy for the League of Arab States – including recommendations for a concerted effort for developing a regional green hydrogen economy on a short, medium and long term.

Policy framework for green hydrogen and PtX in LAS member countries

The table below summarizes GHG emission reduction, renewable energy (RE) and (green) hydrogen targets and ambitions by the League of Arab States Member States.

Table 1: Targets and ambitions related to greenhouse gas emission reduction, renewable energy and (green) hydrogen deployment in the Arab region

Country	(Intended) Nationally Determined Contribution ((i)NDC) targets[7]	RE targets and ambitions	Hydrogen targets and ambitions
Algeria	Algeria submitted its first NDC in September 2015. Emissions reduction targets: By 7% by 2030 (unconditional); 22% by 2030 (conditional)[8]	RE targets according to NDC: Reach 27% of electricity generated from renewable sources of energy by 2030[9] Renewable Energy Development Program: 22 GW installed RE capacity by 2030, including 13.6 GW solar, 5 GW wind, 2 GW CSP, 1 GW biomass, 0.4 GW cogeneration.[10]	Exploratory study on the potential of Power-to-X and green hydrogen published by Algerian-German Energy Partnership in November 2021.[11] National hydrogen strategy has been in development since late 2021.[12] MoU Between Algeria and Germany signed for the development of a 50MW green hydrogen plant in December 2022.[13]
Bahrain	Bahrain submitted its revised NDC in October 2021. Emissions reduction target: not specified.[14]	RE targets according to NDC: 5% of peak capacity by 2025 and 10% by 2035[15] National Renewable Energy Action Plan (NREAP): 255 MW of installed RE capacity by 2025 (including 50 MW wind and 200 MW solar), and 710 MW by 2035 (including 300 MW wind and 400 MW solar).[16]	Plans to establish a 4 MW plant for the production of green hydrogen.[17]
Comoros	The Union of the Comoros submitted its revised NDC in November 2021. Emissions reduction targets: 23% (excluding Land Use, Land Use Change and Forestry) and an increase of CO2 absorption by 47% by 2030.	N/A	N/A
Djibouti	Djibouti submitted its first NDC in November 2016. Emissions reduction targets: 40% by the year 2030[18]	RE targets according to NDC: 60 MW onshore wind, 250 MW solar PV by 2025; exploitation of 1200 MW geothermal energy potential by 2030[19]	MoU between Ministry of Energy and Natural Resources of Djibouti and a renewable energy company to implement a 10 GW renewable energy and green hydrogen project (December 2022).[20]
Egypt	Egypt submitted its revised NDC in June 2022. Emission reduction targets: 33% in the electricity sector, 65% in the oil and gas sector, and 7% in the transportation sector by 2030	Integrated Sustainable Energy Strategy 2035: Install additional RE capacities to reach electric power contribution target of 42% by 2035.[22]	Hydrogen targets in NDC: "Replace feedstock with green hydrogen to produce green ammonia and transition towards low carbon nitrogen fertilizer production." Framework of Egypt's low-carbon hydrogen strategy announced during COP

	compared to business-as-usual (BAU) (conditional on external support)[21]		27 in November 2022,.[23] MoU signed by European Commission with Egypt's Minister for Petroleum and Minister for Electricity and Renewable Energy on a strategic partnership on renewable hydrogen.[24] European Bank for Reconstruction and Development (EBRD) to finance 100 MW electrolyser facility powered by renewable energy[25]
Iraq	Iraq submitted its revised NDC in October 2021. Emission reduction targets: 15% by 2030 (conditional); 2% by 2030 (unconditional).	RE targets according to NDC: 5% of generation capacity from renewable energy by 2030; 2000 MW RE share over the next four years.[26]	N/A
Jordan	Jordan submitted its revised NDC in October 2021. Emission reduction targets: 31% by 2030 (conditional); 5% by 2030 (unconditional).[27]	RE targets according to NDC: Increased Percentage of Electricity Generated from RE (20% in 2020 to 35% in 2030). Introduction of concentrated solar power (CSP) of 100 MW and CSP 300 MW.[28] Master Strategy for the Energy Sector 2020-2030: 31% share for RE in total power generation capacity and 14% of the total energy mix by 2030.[29]	Green hydrogen roadmap developed in October 2022; green hydrogen strategy under preparation.[30]
Kuwait	Kuwait submitted its revised NDC in October 2021. Emission reduction targets: Reduction of 7.4% in 2035 relative to BAU.[31]	National RE target: Increase share of RE generation to 15% to be reached by 2030.[32]	White paper on Hydrogen Strategy published in January 2021[33]
Lebanon	Lebanon submitted its revised NDC in March 2021. Emission reduction targets: 31% by 2030 compared to BAU (conditional); 20% by 2030 (unconditional).[34]	RE targets according to NDC: 18% of the power demand and 11% of its heat demand (in the building sector) from RE sources in 2030 (unconditional). 30% of the power demand and 16,5% of its heat demand (in the building sector) from RE sources in 2030 (unconditional).[35]	N/A
Libya	Not available	2030 vision of the General Authority for Electricity and Renewable Energy: 22% of RE share by 2030[36]	N/A
Mauritania	Mauritania submitted its updated NDC in October 2021. Emission reduction targets: 11% by 2030 compared to BAU (unconditional). 92% by 2030 compared to BAU (conditional).	RE targets according to NDC: 13 GW additional RE by 2030.[37] National energy strategy (2020): increase the share of renewable energy in its energy mix to 60% by 2030.[38] Extension of the Nouakchott wind power plant from 300 MW to 50 MW.[39]	Green Hydrogen Development Programme AMAN: 18 GW of wind capacity and 12 GW of solar planned to produce an estimated 1.7 million tons of green hydrogen or 10 million tons of green ammonia annually.[40]

Morocco	Morocco submitted its revised NDC in June 2021. Emission reduction targets: 18.3% reduction by 2030 (unconditional) compared to business as usual. 45.5% reduction by 2030 (conditional) compared to business as usual.	RE targets according to NDC: 52% (of which 20% solar, 20% wind, 12% hydro) by 2030[41] National Energy Strategy: Economy-wide: 52% RE by 2025 and 64% by 2030. Power: 52% by 2030 and 100% by 2050.[42]	The Moroccan Ministry of Energy, Mines and Environment set out a roadmap on green hydrogen in 2021 under the National Hydrogen Commission (created in 2019). The country is expecting a demand up to 30 TWh by 2030 and 307 TWh by 2050, that would require 2GW in renewable energy sources.[43]
Oman	Oman submitted its revised NDC in July 2021. Emission reduction targets: 4% below BAU during the period 2020-2030 (unconditional); 7% below BAU during the period 2020-2030 (conditional).	RE targets according to NDC: Attain 20% (2,660 MW installed capacity) and 30% of electricity from renewable sources by 2027 and 2030, respectively.[44]	In August 2021, The Ministry of Energy and Minerals established a national alliance for green hydrogen (named as Hy-Fly). Oman plans to produce 1 million tonnes of green hydrogen per year by 2030. The target is from 32,500 to 3.75 million tonnes per year by 2040 and from 3.5 to 8.5 million tonnes per year by 2050.[45] National Hydrogen Strategy planned.[46]
Palestine	The State of Palestine submitted its revised NDC in October 2021. Emission reduction targets: 26.6% in an independence scenario and 17.5% in a status-quo scenario (conditional) by 2040, compared to BAU.	RE targets according to NDC: 20-33% of electricity from RE sources by 2040, primarily from solar PV (conditional).[47]	N/A
Qatar	Qatar submitted its revised NDC in August 2021. Emission reduction targets: Reduction of 25% by 2030, relative to BAU scenario[48]	Qatar National Vision 2030: Generate 20% of electricity from renewable energy sources by 2030.[49]	Qatar Investment Authority (QIA) is considering investing in a $1 billion green hydrogen and ammonia project in Egypt.[50]
Saudi Arabia	Saudi Arabia submitted its revised NDC in October 2021. Emission reduction targets: Reduction by 278 million tons of CO2eq annually by 2030 (based on 2019)	RE targets according to NDC: Renewable energy share to reach around 50% of the energy mix by 2030.[51] 2030 vision: 58.7 GW of installed RE capacity in 2030 (40GW of PV, 16GW of wind and 2.7GW of CSP)[52]	Hydrogen ambitions in NDC: Flagship giga-project NEOM to be powered by 4 GW RE from solar and wind is expected to produce 650 t/d green hydrogen by electrolysis and 1.2 million t/y of green ammonia from 2025 onwards. A national hydrogen strategy is currently under preparation.[53]
Somalia	Somalia submitted its revised NDC in July 2021. Emissions reduction targets: 30% below business-as-usual by 2030 (conditional on international public and private support)	RE targets: Development of renewable energy electricity (solar and wind) – not further specified[54]	N/A
Sudan	Sudan submitted its revised NDC in September 2022. Emission reduction targets: 38% in the energy sector, 45% in the forestry	RE targets according to NDC: 20% of power system by 2030. 5,056 GWh of fossil-fired electricity displaced by utility	N/A

	sector, and 20% in the waste sector by 2030 compared to business-as-usual (conditional).	scale grid connected solar and wind power plants in 2030.[55]	
Syria	Syria submitted its first NDC in November 2018. Emission reduction targets: Not set quantitively.	RE targets according to NDC: 10% of power supply by 2030 (conditional).[56]	N/A
Tunisia	Tunisia submitted its revised NDC in October 2021. Emission reduction targets: 45% below 2010 levels by 2030 (conditional). 27% by 2030 compared to 2010 levels (unconditional).	RE ambitions according to NDC: "Mass development of renewable energy, which includes mainly five main fields: wind (on-shore and off-shore), photovoltaic, concentrated solar power (CSP), biogas and green hydrogen."[57] Solar Plan: 30 % of electricity to be produced from renewable energy sources by 2030, including 3.8 GW from solar energy[58]	National strategy for green hydrogen under development, to be launched in 2024[59]
United Arab Emirates	The United Arab Emirates submitted their updated NDC in December 2020. Emission reduction targets: 23,5% by the year 2030 by 23.5%, relative to the BAU scenario.	RE targets according to NDC: Installed clean power capacity, including solar and nuclear: 19.8 GW by 2030. 30% share of clean energy (RE and nuclear) in the installed power capacity mix by 2030, which the aim to achieve Net Zero in the power and water sector by 2050. [60]	The country's Ministry of Energy & Infrastructure presented a UAE Hydrogen Leadership Roadmap in November 2021. [61] Early July, 2023 UAE had launched its National Hydrogen Strategy which envisages producing 1.4 million tonnes of green hydrogen per year by 2031 and 15 million tonnes by 2050, in order to deliver its ambition to become one of the world's top low carbon hydrogen producers by 2031.
Yemen	Yemen submitted its INDC in November 2015. Emission reduction targets: 14% by 2030 below BAU.	RE targets according to INDC: 15% of generation mix in 2025 (400 MW from wind farms, 160 MW from geothermal power stations)[62]	N/A

In summary, the **policy framework conditions in LAS member states** are characterised by considerable commitment to combating climate change and increasing the share of (variable) renewable energy in the power sector. Several countries are also embarking on the implementation of strategies for the production and use of green hydrogen.

Except Iraq, Libya and Yemen all League of Arab States countries have ratified the Paris Agreement, while Iraq, Libya and Yemen have signed but not yet ratified the Agreement.[63] Apart from Comoros, all member states have defined **renewable energy targets** either as part of their (Intended) Nationally Determined Contributions, or through national energy strategies or plans. According to RCREEE (2020), the installed renewable energy capacity in the Arab region is projected to reach about 180 GW by 2030.[64] Several countries, including Algeria, Morocco, Saudi Arabia, Tunisia and United Arab Emirates, have announced the instalment of variable renewable energy plants at Gigawatt-scale.

Algeria, Egypt, Jordan, Kuwait, Morocco, Oman, Saudi Arabia, Tunisia, and the United Arab Emirates are either currently preparing for the development, are developing or have already developed national **strategies or roadmaps for (green) hydrogen**. The

United Arab Emirates, developed and launched its National Hydrogen Strategy on July , 2023.

Currently, **hydrogen is already being produced and utilised** across several Arab countries. This is mainly related to demands in oil refining, petrochemicals and steel industries. More than 90 % of the hydrogen produced in region is grey hydrogen, i.e., generated from natural gas with respective adverse effects on climate change.[65] Several Arab States that are however actively pursuing and/or planning new green hydrogen projects. These include Algeria (50 MW), Bahrain (4 MW), Djibouti (10 GW), Egypt (23 MOUs have been signed with major international developers with total RE capacities reaching 100 GW. During COP27 Activities, 9 partnership agreements with a capacity of 100 MW have been signed with qualified international developers), Mauritania (30 GW), Morocco (2 GW), Oman, (1 million tonnes of green hydrogen per year by 2030), Saudi Arabia (4 GW), United Arab Emirates (1.4 MT p.a. of low carbon hydrogen by 2031). These plans range from first political announcements to signing of MoU or the launch of tendering processes.

Spotlight on Morocco: National Green Hydrogen Strategy

Morocco has positioned itself as a forerunner in the field of renewable energies in the Arab region with ambitious targets of 52% installed renewable energy capacities in 2030. In 2021, Morocco launched a national strategy for the development of green hydrogen has been put in place. According to estimates of preceding studies, Morocco can cater for up to 4% of the global demand for green hydrogen. The objective of the national strategy is to satisfy local demand and optimize the exploitation of national potential of green hydrogen. The strategy foresees the following potential applications of green hydrogen on a short, medium and long term:

Table 2: National Green Hydrogen Strategy Morocco[66]

Timeframe	***Potential green hydrogen applications***
2020-2030	• *Local use as feedstock in industry* • *Export of green hydrogen products* • *Exploration of natural hydrogen deposits*
2030-2040	• *Development of the first economically viable projects* • *Synthetic liquid fuel exports* • *Green hydrogen as an energy storage medium*
2040-2050	• *Improved capacity to produce ammonia, hydrogen and e-fuels for export* • *Local use of green hydrogen in industry, heat production, residential sector, urban mobility and air transport*

Assessment of green hydrogen and PtX potential in the region

Renewable energy potential

The Arab region's **potential for renewable energy** is very high, particularly for wind and solar energy. Most Arab countries benefit from solar irradiation levels in the range of 6.5 kWh/m² per day.[67] The conditions for wind energy are also favourable in several areas - wind speeds in countries such as Morocco, Egypt and Tunisia are amongst the highest in the world.[68] Yet, the Arab region's power system matrix is still characterized by a high share of fossil-based energy sources. According to RCREEE (2020), the renewable energy sources only accounted for 6% of installed power capacities in 2018.

However, there has been substantial progress in the **deployment of renewable energy-based power sources** during the past years. Total installed renewable energy capacities have increased from 18.3 GW in 2018[69] to 25.3 GW in 2022 in Arab states.[70] The region's countries with the largest installed renewable energy capacities include Egypt, Morocco, United Arab Emirates, Jordan and Sudan.

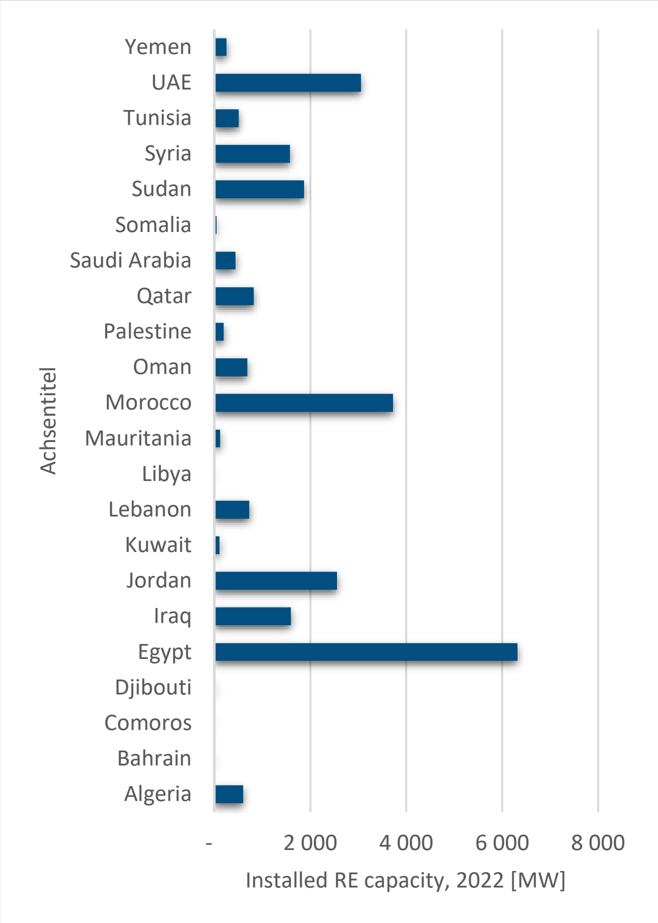

Figure 1: Installed Capacity - Total Renewable Energy, 2022 [MW]
Source: Own elaboration based on IRENA (2022)[71]

In terms of total installed **variable renewable energy (vRE) capacities**, Egypt, UAE, Jordan and Morocco are the region's current leaders. In 2022, solar energy accounted for 3 GW installed capacity in UAE, 1,9 GW in Jordan, and 1,7 GW in Egypt. Installed wind energy capacities were at 1,6 GW in Egypt, 1.6 GW in Morocco, and 0.6 GW in Jordan. Algeria, Kuwait, Lebanon, Mauritania, Oman, Palestine, Qatar, Tunisia and Yemen also possess installed variable renewable energy capacities in the three-digit Megawatt scale.[72]

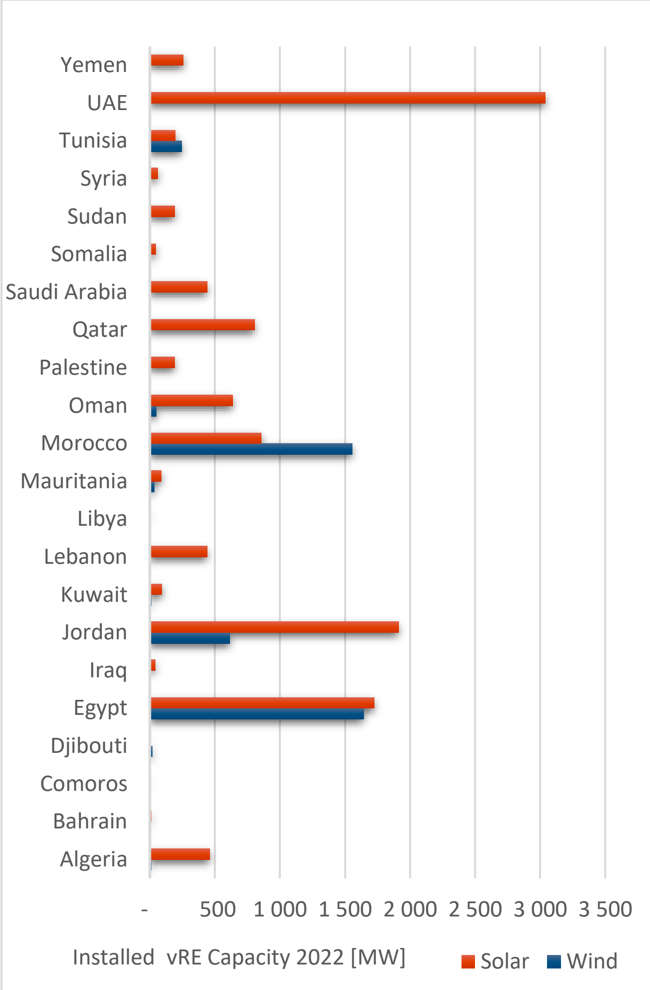

Figure 2: Installed Capacity – Wind and Solar Energy, 2022 [MW]
Source: Own elaboration based on IRENA (2022)

For the potential of blue hydrogen production, **natural gas resources** are a determining factor. With annual production levels of more than 100 billion cubic meters (bcm) in 2021, Qatar, Saudi Arabia and Algeria are among the biggest global producers of natural gas. Egypt, UAE, Oman, Bahrain, Kuwait, Iraq, and Syria also have notable production capacities.[73] Qatar, Algeria, Egypt, Kuwait and Oman are net exporters of natural gas.[74] According to UNESCWA[75], available natural gas resources are likely to be prioritized for generation of electricity. Nevertheless, in few Arab countries with gas surplus and respective infrastructure - such as Qatar, Saudi Arabia and the United Arab Emirates, natural gas could also be used to produce blue hydrogen for export after meeting domestic market needs.

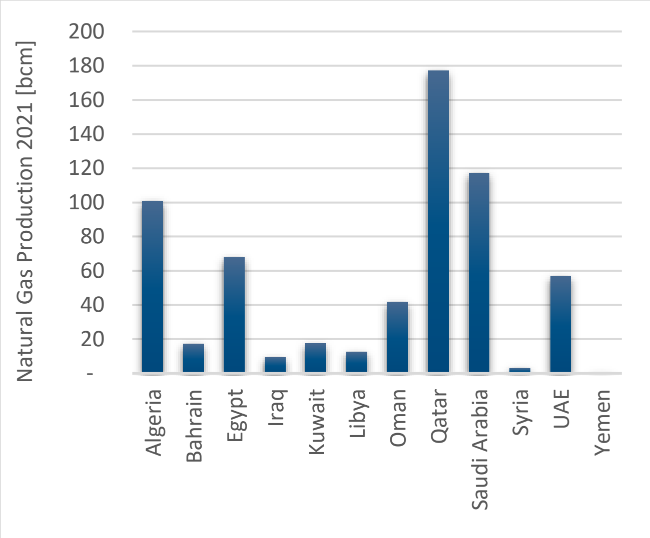

Figure 3: Natural gas production 2020 [bcm]. Source: Own elaboration based on BP (2022)[76]

Green hydrogen production and PtX potential

The estimation of the **green hydrogen potential** sources data from the Power-to-X Atlas [77]. The respective methodology is based on a GIS analysis, considering multiple eligibility criteria to produce green hydrogen. One key criterion is the access to seawater or surface water resources, which constrains the analysed production potential to coastal areas and interior areas in the vicinity of surface water resources. Desalinated water only adds about 1 per cent to the cost of green hydrogen, so with the proper mechanisms, water scarcity issues can be avoided[78] Therefore, major shares of the interior country area are not considered where the water access criterion is not fulfilled[79]. In the used data source are no wind power plants considered for the hydrogen production in Algeria, Jordan, Oman and UAE. With available data however, the displayed potential could rise significantly, as it would be for Jordan, for example. Therefore, the hydrogen production pathways based on renewable wind energy were not analysed for these countries but will have to be evaluated in the future. Furthermore, no volume potential data was available for the following countries: Bahrain, Comoros, Lebanon, Qatar and the Palestinian Territories on the consulted source.

The **theoretical yearly green hydrogen production volume potential** is shown in figure 5 per country. It was estimated assuming a theoretical full development of renewable in the potential identified areas. This is also based on land-use constraints and water availability, without explicit consideration of the additionality criteria for renewable energy sources. However, considering the underlying approach, only geographical areas with access to the coast or interior area within close distance to surface water bodies are considered for the estimation of the green hydrogen production potential. Thus, a large share of the countries' area is not considered for the production of green hydrogen and would be still available for the installation of additional RES capacities. According to the PtX Atlas, the countries with available data and the highest potential for green hydrogen production include Egypt, Libya, Somalia and Saudi Arabia. This is based on the identified PtX potential areas in the country and using site-specific expansion and deployment optimizations.

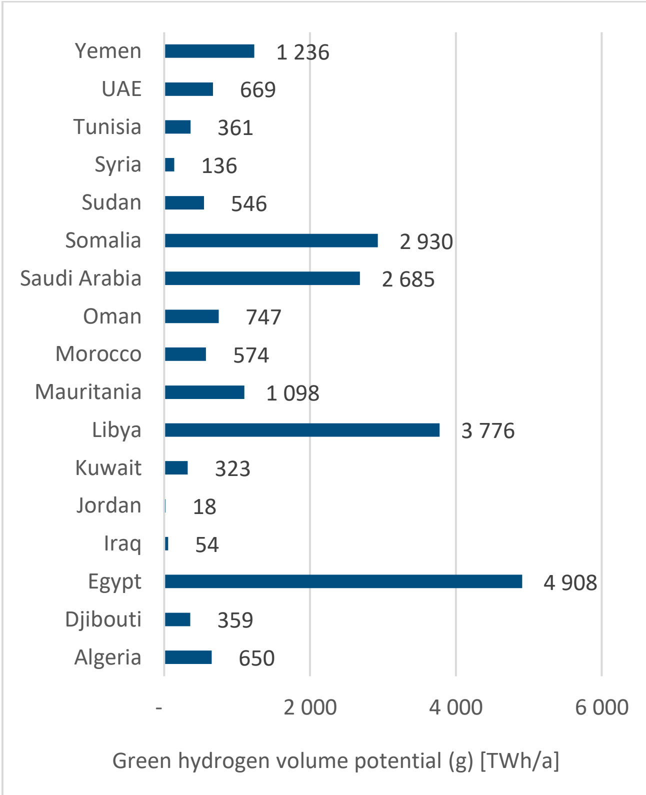

Figure 4: Green hydrogen volume potentials (compressed, high temperature electrolysis) of countries with available data. Source: Own elaboration based on PtX Atlas[80]

Figure 5 below shows the **countries' PtX socio-economic potential** according to the PtX-Atlas. This high-level country analysis measures the socio-economic potential of a country for green hydrogen production and export based on the areas of economy, politics, society, technology, natural conditions and – in view of future export options - proximity to Germany. The selection of these topics is based on the assumption that, in addition to natural resources (solar or wind potential), socio-economic factors are also important for investment decisions when it comes to identifying a potential PtX export country.[81] According to the PtX Atlas, only UAE, Qatar, and Morocco hold a "medium" socio-economic potential (score of 3,0 or higher) for the production of green hydrogen and its derivates as well as their export to Germany. The socioeconomic potential for Algeria, Bahrain, Egypt, Jordan, Kuwait, Lebanon, Oman, and Saudi Arabia is considered as "small" (2,5-3,0), for the other member states with available data as "very small" (<2,5).[82]

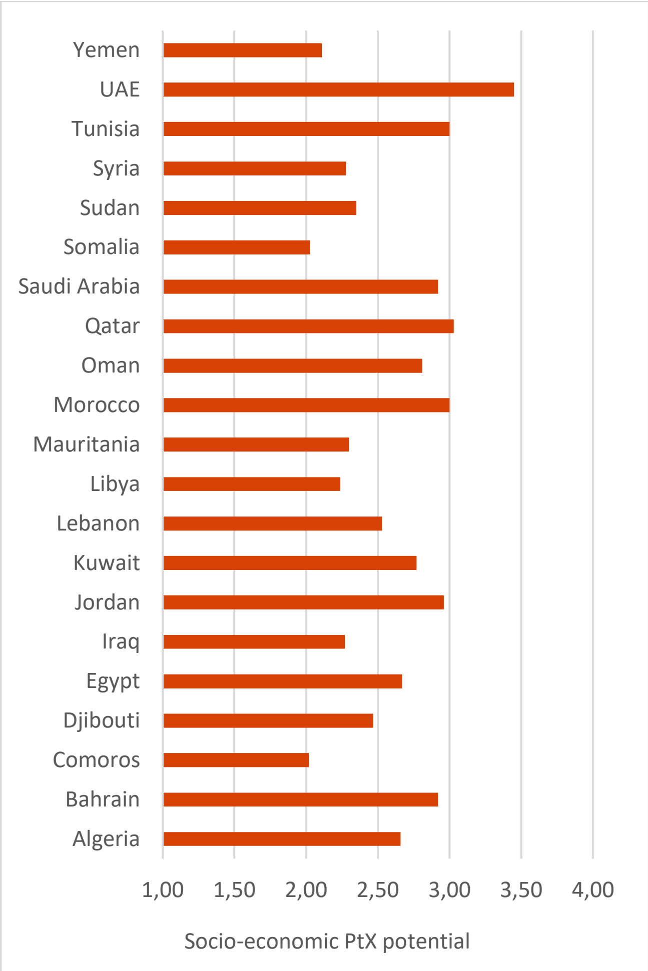

Figure 5: Socio-economic PtX potential of countries with available data. Source: Own elaboration based on PtX Atlas[83]

In the figures below, potential **generation volumes of green hydrogen and its derivates** for Egypt, Morocco, Saudi Arabia and UAE are shown, based on respective water supply and power sources for electrolysis. The following green hydrogen products and derivates are considered: FT fuels (diesel, kerosene), synthetic methanol (CH_3OH), compressed or liquid Methane (CH_4), compressed or liquid hydrogen (H_2), and synthetic ammonia (NH_3). Different climatic and geographic conditions result in different generation potentials: While e.g., in Egypt the potential for liquid hydrogen generated from hybrid resources on inland waters is the highest, the PtX Atlas assesses the biggest production in UAE for compressed hydrogen generated from PV on coastal waters.

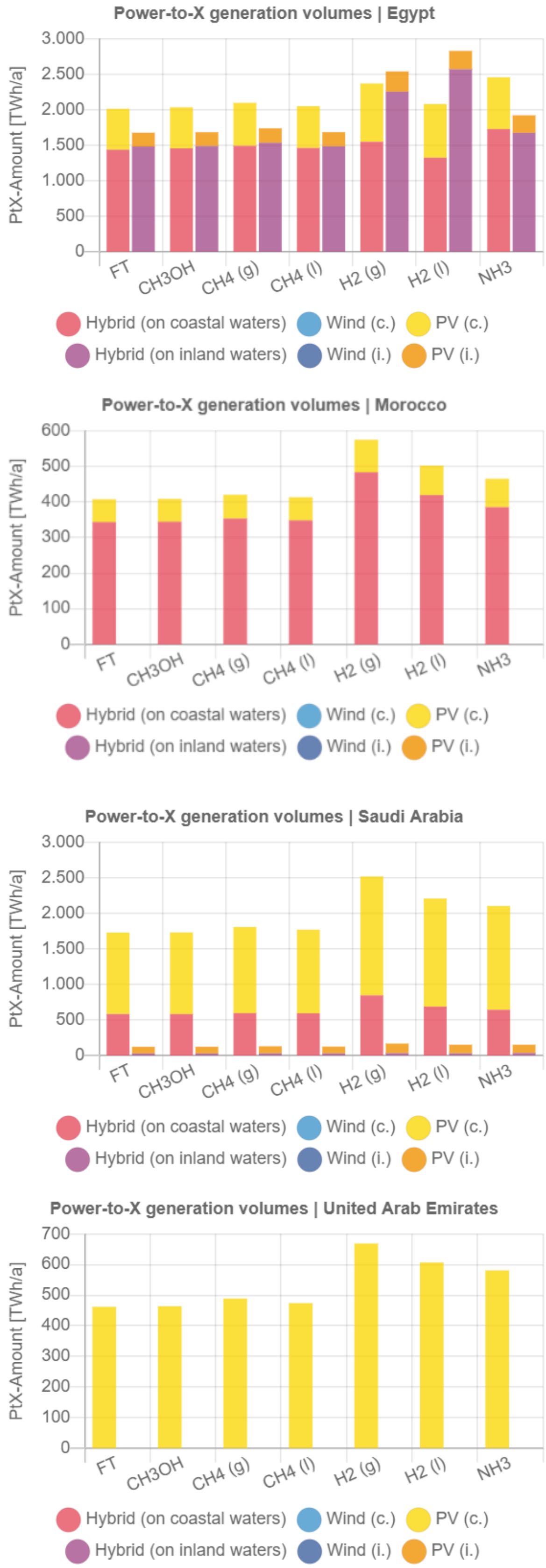

Figure 6: Potential Power-to-X generation volumes (high temperature electrolysis) for selected countries. Source: PtX Atlas[84]

According to UNESCWA (2021), **Arab countries with existing infrastructure** and potentially low costs of electricity generated from variable renewable energy (solar and wind) - such as Jordan, Morocco, Saudi Arabia and the United Arab Emirates - offer a key comparative advantage in the production of green hydrogen. However, this advantage can only be captured when the utilization level of electrolysers increases, depending on the availability of renewable electricity. In the Gulf area alone, a study by the MENA Hydrogen Alliance estimates that annual investments of $16 to $25 billion would be required over a period of 25 years to install 150 to 210 GW of electrolysis capacity to achieve a green hydrogen production capacity of 50 to 70 million tons by 2050. These investments cover expenditures for storage and conversion, renewable energy and electrolysers.[85]

Spotlight on Saudi Arabia: NEOM Green Hydrogen Project

Once commissioned, NEOM will be the world's largest utility scale, commercially-based hydrogen facility powered entirely by renewable energy. The $5 billion project is being developed by a joint venture between Neom and ACWA Power of Saudi Arabia and Air Products of the United States. Upon finalisation in 2026, the facility will include over 4 GW of renewable energy, will produce 600 tonnes per day of clean hydrogen by electrolysis and up to 1.2 million tonnes per year of green ammonia.[86] Furthermore, plans have been announced to develop an assembly plant in the city of Neom to produce up to 10,000 hydrogen fuel cell-powered vehicles a year as part of an MoU between Hyzon Motors of the United States and the Modern Industrial Investment Holding Group and Neom company of Saudi Arabia.[87]

Potential applications

Potential applications for hydrogen are sketched out in the figure below. Globally, hydrogen is currently used mainly as a feedstock rather than as an energy carrier. The main applications are in refineries, e.g., for ammonia or methanol production, and in first applications in the iron and steel industry. Together these applications account for about 75% of current hydrogen use.[88] This also applies to the Arab region - most of the **hydrogen is currently used in oil refining**, petrochemicals and the steel industry. Gas-based chemical industry, such as ammonia and methanol plants, mainly in countries with vast natural gas resources (e.g., Algeria, Egypt, Saudi Arabia and UAE), rely exclusively on grey hydrogen sources. All steel plants produce and use grey hydrogen - only hydrogen used in the Emirates Steel DRI plant (UAE) is produced from natural gas.[89]

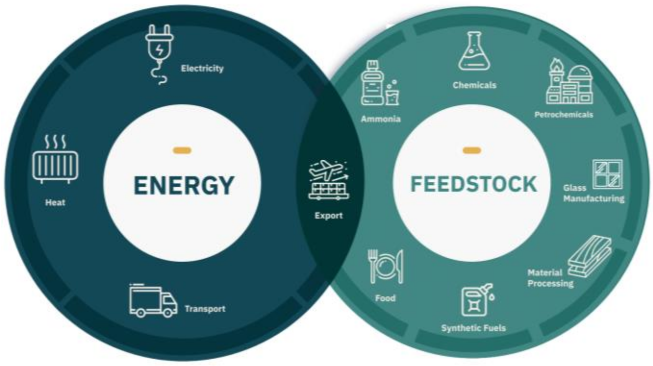

Figure 7: Potential applications for hydrogen. Source: Friedrich-Ebert-Stiftung 2022[90]

In order to meet the countries' climate change mitigation targets, these industries impose challenges sectors that need to be addressed by a growing green hydrogen economy. Replacing grey hydrogen with hydrogen generated with renewable electricity is one option for contributing to the decarbonisation of aforementioned existing **industry applications**. That said, new opportunities for green hydrogen use are emerging in the industry sector. Options for the application of green hydrogen are specific for each industrial segment, ranging from replacing fossil-based hydrogen to changing the entire industrial production process: Hydrogen could, e.g., replace coal as a reducing agent in steel production[91], be applied in refineries, or be applied in the production of green ammonia. Today, the production process of raw steel from iron ore is based on fossil fuels, either in the blast furnace (BF) process using metallurgical coal as reducing agent or the direct reduced iron (DRI) process with methane as reducing agent in combination with electric arc furnaces (EAF). Green hydrogen can be used in the future to replace fossil fuels partly (in BF process) or completely (in DRI process). Since DRI plants are commonly used in countries with natural gas resources, DRI plants are widely spread in most Arab countries. Replacing natural gas with green hydrogen by H2 in the DRI process is considered as a feasible option on a medium term in the Arab region, and associated with only limited investment costs. For the utilisation of green hydrogen in the refineries, investment in hydrocracking or hydrotreatment units is required. The existing refineries could reduce sulphur ratios and optimise octane ratings to lower the direct emissions. Hydrocracking or hydrotreatment would generate additional demand for green hydrogen. Ammonia is currently almost exclusively produced in large-scale by combining nitrogen and hydrogen via the Haber-Bosch process. In Arab countries, the ammonia production is derived from 100% natural gas. Ammonia production is the most energy-intensive process in the fertilizer industry. The expected growing global demand for ammonia could offer an additional chance to establish green ammonia production in locations with the potential to generate large amounts of low-cost renewable electricity.

Spotlight on Tunisia: Green hydrogen and PtX opportunities in industry

A study commissioned by GIZ (2021) investigated the opportunities of Power-to-X in Tunisia. The findings related to opportunities for PtX in the industry sector are summarised below:

	Current applications of hydrogen	Relevance for Tunisia today	Long-term development potential Tunisia
Refining	Desulphurise and upgrade heavy crude oil via • Hydrocracking • Hydrotreating	The country has one refinery with no further treatment unit so currently no demand for green hydrogen for refining exists in Tunisia.	New refinery or adding treatment units could create limited demand in the future. But these options entail risks like technological lock-in effects or stranded investments.
Iron and steel	Direct reduction of iron (DRI) in primary steel production	Tunisia has one steel mill with secondary steel production from scrap in an electric arc furnace. This process does not require hydrogen.	Establishment of new steel industry with DRI and related hydrogen demand unlikely. Especially as Tunisia has only limited iron ore reserves.
Chemicals	• Ammonia production • Methanol production • Other chemical processes	Currently no ammonia or methanol production in Tunisia, both commodities are imported. Only indirect demand for hydrogen today.	Green ammonia and methanol could be produced in Tunisia from hydrogen generated with renewables to cover domestic demand and for export.
High temperature heat	No application today, but potential application in the future	No application of hydrogen for heat in the industry in Tunisia.	No potential applications in Tunisia in short to medium term. Long-term demand development possible but direct use of concentrated solar heat could be a more feasible option.

Figure 8: Green hydrogen and PtX opportunities in Tunisia. Source: GIZ (2021)[92]

Green hydrogen fuels could also play a certain role in decarbonising the Arab region's **transport sector.** Theoretically, heavy transport, including buses, trucks, ships and aircraft, could be powered by hydrogen in the future. In addition, hydrogen can be converted into methane, methanol and ammonia, which can be used directly as fuel or converted and upgraded into synthetic diesel, gasoline or kerosene. Synthetic fuels are technically no different from their conventional counterparts and can therefore be used directly in combustion engines without requiring any technological change or investment in new infrastructure. These technologies are not yet competitive with conventional fuels and technology advances and availability still vary between different applications. According to GIZ (2021), many technologies should however be ready for commercial applications by 2030.[93] Potential primary adaptors in road transport in the Arab region could be national bus services or any other public organisation using substantial number of busses or heavy-duty vehicles. For the maritime shipping industry, ammonia is attracting particular interest. To date, however, the use of hydrogen-based fuels, including ammonia, in shipping has been limited to research and demonstration projects. Hydrogen use for rail cargo transport is also at its early development stages where different drivetrain options such as hydrogen fuel cells, gas engines or hybrid concepts are investigated along with the use of PtX fuels. Electrification in train sector via overhead lines would require large infrastructure investments, which are usually only viable for high-traffic routes[94]. For the application in aviation, costs are also a deciding factor. Energy-based kerosene is expected to be at least 2 to 4 times more expensive than conventional kerosene [95] . Therefore, any introduction of green kerosene in the region would have to be accompanied by financial incentives or other supporting measures.

According to GIZ (2021), the following application potentials for green hydrogen exist in the **electricity and gas sector**: With increasing shares of variable renewable energy sources in the electricity mix, flexibility and storage options for generation peaks will become increasingly important to meet the demand peaks. PtX technologies can support the power supply in three ways: i) by managing surplus electricity generated from non-dispatchable variable renewable electricity sources; ii) by providing ancillary services to stabilise the grid frequency or iii) (4) as power solutions for off-grid systems. Converting surplus renewable electricity into hydrogen and re-electrification would allow energy to be stored and used at times when it is most needed. Hydrogen can also be injected into existing natural gas pipeline networks, either directly or through conversion into green synthetic natural gas (SNG). According to current assumptions, a share of up to 20% hydrogen does not require any technical adjustments to the existing natural gas infrastructure. [96] If the share of renewable energy significantly increases, balancing temporal and spatial mismatches between electricity supply and demand in the Arab region could become relevant in the future. Blending green hydrogen into the existing natural gas infrastructure could help to reduce the carbon footprint of the current energy mix of some Arab countries.[97] [98]

Hydrogen export potential: Transport options and supply costs

Several countries outside of the Arab region – above all in the European Union - are planning to introduce green hydrogen into their economies, especially in sectors where it is hard to electrify and abate carbon. Based on current projections, the domestic green **hydrogen supplies of Europe** will not be sufficient to meet their projected hydrogen demand on a long term. Consequently, this opens opportunities for low-carbon hydrogen imports from the League of Arab States. [99] Hydrogen can either be transported via pipelines, or via ships – carrying liquified hydrogen, liquified organic hydrogen carriers, or synthetic e-fuels such as methanol or kerosene. For transport in pipelines, hydrogen is blended in natural gas pipelines, transported in new or retrofitted pipelines. Blending can be done at up to 2%. The costs of new pipelines are estimated to be about 20% higher than natural gas pipelines; estimated costs for retrofitting are about 10%-15% of those for new pipelines.[100]

The EU hydrogen strategy identifies particularly North Africa - due to its geographical proximity – as a potential provider of cost-competitive green hydrogen supplies. The European Hydrogen Backbone (EHB) initiatives indicates that **hydrogen imports from North Africa**, planned for 2040 or possibly earlier, would be routed through Italy and Spain. [101] Öko-Institut e.V. (2022) analysed total supply costs of green hydrogen in North African countries including transport to the European Union (Spain/Italy) in 2030. The study concluded that, while production costs are in the same range for the analysed countries, the supply costs vary especially due to the transport costs.[102] Repurposing natural gas pipelines for the transmission of hydrogen can cut investment costs 50-80%, relative to the development of new pipelines.[103] Egypt is assumed not to be able to transport hydrogen via pipelines and therefore it is unlikely that Egypt will export liquified hydrogen competing with countries that are connected to the EU via pipelines. Instead, ammonia or methanol or even e-fuels could be an option. As shown in figure 9 below, the transport cost for Algeria, Morocco and Tunisia in contrast are assumed to be much lower.[104]

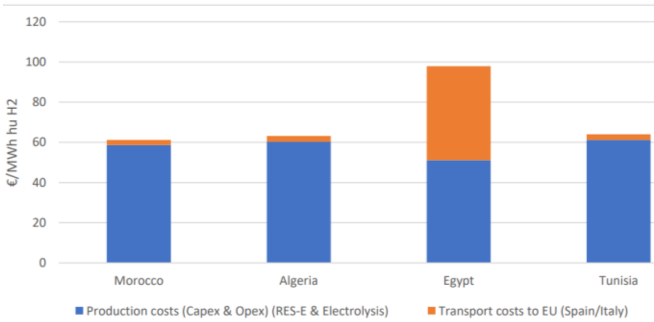

Figure 9: Supply costs of green hydrogen from North Africa to Spain/Italy in the year 2030, considering both pipelines and shipping. Source Öko-Institut e.V. (2022) [105]

Gas pipeline projects **from the Middle East to Europe** are also unlikely to materialise on the short to medium-term. Hence, potential low-carbon hydrogen supplies from the Middle East are more likely to be shipped to Europe. Currently, there are no significant hydrogen gas export projects from the Middle East, apart from aforementioned Neom hydrogen project in Saudi Arabia. [106] Figure 10 below shows estimated supply costs of liquified hydrogen from Arab countries to Europe (Germany), based on available data from the PtX Atlas. Assumed is a transport by ship, which is propelled with the fuel to be transported. [107] The higher transport costs for import from countries in the Middle East to Europe become evident compared to North African countries. Given the cost challenges of pure hydrogen transportation across long distances, shipping low-carbon ammonia from the Middle East to Europe would present a more feasible option.[108]

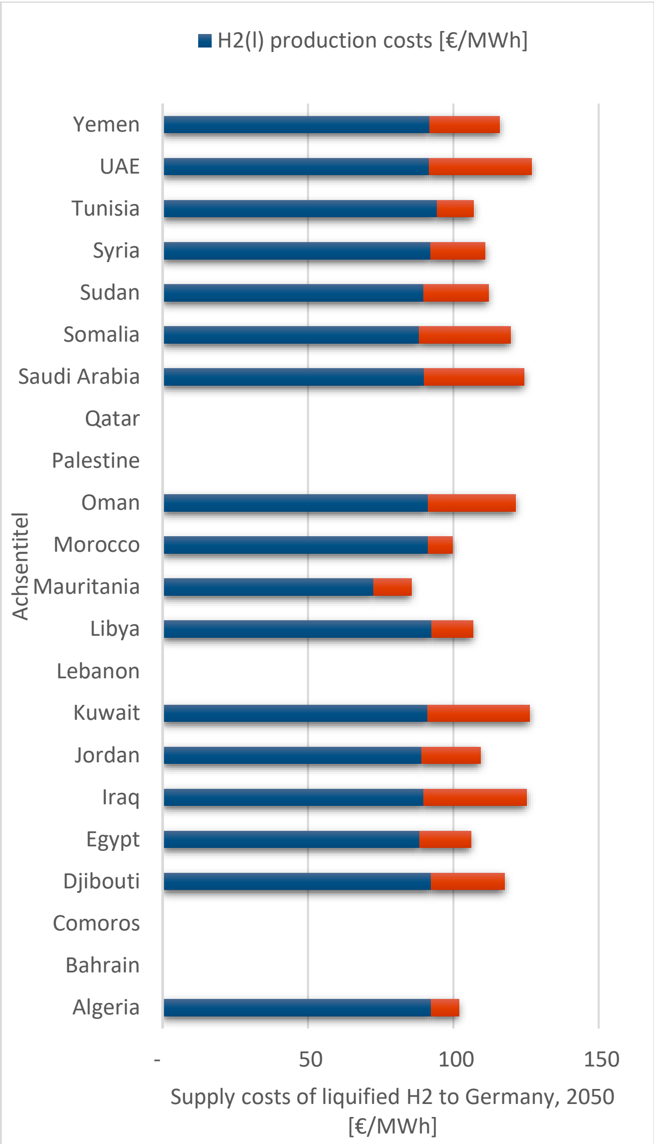

Figure 10: Supply costs of liquified hydrogen to Germany via ship, 2050. Source: Own elaboration based on Fraunhofer (2023)[109]

Economic, social and environmental considerations

One of the key barriers to low-carbon hydrogen development is the **higher cost compared to hydrogen produced from fossil fuels**. Depending on regional gas prices, the levelized cost of hydrogen production from natural gas ranged from USD 0.5 to USD 1.7 per kilogramme in the year 2019, as shown in figure 11 below. Applying carbon capture, utilisation and storage (CCUS) technologies to reduce the greenhouse gas emissions increases production costs to around USD 1 to USD 2 per kg.[110] Producing hydrogen from fossil fuels with CCS/CCUS will likely remain the cheapest low-carbon route in regions with low-cost domestic coal and natural gas and available CO2 storage, such as the Middle East.[111] Using renewable electricity to produce hydrogen currently costs USD 3 to USD 8 per kg.

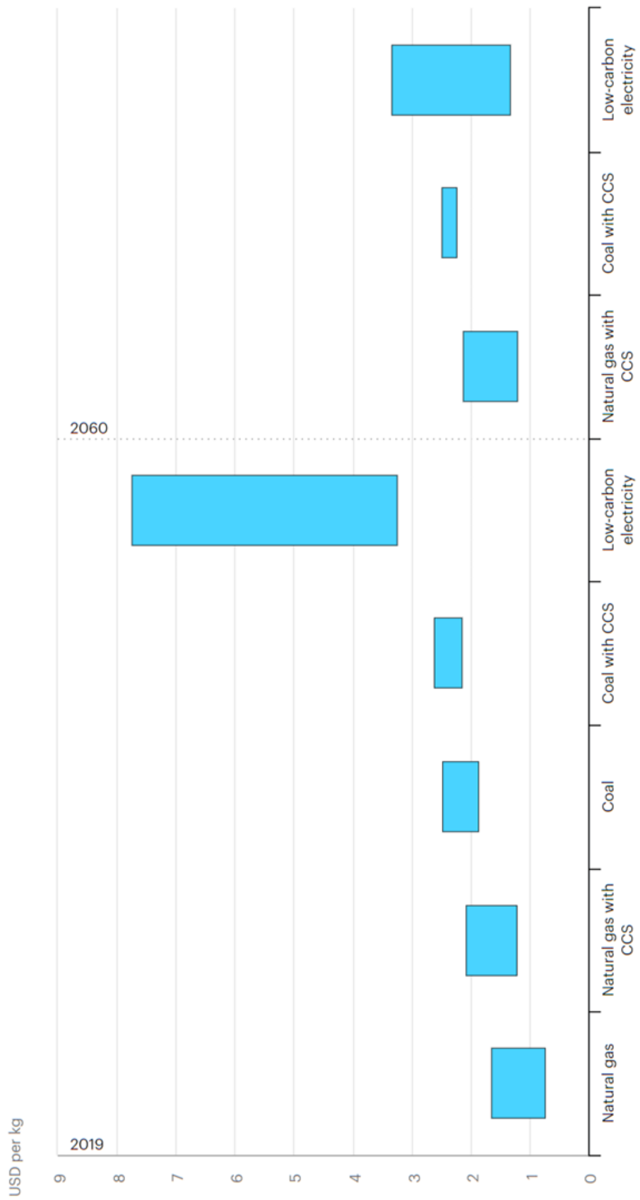

Figure 11: Global average levelised cost of hydrogen production by energy source and technology, 2019 and 2050. Source: IEA (2020)[112]

According to the IEA's Net Zero Emissions (NZE) by 2050 Scenario, green hydrogen production costs can decrease to as low as USD 1.3 per kg by 2030 in regions with excellent renewable resources – such as North Africa. In the longer term, hydrogen costs from renewable electricity fall as low as USD 1 per kg (range USD 1.0-3.0 per kg) in the NZE Scenario, making hydrogen from solar PV cost-competitive with hydrogen from natural gas even without CCUS in several regions.[113]

Water requirements of green hydrogen production plants limit their use in freshwater-scarce regions of the world. electrolysers require between 10 litres and 24 litres of water per kg of hydrogen, depending on the process efficiency. [114] According to a study by University of Stavanger and GH2Lab, desalinated water only increases green hydrogen production costs by one per cent[115], so with appropriate mechanisms, water scarcity issues can be avoided. However, the adverse environmental and social impacts of freshwater usage are an extremely important consideration in the Arab region, especially in inland areas with no access to potential sources of desalinated seawater. Climate change is further accelerating the water stress in several regions by prolonging drought periods, rising temperatures, and changing rainfall patterns.[116] Even if accessible, the desalination of seawater is an energy-intensive and costly process which needs to be assessed carefully in the respective local or regional context. On the other hand, a sustainable way of developing additional seawater desalination capacity for green hydrogen production could also provide opportunities to supply freshwater to local communities.[117]

Further environmental risks associated with the deployment of green hydrogen also need to be evaluated. These risks are e.g., related to the discharge of concentrates and chemicals into the marine environment, such as increase in seawater temperature, salinity and water flow. Land use requirements also need to be considered: Estimates for electrolysers vary between 8 m^2 and 60 m^2 required land area per MW. Areas required for the required renewable energy capacities are much larger. In regions high radiation levels such as the MENA region, about 20,000 m^2 are required per MW PV installation. Wind projects currently have an estimated land requirement of about 200,000 m^2 per MW.

Towards a Pan Arab Green Hydrogen Strategy for the League of Arab States

Rationale for a Pan Arab Strategy

The analysis in the scope of this study shows a high potential for variable renewable energy technologies in the Pan Arab region. Solar irradiations are among the highest in the world; a few countries also possess substantial wind energy potentials. Several member states have ambitious expansion plans for renewable energy technologies in the coming decades as part of their energy policies or climate change mitigation strategies. The **potential for green hydrogen** however varies substantially between the countries due to differences in water availability, existing infrastructure, as well as geographical and socioeconomic factors. As main challenges, environmental and social concerns – e.g., related to water scarcity in countries without ocean access, high production and transport costs, as well as limited political and economic stability in several countries have been identified. The costs associated with the production of green hydrogen are not yet competitive with other generation forms or energy sources. With continued technological advancements, expansion and decreasing costs of renewable energy and electrolysers, this may change in the coming decades. Blue hydrogen - the production from natural gas with carbon capture – is currently considered more economic and explored by several countries with vast natural gas resources. In terms of transport, options for the export of hydrogen from North African countries via pipelines to Europe are being explored; for Arab gulf states, shipping currently seems the only feasible option.

The region is also characterised by diverse advancements in exploring options for the production and application of (green) hydrogen in the individual countries. Only few countries have launched national hydrogen strategies or plans; existing electrolysers are limited to pilot scale and single countries. Yet, national strategies are under development in a growing number of member states, and the first mega-projects for the production of green hydrogen are announced, e.g., in Saudi Arabia. Bundling of these efforts will be essential for the sustainable **development of a green hydrogen economy in the region**. Ramping up green hydrogen industries in member countries will not only help to achieve the national greenhouse gas emissions targets according to Nationally Determined Commitments (NDC), but also align investment needs with policies for attracting possible green loans from international financial institutions.

Against this background, this study advocates forth the development of a **Pan Arab Green Hydrogen Strategy for the League of Arab States**. A harmonised approach can support knowledge transfer and research & development, the alignment of national strategies and plans, the joint exploration of feasible options for the production and regional application of hydrogen, as well as common ground in the initiation of interregional trade agreements. Potential pathways, potential partners, required actions and next steps for the development of a respective chapter are described in this chapter.

Proposal for a regional green hydrogen roadmap 2023-2050

In this chapter, a **green hydrogen roadmap** for the Arab region is presented. To reflect the evaluation of the industry maturity and the expected increased deployment of green hydrogen, three development stages have been defined: Piloting, demonstration phase (2023-2030), market creation & scale-up phase (2030-2040), and mass-market/competition phase (2040-2050). Associated key objectives, challenges and requirements are described in table 3 below.

Table 3: Green hydrogen roadmap 2023-2050 for the Arab region: Development stages

2023-2030: **Piloting & demonstration**	**2030-2040:** **Market creation & scale-up**	**2040-2050:** **Mass-market/competition**
Status: Green hydrogen production limited to demonstration or piloting projects. It is mostly produced on-site, decentralized with limited infrastructure development.	**Status:** Increasing hydrogen demand and realising economies of scale for production and infrastructure. First benefits from synergies between applications, e.g., in industrial clusters.	**Status:** Green hydrogen and its derivatives are become widely used and have become competitive both for supply side and in its end uses.
Key objective: Encourage and accelerate further deployment of green hydrogen supply infrastructure.	**Key objective**: Close the profitability gap by scaling up the operationally proven technologies	**Key objective**: Ensure cost efficiency and benefits from all technologies for overall climate policy framework.
Key challenge: Production and transport costs	**Key challenge:** Creating demand and markets for the products	**Key challenge:** Allowing cost optimisation across sectors
Key requirements: Short-term policies and actions that help close cost gaps, e.g. R&D funding, risk mitigation policies and co-funding of large prototypes and demonstration projects.	**Key requirements:** Ensure reliable demand in the short, medium and long term, as well as sufficient renewable electricity generating capacity.	**Key requirements:** Previously introduced incentives might be not technology-neutral and hinder cost optimisation. Phase-out or relaxation of some quotas or obligations is required.

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For the identified development stages, **technology roadmaps** for the different market segments have been developed. Identified opportunities for production and distribution, industry, transport, electricity and gas, as well as export on a short, medium and long term are described in the non-exhaustive table 4.

Table 4: Technology roadmap 2023-2050 for scaling up a green hydrogen economy in the Arab region, market segments.

2023-2030: **Piloting & demonstration phase**	**2030-2040:** **Market creation & scale-up phase**	**2040-2050:** **Mass-market/competition phase**
Production and distribution Design and installation of wind and/or PV systems for electrolysis Installation of adequate capacities of electrolysis, depending on country potentials and power infrastructure Identify pipelines sections and corridors which can be retrofitted in the future for pure hydrogen transport. Assess integrity, lifetime, capacity, and costs.	**Production and distribution** Expansion of renewable energy and electrolyser capacities. Scale up green hydrogen supply models with demand-based electrolyzer capacity across the region. Design and installation of new pipelines or retrofit existing pipelines for the transportation of hydrogen depending on the country condition	**Production and distribution** Large scale production of key components (e.g., electrolysers) in the region. Electrolyser capacities exceed local demands and meet demands of interregional trade. Retrofit selected existing natural gas pipelines for 100% operation or newbuilt dedicated hydrogen pipelines.
Industry	**Industry**	**Industry**

Steel: Test injection of hydrogen in existing steel production plants (e.g., in direct reduced iron and blast furnace process). Ammonia: Insall demonstration plants using green hydrogen for ammonia production. Storage: Investigate options and availability of large-scale hydrogen storage for industry applications, e.g., in depleted oil and gas fields.	Steel: Increase blending with green hydrogen in steel production plants. Ammonia: Retrofit existing ammonia plants to increase load flexibility for green hydrogen. Oil: Scale up in hydrocracking or hydrotreatment in existing refineries. Transport: Scale up green hydrogen distribution pipeline systems to industry clusters.	Steel: Conversion of steel production plants for 100% hydrogen-readiness. Ammonia: Large-scale application of green ammonia in fertiliser production. Oil: Desulphurise and upgrade heavy crude oil via hydrocracking or hydrotreating. Production: Install decentralized hydrogen production capacities at industry clusters.
Transport Road transport: Develop and optimise hydrogen refuelling station design and manufacturing. Explore options for the production of of fuel cell components (cell membrane, catalyst layer, bipolar plate). Ships: Explore low-carbon fuel options for freight ships, in particular ammonia fuel; and for extension of selected harbours.	**Transport** Road transport: Install refuelling stations, including hydrogen distribution networks along major transport routes and pilot urban areas. Introduce fuel cell electric vehicles in medium- or heavy-duty transport. Trains: Explore options for hydrogen applications in trains – e.g., where overhead powerlines are too costly or difficult to implement. Aviation: Demonstration pilot projects for using hydrogen based synthetic fuels in the aviation sector.	**Transport** Road transport: Install decentralized hydrogen production capacities at selected refuelling stations. Introduce fuel cells for light-duty passenger vehicles where feasible. Ships and trains: Scale up of hydrogen-based fuel options for maritime and rail transport. Aviation: Large scale production of sustainable aviation fuels in selected countries with lower LCOH and high potential of green hydrogen.
Electricity and gas Identify demonstration plants for retrofitting natural gas turbines to accept an increasing hydrogen blend. Blend up to 5% green hydrogen with natural gas in existing natural gas power plants without technological modifications. Explore technology options for using hydrogen for storage and electrolyser for power balancing in the region.	**Electricity and gas** Increase the share of green hydrogen blending as a fuel until 40% in natural gas power plants. Retrofit of existing facilities using diesel generators (e.g., food production, hotels, hospitals, construction areas) with fuel cells for power generation. Balance temporal and spatial mismatches between power supply and demand with electrolyser operation.	**Electricity and gas** Retrofit existing and build new power plants for operation on 100% green hydrogen content. Use green hydrogen as backup power solutions for data centres and telecommunication services. Use green hydrogen as storage in countries high shares of variable renewable energy.
Export Investigate the technical compatibility of existing LNG and ammonia terminals for the future export of liquid hydrogen and green ammonia. Explore options for using existing natural gas pipelines for exporting blended green hydrogen.	**Export** Install new hydrogen pipelines to connect production sites with existing pipelines or harbours for export. Blend green hydrogen with natural gas for export via existing pipelines. Deploy adapted harbour infrastructure for export.	**Export** Green hydrogen production capacities cater for meeting regional demands and interregional trade with partner regions, e.g., the European Union. Explore options for new hydrogen pipelines to partner regions.

Enabling framework conditions for strategy implementation

Implementing the developed roadmap in the Arab region requires an **enabling policy and regulatory environment** in the member states. As described in the previous chapters, the resources, potential and conditions for green hydrogen production and utilisation vary substantially between the Arab countries. Yet, only with a clear policy vision clear targets and accompanying measures an organic and sustainable growth of the regional green hydrogen market can be achieved. In its Global Hydrogen Review 2022,[cxviii] the International Energy Agency provides the following policy recommendations to accelerate low-emission hydrogen production and use:

Move from announcements to policy implementation: Green hydrogen and PtX technologies are ready to scale, but the market is still nascent and its future evolution is uncertain, discouraging first movers from reaching FID. Governments need to implement policies to reduce risk and improve the economic feasibility of low-emission hydrogen projects.

Raise ambitions for demand creation in key applications: Despite sharp increases in fossil fuel prices during the past years, investment decisions continue to be hindered by general uncertainty around the long-term development of energy prices. Policies to create demand for green hydrogen are needed, using instruments such as auctions, mandates, quotas and requirements in public procurement. This should be complemented by innovation and demonstration efforts, e.g., in heavy industry, heavy duty road transport and shipping.

Ensure that short-term actions align with long-term plans: The development of hydrogen infrastructure needs to be accelerated, both in terms of new assets and repurposing existing infrastructure. Despite technical challenges, it is required to carefully consider how new gas-related infrastructure may potentially support the future development of hydrogen in the context of climate ambitions.

Intensify international cooperation for hydrogen trade: the development of an international market for low-emission hydrogen will strongly depend on effective international cooperation. There are a number of areas where governments need to work together: developing a standard for emissions intensity of hydrogen production and transport, defining robust and workable regulations, and cooperation on certifications to ensure interoperability and avoid market fragmentation.

Remove regulatory barriers: Clear and stable regulatory framework must be balanced with a dynamic regulatory approach, calibrated to regular market monitoring. Improving regulatory processes, such as licensing and permitting, can help shorten project lead times. Governments should work to increase the efficiency and co-ordination of these processes without compromising environmental standards and public consultation.

Policy and regulations need to be framed by support to **research, innovation and capacity building**, as well as market incentives for the development of a green hydrogen economy. Regional coordination and alignment complement these three columns by improving knowledge transfer, resource efficiency and a strengthened position on the global market. The table below describes the suggested approach to ensure enabling conditions for implementing the proposed green hydrogen roadmap:

Table 5: Enabling framework conditions for implementing the technology roadmap

Research, innovation & capacity development	**Policy & regulation**	**Market incentives**
Establish R&D **competence centres** for green hydrogen Promote regional and international research & Facilitate **collaboration** and technology/knowledge transfer between academia, policy, industry, and civil society Realise lighthouse **pilot and demonstration projects** that support green hydrogen value chains Launch **workforce programs** for the usage of green hydrogen in their industrial process Integrate green hydrogen and PtX as cross-cutting themes into tertiary, vocational and professional **education**. Strengthen **institutional capacities** of public sector and industry associations.	Integrate green hydrogen and PtX into energy and climate change **policy targets** **Regulate the utilization** of hydrogen in industry and transport, in line with international standards Regulate the **integration of electrolysers** into power systems Introduce **quality standards and sustainability criteria** for green hydrogen and derivates production, transport, storage and utilisation Establish **licencing and permitting procedures** for green hydrogen and derivates production plants, as well as refuelling infrastructure Regulate the use of **green hydrogen as fuel** in the vehicles, trains or in aviation Introduce minimum **hydrogen blending standards** in the gas network. Phase out **fossil fuel subsidies**	Introduce **carbon incentives or levies** favouring green hydrogen Establish GHG emission trading schemes Establish subsidy programmes for purchase of Fuel Cell Electric Vehicle and H2 refuelling stations. Define of a **fixed hydrogen selling price** at refuelling station to support market entry Introduce incentives to switch to **using green ammonia** in fertiliser production. Introduce **de-risking instruments** both on the political and the financing side **Engage in PPPs** to deploy the necessary infrastructure. Explore additional **support measures**, such as international funding schemes.

Regional coordination and alignment

- Develop a common definition and region-wide criteria for the **certification of green hydrogen** and derivates.
- Organise regional stakeholder **information exchange** fora and platforms on green hydrogen
- Establish a regional **experts coordination group** with energy or industry ministries in Arab countries for green hydrogen
- Set-up a **regional hydrogen pipeline** gathering info about upcoming green hydrogen and PtX projects in Arab states
- Develop **a regional investment agenda** to stimulate production and use of hydrogen and build a regional project pipeline
- Set-up a regional **centre of excellence** for advising and monitoring the development of the regional hydrogen economy
- Harmonize **national and regional regulatory frameworks** for green hydrogen and derivatives.
- Establish **regional infrastructure** for green hydrogen and derivates trade

Recommended way forward

As a **first step towards the development of a regional strategy**, the development and alignment of national strategies and roadmaps for green hydrogen shall be encouraged. By identifying the potential for production, application and export of green hydrogen as well as related investment needs in Member States, common interests and opportunities can be identified and the planned actions harmonised across the region. Table 6below summarises the status quo of national hydrogen strategies and roadmaps.

Lessons learned and knowledge gained in countries with substantial progress can support other States in advancing their policy plans accordingly. The **League of Arab States** can play a central role in facilitating this knowledge transfer, e.g., by developing standardised templates and building capacities for the development of national strategies or roadmaps. As a second step, LAS can catalyse and coordinate the joint development of a Pan Arab Green Hydrogen Strategy. The proposed respective process is shown in figure 11 below:

Table 6: Status of national hydrogen strategies and roadmaps in the Arab region

Country	National hydrogen strategy or roadmap
Algeria	National hydrogen strategy under development.
Bahrain	Not available
Comoros	Not available
Djibouti	Not available
Egypt	Low-carbon hydrogen strategy under development.
Iraq	Not available
Jordan	Green hydrogen roadmap published, green hydrogen strategy under development.
Kuwait	Hydrogen strategy under development.
Lebanon	Not available
Libya	Not available
Mauritania	Not available
Morocco	Green hydrogen roadmap published.
Oman	National hydrogen strategy planned..
Palestine	Not available
Qatar	Not available
Saudi Arabia	National hydrogen strategy under development.
Somalia	Not available
Sudan	Not available
Syria	Not available
Tunisia	National green hydrogen strategy under development.
United Arab Emirates	Hydrogen Leadership Roadmap developed, national hydrogen strategy developed.
Yemen	Not available

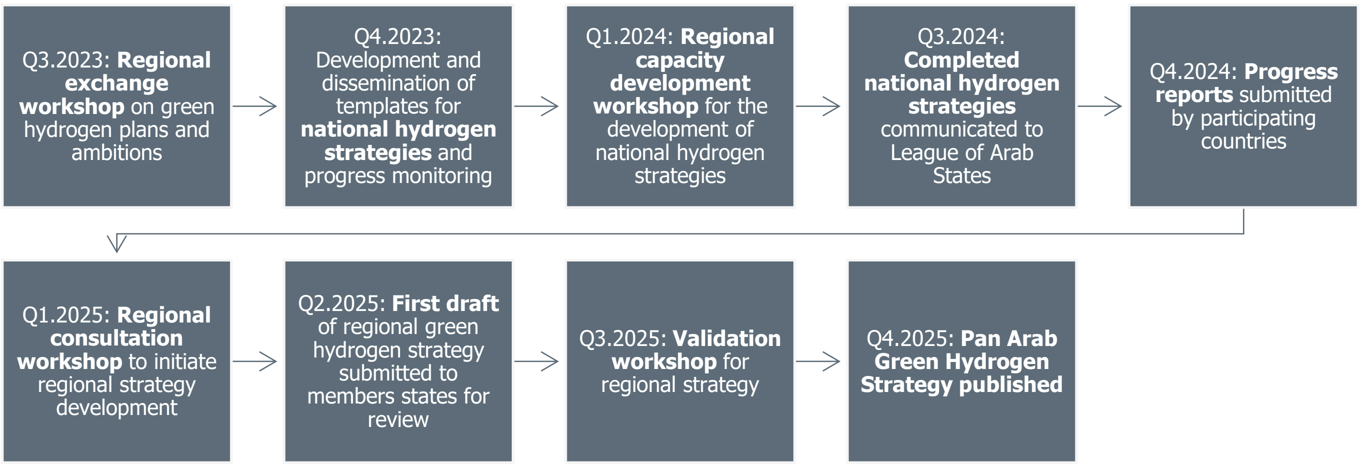

Figure 12: Recommended process for the development of a Pan Arab Green Hydrogen Strategy

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