TeasiMed

TOWARDS AN EFFICIENT, ADEQUATE, SUSTAINABLE AND INTERCONNECTED MEDITERRANEAN POWER SYSTEM

Identification And Quantification of Long-Term Sectoral Perspectives in Mediterranean Region

Part 2: Power-to-gas and green hydrogen

Med-TSO
MEDITERRANEAN TRANSMISSION SYSTEM OPERATORS

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TASK 1 Update of the Mediterranean Master Plan and improvement of methodologies for its delivery

Activity 1.3: Med-TSO Very Long-Term Scenario

Deliverable 1.3: Med-TSO Very Long-Term Scenario - *Power-to-gas and green hydrogen*

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Abbreviations

EAF	Electric Arc Furnace
CNG	compressed natural gas
DRI	Direct Reduced Iron
GH2	Green Hydrogen
IPCEI	important projects of common European interest
Ktons	1000 tons
LNG	liquefied natural gas
LCoH	Levelized Cost of Hydrogen
Mt	Million tons
MoU	Memorandum of Understanding
NDC	Nationally Determined Contribution
NH3	Ammonia
PtX:	Power to X
RE	Renewable Energy
RES	renewable energy source
SME	small and medium enterprise
SCZONE	Suez Canal Economic Zone
TAP	trans-Adriatic pipeline
Tpa	ton per annum
TYNDP	ten-year network development plan

Introduction

Hydrogen is a chemical energy carrier that is increasingly been considered as a decarbonization option in national plans and strategies, especially for some hard-to-abate final sectors (notably heavy industry and long-distance transportation). Although it is one of the most abundant elements on earth, hydrogen is not available in its pure form on our planet. Thus, just like electricity, hydrogen is not a primary energy source, but it is rather an energy carrier that needs to be produced through different technological pathways. Hydrogen can be used in its pure form as an energy carrier or as an industrial raw material. It can also be combined with other inputs to produce what are referred to as hydrogen-based fuels and feedstocks[1].

Hydrogen shows barriers and opportunities along each step of the value chain. It needs to be generated, compressed or liquefied to be transported and stored, and often converted to electricity in a fuel cell to be used in final sectors.

[1] IEA (2019). The future of hydrogen, p. 33.

Hydrogen generation

The two main options that are currently considered for low-carbon hydrogen generation are the electrolysis coupled to renewable electricity (usually called green hydrogen) and the steam reforming from natural gas coupled to carbon capture and storage (referred to as blue hydrogen).

The current world hydrogen supply is virtually all produced from fossil fuels, mainly natural gas and coal, via steam reforming and other processes (autothermal reforming, partial oxidation and coal gasification). Hydrogen produced from fossil fuels without carbon capture is usually known as “grey hydrogen”.

Carbon capture coupled to hydrogen production is considered as a mature technology, although this is not currently applied in the industry. Experts agree on its lower cost compared to the electrolysis pathway in most applications, especially on the short term. It is important to remark that the capture rate may not reach a full removal of the carbon dioxide produced in the process, and a typical capture rate may remain around 90%. Another potential option to produce hydrogen from fossil fuels without emitting greenhouse gases is the pyrolysis, which could produce solid carbon as a by-product, but the process is not yet commercially demonstrated at scale.

Many national strategies and targets are explicitly aiming at producing hydrogen without relying on fossil fuels, thus promoting the power-to-gas pathway, on the hypothesis that the current higher cost of green hydrogen will decrease thanks to favourable learning curves for both electrolysers and renewables. One notable issue to decrease production costs is the annual load factor: when directly coupled to solar or wind generation, an electrolyser has a limited number of annual hours to operate, decreasing its economic profitability. For this reason, experts are proposing to couple wind and solar to increase the annual productivity, or to select locations around the world with very high radiation or wind speed.

Hydrogen transport and distribution

While hydrogen shows a high energy density per unit of mass (around three times the one of gasoline), its energy density per unit of volume is quite low (around one third of natural gas). Thus, it needs to be transported either in liquid form (at 90°C below LNG, i.e. -253°C), or at high pressures or converted to other chemical compounds.

The two alternative options for long-distance transportation are pipelines and ships. Hydrogen pipelines are already operating in some industrial facilities and compared to natural gas pipelines they require a higher quality of steel to avoid leakages and embrittlement. While many of the new long-distance natural gas pipelines are suitable to be directly converted to hydrogen[2], older pipelines and most of the distribution network would need to be refurbished or replaced.

Some operators are also considering the possibility of gradually adding an increasing share of hydrogen in the current natural gas operation. Most of the current equipment could operate at volumetric concentrations up to 10% of hydrogen, although due to the lower energy density this level corresponds to a 3.5% concentration in energy terms (thus leading to 3% emissions reduction in the hypothesis of green hydrogen). Moreover, for this very same reason, switching the current network to hydrogen would allow to operate at only one third of the current capacity, and increasing the pressure is often not an option. However, in the hypothesis of significant energy efficiency measures and the electrification of a considerable share of the heat demand that is currently supplied by natural gas systems, hydrogen could be used to supply the remaining load.

Long distance transport could be done by shipping liquid hydrogen or other chemicals compounds that are easier to store, such as ammonia (which could be then directly used in some applications without further converting it back to hydrogen). Liquid hydrogen transportation is being tested in some international routes, although it potentially presents significant boil-off problems. Transporting compressed hydrogen may not be an option due to its low volumetric energy density. For these reasons, some experts are quite sceptic about the possibility of a large international hydrogen market compared to the current LNG market.

Hydrogen storage

One of the advantages of hydrogen is the fact that it can be stored for longer times without significant losses. Hydrogen is also being considered an option for long-term storage of electricity produced from renewables. Although the roundtrip efficiency is rather low (due to the energy losses in the electrolyser, the fuel cell and the storage system), it remains one of the few foreseeable options for seasonal storage of electricity generation. Some sites that are currently used for large-size storage of natural gas, such as depleted fossil fuels reservoirs or salt caverns, could be adapted for hydrogen storage, although the smaller size of the molecule compared to methane may pose problems of potential leakage.

[2] reference : European Hydrogen backbone - April 2022
https://ehb.eu/files/downloads/ehb-report-220428-17h00-interactive-1.pdf

Hydrogen in final uses

The current global hydrogen production is virtually all used in industry, mostly as a feedstock for ammonia or methanol production and in refineries. Other industrial applications that seem promising are steel factories, where it could be used to obtain low-carbon products.

Some experts suggest that hydrogen could also play a role in other sectors, such as long-distance transportation.

In general, hydrogen (and hydrogen-based fuels) may have a competitive advantage for applications that need long range (such as ships) and for which electric batteries may prove to be too costly, or in industrial processes that need very high temperatures, which may be impossible to reach with electricity-driven solutions. In some applications hydrogen-based fuels, such as ammonia, may be more appropriate than a direct use of pure hydrogen. For this reason, hydrogen use is more likely to penetrate hard-to-abate sectors, when no other option is available.

1 Synthesis

European countries are pushing at different speeds towards low-carbon hydrogen as a part of the solution for reaching the net-zero targets ahead. Hydrogen strategies are being developed, often with both short- and long-term targets and visions. The biggest role in evaluating the potential of hydrogen in decarbonization strategies is being played with Germany, which has developed a number of strategies and projects, including the implementation of agreements with foreign governments for future green hydrogen supplies. Although Germany is not part of the countries that are being studied in this report, it is important to remember its role and the potential effect of such a huge market in the development of green hydrogen export strategies in MENA countries.

Country-level strategies are part of a larger framework, as the European Union is pushing towards increasing green hydrogen targets, even proposed as part of the solution to reduce the high natural gas dependency on Russia. The Repower EU plan, proposed in summer 2022, aims at reaching 20 million tonnes of annual hydrogen use by 2030, half produced on site and half imported from non-European countries. This is a significant increase compared to the 5.6 million tonnes foreseen within the revised Renewable Energy Directive, published in July 2021. However, it is important to notice that many international experts are sceptical about the feasibility of such huge targets in a relatively short time frame, especially considering that the industry is at a relatively low level of maturity.

Regarding the MENA region, the discussion on the development of green hydrogen is relatively recent and was triggered mainly by local demand and the import demand announced by Europe and particularly by Germany. The latter country, through technical cooperation, massively supports these countries to lead a political dialogue on the future development of green hydrogen.

Thus, given the novelty of the subject, the non-European countries are in different stages on green hydrogen (GH2) development and we can classify them into three categories:

- Countries at advanced stages and have adopted medium- and long-term objectives and where the market development is more progressive through the launch of initiator projects and the signing of MOUs with international investors. These include Morocco, Egypt and to a lesser extent Turkey, which are today the most advanced among the countries of the region in this framework.
- Countries that are starting an active dialogue on the subject through the launch of preliminary studies and the preparation of roadmaps supported by international cooperation. These are in particular Tunisia, Jordan and Algeria
- Countries lagging behind given their national context.

Israel is a particular case and positions itself in a different way on the market. It targets the P2G value chain technology development for the international market, through research and development and start-up’s supporting.

2 MENA countries

2.1 Morocco

2.1.1 Review of current trends

Pure hydrogen: The current consumption of pure hydrogen is very low used mainly in some food industry processing, electronics manufacturing and in thermal power plants for rotors and magnetic circuits cooling. It is also used as a medium in the electronics industry and as a fuel in laboratories.

Ammonia: The national phosphate company OCP[1] imports 1.5 to 2 million tons of ammonia per year to produce fertilizers. In 2020, more than 1.6 million tons were imported from Russia (809 thousand tons) and Trinidad and Tobago (829 thousand tons) for 3.44 billion dirhams (MDH). The same trend was observed in 2021[3]. The OCP group intends to increase its production capacity to meet growing demand. It thus aims to increase fertilizer production in 2022 by 1.2 million tons, from 10.76 million tons in 2021 to 11.9 million tons in 2022. From the fourth quarter of 2022 and until 2023, OCP expects that its annual installed capacity of fertilizers increases by 3 million tons helping the group to increase the production of tailor-made fertilizers, in order to meet the needs of customers in key geographies, notably Africa[4].

2.1.2 Futurs trends

2.1.2.1 Existing strategies, quantitative objectives

Morocco has published its Green Hydrogen roadmap by end of 2021[5], presenting a reference and optimistic scenario According to the reference scenario, the electricity demand to satisfy the national market (energy and ammonia) is expected to reach 3.6 TWh by 2030, 22 TWh in 2040 and 40 TWh in 2050. For local market development, the roadmap provides the following steps:

- Short term (2020-2030): H2 for fertilizer production, replacing ammonia imports
- Medium term (2030-2040): Electricity storage, export, trucks, buses, locomotives

[3] https://wits.worldbank.org/
[4] https://www.ocpgroup.ma/fr/op%C3%A9rations-industrielles
[5] Green Hydrogen roadmap of Morocco, 2021.

- Long term (2040-250): Cars, industrial and residential heat, aviation, ships

For the export market, the roadmap targets to reach around 10 TWh of green hydrogen and its derivatives in 2030, 46 TWh in 2040 and 115 TWh in 2050. According to this will require respectively a RE capacity of 5.2 GW, 23 GW and 57.4 GW in 2030, 2040 and 2050[6].

Use	Sectors	2030	2040	2050
Export	Export	10.3	45.9	114.7
Local consumption		3.6	22	39.2
Chemicals	Industry (ammonia and methanol)	3.1	14.1	20.7
Energy	Transport	0.5	5.0	11.2
	Industry		2.7	5.4
	Residential		0.0	1.3
Electricity	Electricity storage		0.2	0.6
Total production TWh		13.9	67.9	153.9

Source: GH2 roadmap of Morocco, 2021

The total investment rises to approximately 8.5 billion euros by 2030 and 72 billion euros by 2050, as detailed in the following table:

Components (Billion euros2021)	**2020 - 2030**	**2030 - 2040**	**2040 - 2050**	**2020 - 2050**
RE sources	5,9	18,7	24,5	49,1
Electrolysers	1,8	5,4	6,5	13,7
Desalination units	-	-	0,1	0,2
Conversion units to Power to Liquid	0,3	1,0	1,9	3,2

[6] The quantity of H2 required for one ton of ammonia (NH3) = 17,6%. The quantity of electricity to produce 1 kg of H2 = 42 to 50 kWh depending on the efficiency of the electrolyser (60% to 66%).

Transformation Haber Bosch – Power to Ammonia	0,7	2,3	3,3	6,2
Total investment	**8,6**	**27,4**	**36,2**	**72,3**

Source: GH2 roadmap of Morocco, 2021

2.1.2.2 Weak signals. possible disruption factors

Main projects and agreements are recently announced by the Moroccan Government:

- Green ammonia project (Hevo Ammonia) signed with Fusion Fuel Green, with a capacity of 183 kt/year from 2026 (600 MW of Electrolysers). The total investment cost is estimated to around €865 million.
- Pilot plant to produce ammonia and green hydrogen in Jorf Lasfar, financed by the Dutch investment fund Invest International with a capacity of 1500 t/year and an electrolyser capacity of 4 MW.
- Agreement with Total Eren for a hybrid hydrogen and green ammonia project (10 GW wind and PV capacity, with a total investment of around $10.7 billion. It is expected that the production will start at the end of 2027.
- The Idea of an hydrogenoduc is discussed to link Morocco to Spain. The pipeline is expected to connect Cespa's San Roque refinery in Cadiz to Morocco.[7]

The announced projects are still not very advanced and come under simple MoU. It now remains to translate these agreements into concrete projects which will require on the one hand their financial closing and on the other hand to sign the contracts with the off takers.

2.1.2.3 Levers and barriers

- Morocco has a large renewable energy potential that can benefit to the development of green hydrogen at large scale.

[7] https://fuelcellsworks.com/news/cepsa-intends-to-build-spain-morocco-hydrogen-pipeline/

- With the implementation of a large RE capacity, Morocco has developed good know-how, human capacity and solid institutional framework to be well prepared for green hydrogen development at large scale.
- Morocco already has a large local demand for ammonia used for the production of fertilizers which can be replaced in the short and medium term by green ammonia.
- Morocco enjoys with an excellent geographical position which allows it to be placed as one of the best future suppliers of Europe.
- However, for the export, Morocco could face strong competition from countries like Saudi Arabia, Egypt, Algeria and Tunisia.
- The legislation on hydrogen in Morocco does not exist yet and a specific framework will need to be developed to foster the implementation of hydrogen projects in the country.

2.1.3 Main uncertainties

Some uncertainties persist regarding the future development of green hydrogen and PtX in Morocco, related in particular to:

- The country's capacity to implement the projects announced within the planned deadlines.
- The ability of announced projects to quickly mobilize the huge financing needs.
- Competition from grey ammonia if the price of natural gas drops in the future.
- Securing long-term contracts with off-takers at national and international level.

2.2 Algeria

2.2.1 Review of current trends

There are three ammonia production complexes from natural gas in Algeria:

- The construction of the Sorfert Petrochemical complex costed 1.6 billion dollars. This petrochemical complex is made up of two ammonia units with a capacity of 2200 Tons/day each and a granulated urea manufacturing unit with a capacity of 3 450 Tons/day. Sorfert Algeria exports 95% of its production of urea and 100% of ammonia.
- Ammonia and urea complex in Arzew, in partnership with the Egyptian company Orascom Construction Industries (OCI) is composed of two ammonia units with a production capacity of 1.5 million tons/year and a urea unit with a production capacity of 1.1 million tons/year.
- Ammonia and urea complex at Mers El Hadjadj (Arzew), in partnership with the Omani partner Suhail Bahwan Group Holding (SBGH) comprising two ammonia units with a production capacity of 1.3 million tons/year and two urea units with a capacity of 2.3 million tons.

In addition, the Spanish group Fertiberia has two production centers in Algeria producing around 0.7 million tons / year of ammonia from of its factories in Annaba and Arzew.

The ammonia manufacturing unit of Fertial, a mixed company 66% owned by the Spanish group Villar Mir and 34% by the public group Asmidal, broke a new record. Indeed, it now goes from 650 to more than 1,000 tons/day of ammonia at the Arzew unit, thanks to the renovation of one of its production trains.

In 2021, Algerian ammonia exports reached an amount of 298 M USD for a quantity of 1.23 M tons. Algeria is the 4th world exporter after Russia, Canada and Indonesia. The main customer countries are: Spain (81 M USD), France (44 M USD) and the Netherlands (43 M USD).

Green hydrogen, produced by electrolysis, is already used in industry, particularly in the agri-food sector and glass production.

Two pilot research projects for the development of hydrogen were launched in 2006. The "solar hydrogen pilot project" and the HYDROSOL project (in cooperation between the CDER and the Institute of Technical Thermodynamics and Solar Research at the Centre German aerospace company DLR) aim to exploit the solar potential of Algeria to produce hydrogen (AHK, 2011).

2.2.2 Future trends

2.2.2.1 Existing strategies. quantitative objectives

The potential of green hydrogen in Algeria is huge regarding the solar resources. Indeed, based on the site-specific hydrogen yield, the overall technical potential for green hydrogen production from photovoltaic energy in Algeria is estimated at 6,650 million t per year by 2030.

In term of market, the domestic demand potential in Algeria is ranging between 118 and 285 TWh per year which is minor compared to the export potential (481 to 665 TWh per year).

Exploratory study on green hydrogen in Algeria, within the framework of the Algerian-German energy partnership has been developed. This has defined an indicative roadmap for export, but there is no formal roadmap developed and adopted by Algeria. However, a working group, made up of experts, scientists and heads of bodies responsible for the development of renewable energies, has been working for several months on the development of a roadmap setting out the approach to be followed in the prospect of providing the country with green hydrogen production. "This roadmap is being finalized, which will allow Algeria to be clear about the measures to be taken to develop this type of energy", according to the Algerian Commissioner for Renewable Energies. According to him, Algeria, endowed with significant solar potential, is well placed to produce green hydrogen at "very competitive" costs.

2.2.2.2 Main projects and agreements:

The Italian energy company Eni and the national oil and gas company Sonatrach has indicated in July 2021 that it would work together on a pilot project for the production of green hydrogen. The realization, on a trial basis, of a hydrogen project in Algeria with German companies is also announced.

2.2.2.3 Weak signals. possible disruption factors

There are currently no concrete actions giving strong signal to develop GH2, such as MoUs signed with private investors.

2.2.2.4 Levers and barriers

- The RE potential is huge and diversified, estimated to around 400,500 TWH:
    - Photovoltaic solar: more than 235,700 TWh per year.
    - Wind power: 12,940 TWH per year
    - Solar thermal: 169,880 TWH per year

- The high solar radiation makes the GH2 cost one of the lowest in the region. According to the exploratory study supported by GIZ, most of the annual hydrogen production is estimated at 151 million tons per year, at an LCoH level between 3.5 and 4.0 USD/kg by 2030. The production potential at the lowest level of LCoH between 2.5 and 3.0 USD/kg is limited to 18 million tons per year.
- Algeria is already a major exporter of ammonia. The change in the international market towards green ammonia will result in economic losses for the country, if the country does not position itself seriously on the production of green ammonia.
- Algeria already produces and exports grey ammonia and therefore has all the infrastructure, the regulatory framework and the knowledge required for green ammonia storage and export.
- Although Algeria aims to set up a large RE capacity by 2035 (15 GW), the current capacity does not exceed 500 MW. The delay in the ER can be a barrier for the development of GH2 due to lack of experience in this field.
- However, for the export, Algeria could face strong competition from countries like Saudi Arabia, Egypt, Morocco and Tunisia.
- The legislation on hydrogen in Algeria does not exist yet and a specific framework will need to be developed to foster the implementation of hydrogen projects in the country. In particular certification system has to be set up to guarantee the origin of the green electricity.

Main uncertainties

Some uncertainties persist regarding the future development of green hydrogen and PtX in Algeria, related in particular to:

- The competition of natural gas for energy sector and for hydrogen, since the country is large hydrocarbon producer and exporter.
- The competition of the neighbouring countries on the GH2 and PtX export
- Securing long-term contracts with off-takers at national and international level
- The large delay in developing RE capacity may constitute a barrier for the quick development of GH2 and PTX on large scale.

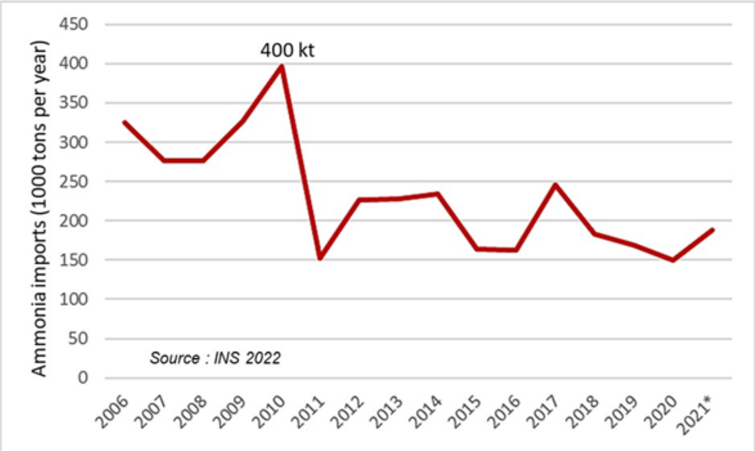
2.3 Tunisia

2.3.1 Review of current trends

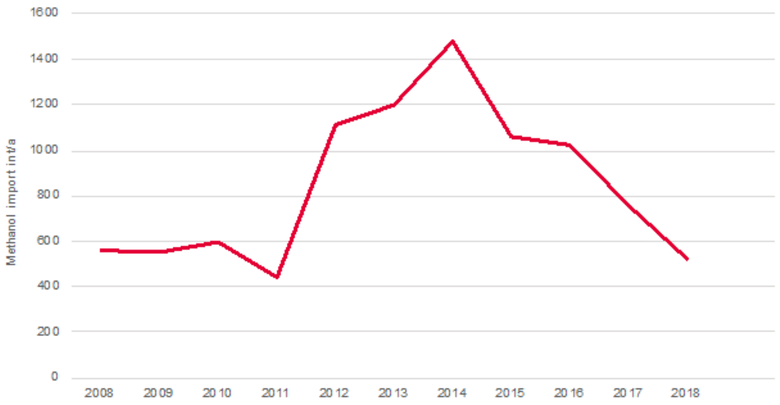
The current demand for hydrogen in Tunisia is mainly in the form of ammonia used in the phosphate industry. In fact, Tunisia's fertilizer industry relies on its large phosphate rock reserves, estimated at 900 Mt. These deposits, located in the Gafsa region, are exploited by the Tunisian Chemical Group (GCT). Phosphate production amounted to around 4 Mt in 2021, which remains below the pre-2011 level of 8 Mt per year (INS). The Tunisian government aims to increase phosphate production to reach 10 Mt/year in the coming years.

Most phosphate is used in Tunisia for the manufacture of fertilizers, mainly in the form of diammonium phosphate (DAP) and ammonium nitrate. The production of DAP has been around 600 kt in recent years against 1280 kt in 2010, as for the production of ammonium nitrate, it has averaged 180 kt.

The production of these two products requires ammonia, totally imported via the port of Gabes in the south. In 2021, Tunisia imported around 200,000 tonnes of ammonia, significantly lower than pre-2011 imports (around 400 kt) as shown in the following graph.



Hydrogen is also used under the form of methanol in small quantities in various industrial fields.
Currently no methanol production in Tunisia. It is totally imported in quantities between 500 tons and 1,500 tons per year, as shown in the following chart:



(Source: WITS 2021)

Finally pure hydrogen is used in small quantities in various applications (power plants, food processing, etc.).

In conclusion, the most important potential of local GH2 production would be in the industrial sector and particularly for the production of green ammonia required in the fertilizers industry.

2.3.2 Future trends

2.3.2.1 Existing strategies. quantitative objectives

There is still no formal strategy for the development of GH2 in Tunisia. However, in cooperation with GIZ, the Ministry of Industry, Mines and Energy has initiated by mid-2022 the preparation of a roadmap and a strategy for the development of GH2 in Tunisia by 2050.

In 2021, with the support of GIZ, the Ministry also carried out an exploratory study on the future opportunities of PtX in Tunisia which gave some indication of the development potential and the prerequisites[8].

The development potential of green hydrogen in Tunisia essentially depends on the country's renewable energy potential.

Thanks to the favorable climatic and geographical conditions, Tunisia has a significant potential for renewable energies, which can be summarized as follows[9]:

- Onshore wind power: 10 GW.
- Offshore wind power: 250 GW.

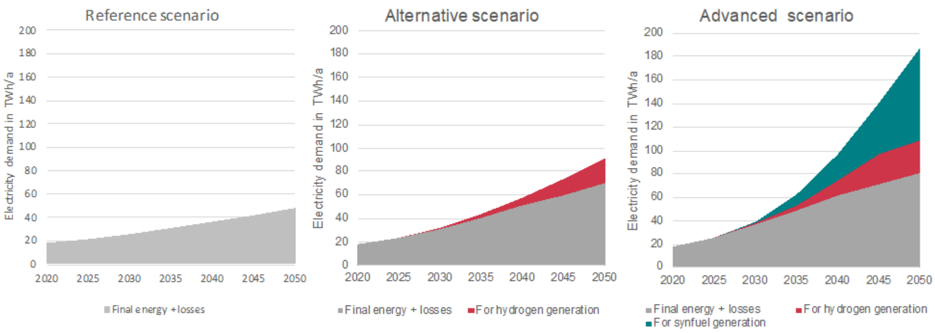
[8] Study on the opportunities of PTX in Tunisia, GIZ/MIME, 2021

[9] Strategic study of the development of RE by 2050, ANME, 2021.

- Solar PV: 840 GWp.
- Solar CSP: 600 GW

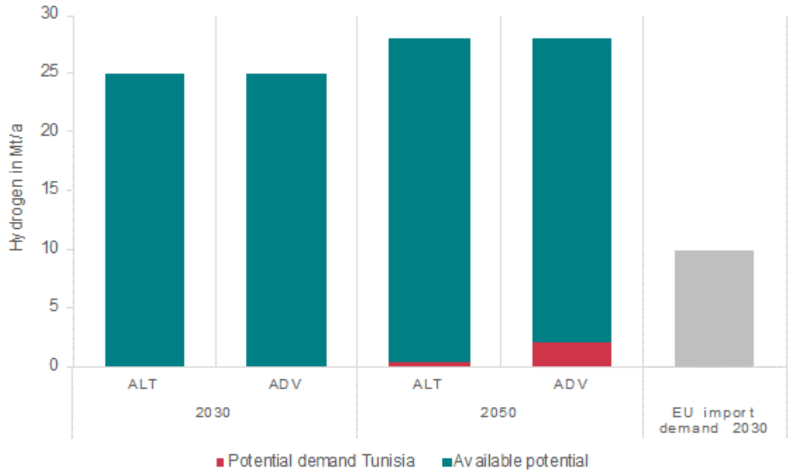
Moreover, given the significant availability of land, particularly in the south of the country, to house the renewable installations on the one hand, and the great possibilities of seawater desalination on the other, it can be concluded that the Tunisia has a technical potential for the production of green hydrogen which greatly exceeds the needs of both the local market and the export market.

First scenarios for Tunisia from the German Aerospace centre (DLR 2020), which are based on regional trajectories, show how demand in Tunisia for electricity to produce hydrogen or synthetic fuels could develop based on different decarbonisation strategies and targets:



Electricity demand scenarios for Tunisia (TWh/a) (Source: DLR 2020: Scenario data for Tunisia developed in the framework of the project MENA-Fuels (BMWi FKZ 03EIV181C). T. Pregger, German Aerospace Center (DLR), personal communication 19th November 2020.)

Taking into account the electricity demand generated for hydrogen and synthetic fuel production in the alternative and advanced scenarios, the total electricity demand for green hydrogen production (and derivates) could range between 0.3 TWh and 3 TWh by 2030 and between 21 TWh and 100 TWh by 2050. Comparing this demand to the technical green hydrogen potential in Tunisia for the best solar energy and onshore wind resources shows that the technical potential is sufficient to meet domestic demand and to produce hydrogen for export:



Comparison of green hydrogen potential and demand scenarios for Tunisia (potential includes solar PV and wind onshore sources with a capacity factor over 20%). (Source: Wuppertal Institut, data sources DLR 2020; Brändle et al. 2020; EU hydrogen strategy 2020)

in operational terms, the Ministry of Industry, Mines and Energy and German Ministry for Economic Cooperation and Development (BMZ), a memorandum of agreement aiming the establishment of a Tunisian-German alliance for PTX. This includes a donation of 30 million euros (the equivalent of 98 MD) granted to Tunisia to develop the green hydrogen market in Tunisia.

At the same time, GIZ is supporting the Ministry of Industry, Mines and Energy through a large technical assistance project including four main strategic components:

- Development of the national strategy for green hydrogen,
- Support for the creation of a green hydrogen economy,
- Strengthening of research, training, innovation
- Establishment of a Tunisian-German technology hub for green hydrogen.

2.3.2.2 Weak signals. possible disruption factors

Unlike some countries in the region such as Morocco and Egypt, there are no major GH2 development projects or MoUs announced by the government.

In fact, there are no concrete projects and actions giving strong signal to develop GH2, such as MoUs signed with private investors. Furthermore, the business environment needs to be improved to attract and large international investors and meet the requirements for the development of green hydrogen.

2.3.2.3 Levers and barriers

- Tunisia has a large renewable energy potential that can benefit to the development of green hydrogen at large scale.
- Although Tunisia aims to reach 4850 MW of RE by 2030, the current capacity does not exceed 500 MW. The delay in the ER can be a barrier for the development of GH2 due to lack of experience in this field.
- Tunisia is also well placed to export to Europe due to its geographical proximity and its potential to produce green hydrogen on a large scale.
- The existence of the TRANSMED gas pipeline that can be converted for GH2 transport to Europe.
- For export, Tunisia could face strong competition from countries like Saudi Arabia, Egypt, Morocco and Algeria.
- Tunisia already has a large local demand for ammonia used for the production of fertilizers which can be replaced in the short and medium term by green ammonia.
- Tunisia has also the required facility for the storage and export of green ammonia
- The legislation on hydrogen in Tunisia does not exist yet and a specific framework will need to be developed to foster the implementation of hydrogen projects in the country. In particular, certification system has to be set up to guarantee the origin of the green electricity.

2.3.3 Main uncertainties

- The ability of announced projects to quickly mobilize the huge financing needs from investors in the context of the economic situation of Tunisia.
- Competition from grey ammonia if the price of natural gas drops in the future.
- Securing long-term contracts with off-takers at national and international level.
- The competition of renewable electricity given the high targets for the share of RE in the electricity mix announced by Tunisia.
- The risk of competition on the development of shale gas in Tunisia. In fact, it seems that Tunisia has a good potential.
- The country's capacity to implement the projects announced within the planned deadlines.

2.4 Egypt

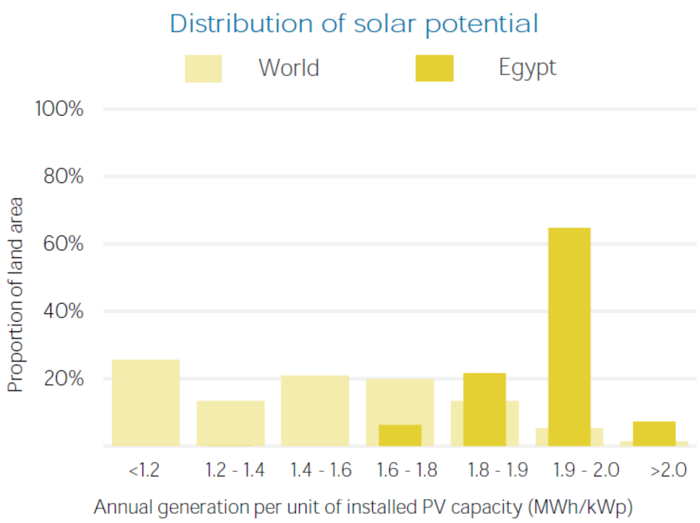
2.4.1 Review of current trends

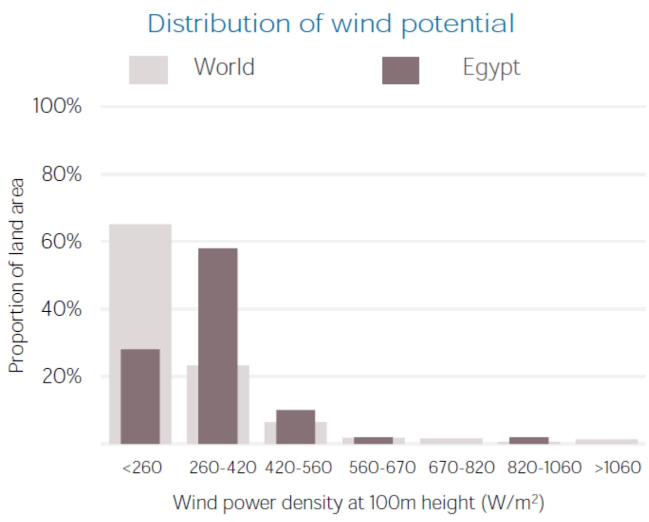
Egypt's current production is 5.1 million tons of ammonia in 2021 (source: USGS). Nutrien owns 26% of Mopco in Egypt and has a capacity of 0.3 million t/year. The multinational OCI produces ammonia at 1.6 million t/year in Egypt. Egypt is one of the major exporters of ammonia. Its exported quantities reached 460 000 tons (source: ITC) in 2020 representing 2.2% of international exports.

In term of H2 production, a study published by the Oxford Institute for Energy Studies (OIES) estimates that the amount of hydrogen produced and consumed is approximately 1.8 million tons per year of grey hydrogen in pure and non-pure forms. A recently released report by the International Renewable Energy Agency (IRENA) estimates that Egypt's annual production of grey hydrogen is around 1.4 million tons.

It is worth to mention that Egypt was among the first countries in the world to produce green hydrogen. In the late 1960s, Kima Aswan - a fertilizer company - installed 144 Electrolysers with a nominal output of 162 MW and around 74,000 kg H2/day. It was the largest alkaline electrolyser of its kind. The electricity supplied to the Electrolysers comes from the Aswan High Dam. The hydrogen produced was used to make ammonia for fertilizers. However, the production of green hydrogen was stopped in 2019 when the KIMA plant was rehabilitated and expanded. Kima Aswan switched to the production of grey hydrogen using the gas-based steam methane reforming process.

Regarding renewable energies which are the basis for green hydrogen production, Egypt has one of the best wind and solar potential in the region as shown in the following figures:





Source: Egypt energy profile IRENA, 2022.

By the end of 2021, the renewable energy installed capacity in Egypt reached around 6,380 MW and it is expected to reach 8,778 MW by end of 2022.

Egypt intends to increase the RE mix in electricity generation to 42% by 2035, with wind energy accounting for 14%, hydroelectricity 2%, and solar energy 25% of the total electricity generated by renewable energy resources[10].

2.4.2 Future trends

2.4.2.1 Existing strategies. quantitative objectives

Egypt is finalizing its green hydrogen strategy and announced key elements during COP27. The target is to produce approximately 3.6 million tons per year by 2030. The investment plan in the hydrogen sector of approximately 100 billion dollars in the production, storage, export of green hydrogen and ammonia by 2030.

[10] Brief review on Egypt's renewable energy current status and future vision, Nour A.Moharram and all., May 2022.

Egypt has also signed and announces many projects and agreements:

- Green ammonia production project in the Suez Canal Economic Zone (SCZONE): 1 million tons with extension to 3 million tons (SCATEC)
- A memorandum of understanding signed with FFI (Fortescue Future Industries") to conduct studies to develop green hydrogen production on at least 8 projects.
- A Memorandum of Understanding with Indian Energy Company, to build an $8 billion green hydrogen production plant in the Suez Canal Economic Zone.

Several memorandums of understanding signed in 2022 between the Egyptian authorities and international project developers (Globeleq, Alfanar, ACME and KK and the ACTIS, Alcazar and Mediterranean funds, Energy Partners, etc.) for 32 billion dollars in the production of hydrogen and ammonia in the Suez Canal Economic Zone (SCZONE

2.4.2.2 Weak signals. possible disruption factors

The main disruption factors may be related to

- The capacity of Egypt to mobilize the huge financing needs in the context of the national and international economic crisis.
- The competition from grey ammonia since that Egypt an important natural gaz producer
- The competition of renewable electricity given the high targets for the share of RE in the electricity mix announced by Egypt.

Several memorandums of understanding signed in 2022 between the Egyptian authorities and international project developers (Globeleq, Alfanar, ACME and KK and the ACTIS, Alcazar and Mediterranean funds, Energy Partners, etc.) for 32 billion dollars in the production of hydrogen and ammonia in the Suez Canal Economic Zone (SCZONE).

It is worth to mention that major part (Nearly 80%) of announced green hydrogen projects are planned in to be implemented in the Suez Canal Economic Zone (SCZONE), which could create an effect of saturation of the area.

2.4.2.3 Levers and barriers

- Egypt has a great experience in both RE and production of grey H2 and ammonia. This can serve as a basis for the take-off of the green GH2 industry in the country.
- The wide availability of non-arable land suitable for the development of renewable projects is a good advantage.
- The significant potential of both solar and wind power makes it possible to develop hybrid projects to produce GH2, which will allow to achieve very competitive production costs of GH2.
- The implementation of the 1st project signed with SCATEC (100 MW) will allow a quick learning particularly in term of regulatory framework development for PTX

2.4.3 Main uncertainties

- The competition of natural gas for energy sector and for hydrogen, since the country is large hydrocarbon producer and exporter.
- The competition of the neighbouring countries on the GH2 and PTX export
- Securing long-term contracts with off-takers at national and international level for the export
- The competition of RE for electricity generation since the country has large target in RE. Indeed, in terms of RE development, priority will be given to the implementation of target capacities planned for the direct production of electricity to the grid, before the development of new RE capacities for the production of green hydrogen. The uncertainty is linked to the capacity of the actors to implement an ambitious program of RE for hydrogen production, in addition to that for the direct production of electricity to the grid (50.5 GW in 2030 and 62.6 GW in 2035)

2.5 Jordan

2.5.1 Review of current trends

In Jordan, ammonia is used to produce the N-based fertilizer products such as diammonium phosphate (DAP), potassium nitrate (NOP), nitrogen phosphorus potassium (NPK), as well as nitric acid. The potential H2 demand is estimated at about 51,000 tons per year, based on the nitrogen-based fertilizer production quantities. It should be noted that today, NH3 supplies in Jordan are imported through the port of Aqaba; in addition, there is some domestic production of ammonia.

The existing crude oil refinery in Zarqa has a production capacity of 60 000 barrels per day (bpd). Based on that, the annual potential H2 consumption is estimated to about 39 000 tons per year.

In 2020, Jordan imported $56.3M in Ammonia, becoming the 27th largest importer of Ammonia in the world. At the same year, Ammonia was the 78th most imported product in Jordan. Jordan imports Ammonia primarily from: Saudi Arabia ($22.7M), Egypt ($11.7M), Qatar ($10.2M), Algeria ($4.99M), and Oman ($4.61M).

In 2020, Jordan exported $133k in Ammonia, making it the 65th largest exporter of Ammonia in the world. At the same year, Ammonia was the 565th most exported product in Jordan. The main destination of Ammonia exports from Jordan are: Saudi Arabia ($83.2k), Sudan ($34.5k), Israel ($13.8k), Mauritania ($1.8k), and India ($84).

2.5.2 Future trends

2.5.2.1 Existing strategies. quantitative objectives

According to a recent study carried out by GIZ and the Ministry of Energy and Mineral Resources (GIZ/MEMR, 2022) related to the opportunities of development of PTX in Jordan, the total potential market for GH2 by 2030 is around 333 ktons[2].

For local consumption, the potential GH2 applications include crude oil refining, fertilizer production gas-fired thermal power plants, urban buses and heavy-duty trucks and port logistics is around 102 ktons[3].

GH2/PtX export potential of Jordan is estimated be 231,363 tons per year, of which 170,720 tpa (or 74% of the total export potential) could be blended with natural gas and transported via international gas pipelines to demand centers (e.g., to Europe) while 60,643 tpa (or 26%) could be converted to ammonia and exported via ships[4].

In term of production, there is a very promising potential of green hydrogen production in Jordan, from:

- Solar energy (solar PV-to-Hydrogen) The average H2 production potential in the case of using solar PV is 4,500 tpa/km². It is observed that the majority of the hydrogen production potential can be produced at cost between 5–6 USD/kg (98% of the total potential).
- In contrast to the PV-to-Hydrogen system, the geographical location of Wind-to-Hydrogen system has a higher impact on the site-specific energy yield as well as on the production cost. The average H2 production potential from Wind-to-Hydrogen system is 3 800 tpa/km². The highest production potential can be observed in the South-East of Jordan, in the Aqaba region with a production potential of above 8,000 tpa/km². The significant variance of wind power generation across different sites in Jordan leads to a high variance of electricity generation and consequently the H2 production cost: An annual production of 392 500 thousand tons per year H2 could be produced at cost level of less than 4 USD/kg.

2.5.2.2 Weak signals. possible disruption factors

Jordan has recently developed a number of studies to prepare for the development of the GH2 industry in the country, with the support of GIZ:

- A study on the evaluation of the technical potential and development opportunities of GH2 and its derivatives
- The GH2 regulatory framework
- The sea water desalination for GH2 and the transport of hydrogen for export
- A study on the geopolitics of the GH2 market

This will better prepare for the development of the PTX industry in the country. However, it still has to develop a real roadmap and strategy for the GH2.

An MoU has also been signed with the Australian company FFI to study the feasibility of developing a first project of GH2 in the Aqaba Special Economic Zone.

2.5.2.3 Levers and barriers

- The RE potential is huge and diversified between solar and wind.
- Jordan has a great experience in RE which will facilitate the take-off of the green GH2 industry in the country.
- Jordan has already well-structured fertilizers industry using ammonia. This ammonia consumption can constitute on the short term a market for green ammonia that can be produced locally.
- Jordan has also the required facility for the storage and export of green ammonia due the existing facilities in Aqaba port
- Lack of access to sea water for desalination to feed the electrolysers since the only access is Aqaba.

2.5.3 Main uncertainties

- The Competition from other neighbouring countries on the export market, especially Egypt and Saudi Arabia which has one of the cheapest GH2 production
- The competition of RE for electricity generation since the country has already large installed RE capacity reaching 26% and ambitious target for the future.
- Securing long-term contracts with off-takers at national and international level for the export

2.6 Israel

2.6.1 Review of current trends

In 2020, Israel imported $32.4M of Ammonia, becoming the 32nd largest importer of Ammonia in the world. At the same year, Ammonia was the 338th imported product in Israel. Israel imports Ammonia mainly from Egypt ($13M), Turkey ($12.3M), United States ($6.34M). The imported amount has increased from $26.2M in 2019 (around 87500 tons).

At the same time, Israel exports part of the imported ammonia mainly to Jordan with around $2.15M in 2020.

2.6.2 Future trends

2.6.2.1 Existing strategies. quantitative objectives

There is no official strategy in Israel regarding GH2 and PTX development, so, there is no long-term target. This may be linked to the large new gas resource and also the to the narrowness of the territory. Israel is focusing on the development or RE for power generation in order to phase out the use of coal. The objective is to move from a share of 7% of RE in the power mix currently to around 30% by 2030.

However, the main driver in GH2 and PTX development is the private sector, as the government only supports R&D. Several research institutions and start-ups are very active on the technology development particularly for fuel cell and electrolysers improvement.

The Israel-based firm Doral has won an ILS 3.3 million (around 1 M$) grant from the Energy Ministry for the country's first green hydrogen project. The facility, located in Kibbutz Yotvata, would generate the green hydrogen for use in industrial infrastructures like transportation and industrial plants, using PV facility with a 400 KW capacity. By the end of 2023, the factory should be up and running.

The 600 MW facility is the first of its kind in Israel, where H2Pro will produce cost-effective systems for producing green hydrogen from water and electricity. Doral has secured access to 200 MW of *H2Pro's systems* (H2Pro's E-TAC technology) for its projects in Europe, the United States and Israel and will purchase minimum quantities subject to the E-TAC technology's performance. The agreement builds on the companies' plan to develop a 400kW pilot in 2023 in Kibbutz Yotvata, Israel.

Alongside its partners, Doral is also leading the efforts to develop a subsequent project extension for a 30MW Hydrogen hub based on H2Pro's technology.

2.6.2.2 Weak signals. possible disruption factors

As mentioned above, the Israeli government seems to focus mainly on the production of technologies relating to GH2 and PTX to position itself as a global supplier of the technology. For this reason, Israel strongly encourages research institutes and start-ups in this field. The government has awarded in total 5.7 million ILS (1,7 M$) to 11 start-up projects and 22.3 million ILS to 17 pioneer and demonstration projects.

Large number of research institutions and start-ups in Israel are actively working on GH2 and PTX technologies, such as :

- **Research centres**: Israel National Research Centre for Electrochemical Propulsion, Israeli Centre for Research Excellence (I-CORE) and Renewable Liquid Fuels centre.
- **Research centres:** Gencell, PO-CellTech, Electriq Global, H2Pro, H2 Energy Now, NrgStorEdge, NewCO2Fuels, Edrei Bio Hydrogen.

Israeli oil companies are also positioning themselves on hydrogen and PTX applications:

- Sonol plans to set up the first hydrogen refuelling station in the Haifa region within the next three years.
- Paz is investing in fuel cell companies.
- Bazan Oil Refineries has established an innovation centre and has shares in the hydrogen company H2PRO, etc.

2.6.2.3 Levers and barriers

- The strong appropriation of technologies on the different parts of the value chain will facilitate the development of projects in the country.
- Existence of a demand for imported ammonia which may constitute a first short-term opportunity for substitution with green ammonia.
- Absence of a clear strategy for the development of production, consumption, and export of GH2 and PTX
- Thinness of the local market for GH2 and PtX
- The low availability of land for RE can be a major obstacle to the development of green GH2 projects at large scale.

2.6.3 Main uncertainties

- The risk of competition from electricity of nuclear origin
- The competition of natural gas, particularly that Israel is now operating large gas field in the east Mediterranean Sea
- The risk of competition with RE for the production of electricity since Israel plans ambitious objectives in 2030 (30%), while the current share of RE in the electricity mix does not currently exceed 7%

2.7 Turkey

2.7.1 Review of current trends

Hydrogen is mainly consumed in Turkey under ammonia form mainly imported. In 2019, Turkey imported around 1 million tons of ammonia at 272 million dollars, coming mainly from Russia with 57% and Algeria with 21%. (Source: WITS World Integrated Solutions).

In 2019, Turkey imported also around 18244 m3 of Hydrogen with a total cost of 43 k$, mainly from Serbia and United Arab Emirates.

Currently there is no production of green hydrogen in Turkey.

2.7.2 Future trends

2.7.2.1 Existing strategies. quantitative objectives

The technical potential of GH2 production is estimated to 415 to 427 million tons mainly from wind [5].

The study on “Priority Areas for a National Hydrogen Strategy for Turkey” published by the Energy policy research in 2021, presented the priority of GH2 development in the light of Zero net objective. A first order estimate was made based on the energy demand of hard to decarbonize sectors of Turkey. An assumption of substituting 5%-15% share of the total production from traditional routes or the energy mix yields a green hydrogen potential of around 4.6 Mtoe per year, equivalent to around 5% of Turkey’s current total final energy consumption. This can be met by a total of 12.1 GW electrolyser capacity (assuming 75% load factor and 67% conversion efficiency). Utilizing this potential implies an **annual local production of 1.6 million tons** (Mt) of green hydrogen and 80 billion kWh electricity[6] by 2050. Investment needs for 12.1 GW electrolyser capacity is estimated at US$9.1 billion at a capital cost of US$750/kW.

By 2030, the total local demand scenario target to reach 0,24 to 0,5 Mt per year.

	Substitution potential	Total hydrogen demand (ktoe/y)	Total installed electrolyser capacity (GW)	Total installed RE capacity (GW)	Total investment needs (USD$ bn)
Iron steel	5% of all EAF integrated with DRI (additional demand)	405	1.1	3.2	4.0
Chemical and petrochemical	Substitution of fuels with 15% synthetic methane	500	1.3	4.0	5.0
Plastic processing	Substitution of fuels with 15% synthetic methane	40	0.1	0.3	0.4
Cement	Substitution of fuels with 15% power to liquid	1200	3.2	9.5	11.9
Road freight, aviation maritime	Substitution of fuels with 15% power to liquid	1785	4.7	14.2	17.7
Gas sector	5% injection in the gas grid	645	1.7	5.1	6.4
Total		4570	12.1	36.3	45.4

Source: Turkish Energy policy research Centre, 2021

In addition to local potential demand of green hydrogen, a new export market, with an export potential ranging from 1.5–1.9 Mt/year by 2050 and estimated supply costs of 1.52–1.73 USD/kg of hydrogen would mean 300 million USD/year for blending (0.15–0.2 Mt/year) and 4.5 billion USD for ammonia (1.35–1.7 Mt/year) with a cost of 500 USD/t NH3 by 2050.

Export Potential		2050
Green H_2 Export Potential[17]	Mt/year	**1.5-1.9**
Injection into Pipelines	Mt/year	0.15-0.2
Ammonia Exports[18]	Mt/year	1.35-1.7

Source: Turkish Energy policy research Centre, 2021

2.7.2.2 Weak signals. possible disruption factors

Turkey will establish the country's first green hydrogen plant in the northwestern coastal city of Balıkesir, the South Marmara Development Agency (GMKA). The cooperation protocol prepared for the Green Hydrogen Plant was signed.

South Marmara Development Agency, Eti Maden, and ASPİLSAN Enerji have signed the corporate collaboration agreement to build a hydrogen plant in Balkesir. Being one of Turkey's largest independent power producers, Enerjisa has four power plants in Balikesir. The company's two gas-fired power plants have 936 MW and 607 MW of installed capacity. The 143 MW wind power plant is located in the southern part of the district, whereas the 2 MW solar PV plant is in the western part.

The Southern Marmara Region is ideal to try to support the hydrogen economy. South Marmara is chosen as the green hydrogen production hub due to its production of 12.50% of Turkey's power, hosting Turkey's most efficient renewable energy plants with renewable source-based electricity.

2.7.2.3 Levers and barriers

- The position close to Europe which is an advantage for export.
- The existence of a gas network well connected to Europe can make Turkey a hydrogen hub. The current Turkish natural gas grid consists of close to 15,000 km of steel and 95,000 km of polyethylene pipelines.
- The availability of strong water resources with good spatial distribution allowing greater flexibility in the location of GH2 production
- The availability of wind, solar and hydroelectric resources that can lower the production costs of GH2 thanks to the high-capacity factors of RE (1.6 to 2.6 USD/kg by 2050).
- However, Turkey seems to be in delay compared to some neighboring countries in terms of projects preparation and MoU signatures with investors.
- It is also in delay in term of regulatory framework preparation.

2.7.3 Main uncertainties

The use of H2 in the energy sector may be competed by:

- The nuclear power of Turkey that stated with Akkuyu Nuclear Power Plant which will provide 10% of the electricity demand by itself.
- The natural gas with all the research that Turkey is doing in the Mediterranean

2.8 Lebanon

Lebanon consumes hydrogen indirectly through the consumption of ammonia, totally imported. In 2019, the quantity imported amounted to approximately 126 kt for a total cost of $58 k. These quantities are almost totally imported from India and Netherland (WITS, 2022).

The imported ammonia is mainly used in the manufacturing of fertilizers by private sector.

Currently there is no ammonia or methanol production in Lebanon, but the potential exploration of natural gas in the Lebanese offshore will may promote the development of the nitrogen fertilizer industrial sector through the production of ammonia.

The Lebanese Centre for Energy Conservation (LCEC) highly believes in the important role of hydrogen in achieving the national targets, however, it is not yet included in the national policies. So, there is no target set for GH2 development in Lebanon.

GH2 in Lebanon can be used in many industries, such as refining petroleum, treating metals, producing fertilizer, and processing foods which are very important for the Lebanese economy, as it will help it to transform into a productive economy.

The transportation sector can remarkably benefit from the use of hydrogen in Lebanon, as it will help reducing the fossil fuels import and use and push the country forward towards reaching its national goals in terms of NDCs.

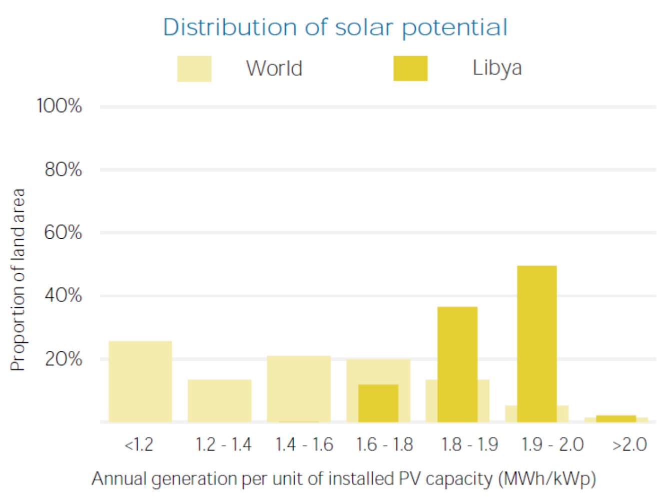
2.9 Libya

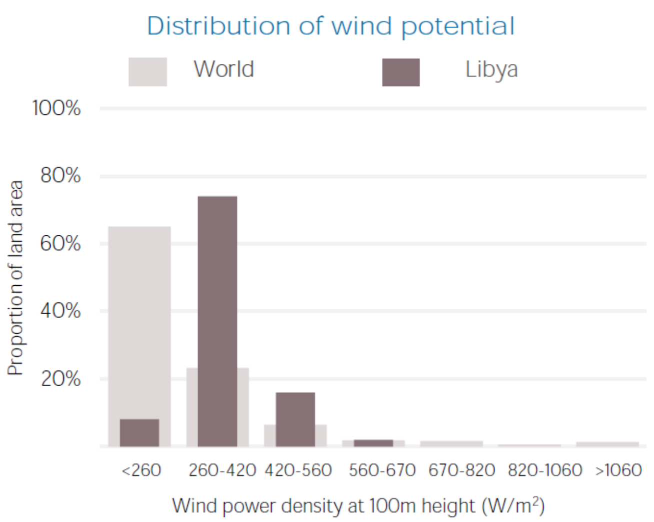
In 2020, Libya exported $2.93M in Ammonia, making it the 43rd largest exporter of Ammonia in the world. At the same year, Ammonia was the 24th most exported product in Libya (WITS, 2022). The main destination of Ammonia exports from Libya are Turkey.

This capacity export is changing from one year to another depending on the political situation in the country. For instance, in 2018, the total ammonia export value of Libya was estimated to around 20 M$ corresponding to around 60 kt (WITS, 2022).

The Ammonia is produced by the Libyan Fertilizer Company (LIFECO) with a total ammonia production capacity of around 700 kt per year destinated mainly for export to Turkey and Europe countries. The ammonia is manufactured from hydrogen obtained for local natural gas.

Moreover, Libya has a potential of renewable energy resources, particularly PV, of very good quality which would allow a very competitive production cost of GH2[11].





[11] Libya energy profil, IRENA, 2022

Source: IRENA, 2022

The proximity of Libya to Europe via Italy is an advantage in favour of the export of GH2.

However, developing the potential of GH2 for local consumption and export will require a number of prerequisites in Libya:

- The political stability of the country to attract international investors.
- The establishment of a regulatory framework and an enabling environment for private investment
- The rehabilitation of the electrical network
- The development of RE which remains insignificant today

2.10 Syria

No information available.

2.11 Palestine

No information available.

[1] Office Chérifien de Phosphape (Moroccan state-owned phosphate rock miner, phosphoric acid manufacturer and fertilizer producer)

[2] Tractebel (2022), "Study on energy system impacts and business potential of hydrogen production in Jordan" commissioned by GIZ

[3] Tractebel (2022), "Study on energy system impacts and business potential of hydrogen production in Jordan" commissioned by GIZ

[4] Tractebel (2022), "Study on energy system impacts and business potential of hydrogen production in Jordan" commissioned by GIZ

[5] Green hydrogen production potential for Turkey with solar energy (G. KubilayKarayel and all.), May 2022.

[6] Priority Areas for a National Hydrogen Strategy for Turkey, Energy policy research centre, 2021

3 European countries

3.1 Portugal

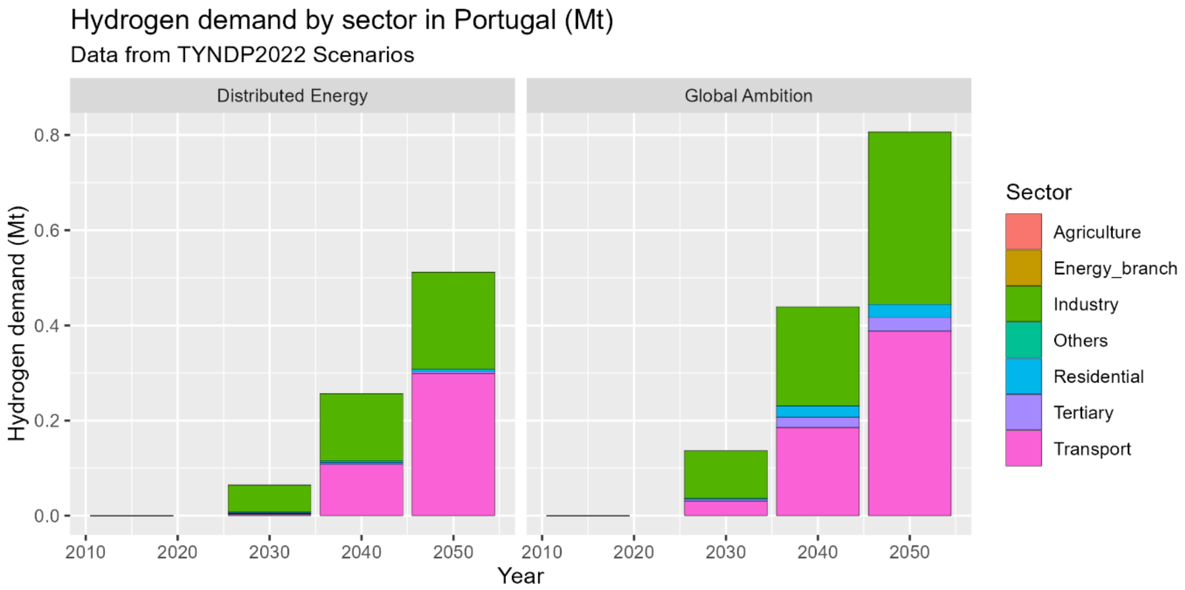
3.1.1 Review of current trends

The current hydrogen demand in Portugal is estimated to be around 107,000 tonnes per year (data from FCHO, 2019). The main final use is in refineries, which account for 84% of the total demand, followed by other chemicals (9%). Energy usages remain around 6% of the total.

3.1.2 Future trends

3.1.2.1 Existing strategies, quantitative objectives

The TYNDP scenarios expect between 0.5 and 0.8 million tonnes of hydrogen demand in Portugal by 2050. When considering a power-to-gas perspective, 22 to 41 TWh of low-carbon electricity would be required for its generation. As a comparison, electricity generation from renewables in Portugal in 2021 has reached 31 TWh, of which mostly from wind (42%) and hydro (37%). The following chart shows the distribution of hydrogen demand across sectors in the two TYNDP-2022 scenarios.



Portugal has published a National Hydrogen Strategy in August 2020, in the Council of Ministers' Resolution 63/2020. The strategy, which is part of the climate and energy targets of the country to decarbonize its economy and reach a decarbonized natural gas and power plant network by 2050, presents some specific goals to be reached by 2030 and 2050. Supported by a 7-billion-euro funding, the strategy aims at reaching a 5% share of hydrogen in final energy consumption by 2030. Other specific targets include a gradual increase of hydrogen in the transport sector, up to 20% of the road transport energy consumption by 2050, up to 100 hydrogen filling stations by 2030, and the installation of 2 GW of electrolysers by 2030 and 5 GW by 2050. The strategy also reports some 2030 targets of green hydrogen supply to natural gas grid (10% to 15%) and hydrogen consumption in industry (2%-5%), road transport (1%-5%) and domestic maritime transport (3%-5%).

In 2020 Portugal has signed with the Netherlands a Memorandum of Understanding on production and transport of hydrogen, and in 2021 another cooperation agreement was signed with Morocco, focusing on cooperation in the field of green hydrogen development.

The leaders of France, Spain and Portugal have confirmed in October 2022 the intention of developing an underwater green energy corridor that will eventually transport hydrogen from Barcelona to Marseille, in substitution of a proposed natural gas pipeline connection.

3.1.2.2 Weak signals, possible disruption factors

There are some projects at different scales currently in operation in Portugal. Two Portuguese firms are also involved in some Important Projects of Common European Interest (IPCEI) in the Hydrogen Technology Value Chain – "IPCEI Hy2Tech" and in the Hydrogen Value Chain – "IPCEI Hy2Use". The direct participants will closely cooperate with each other through numerous planned collaborations, and with over 300 external partners, such as universities, research organisations and SMEs across Europe. This could foster additional activities related to the development of the hydrogen supply chain in the country.

3.1.2.3 Levers and barriers

- Portugal already has a significant share of renewable power generation: renewables accounted for 62% of the total electricity production in the country in 2021. Solar generation is still relatively low, and it may be further developed to be coupled with green hydrogen production, given the potential of the country.
- The country already has a quite developed natural gas network, which could be repurposed to serve hydrogen on the long-term.
- The legislation on hydrogen in Portugal remains limited, and a specific framework will need to be developed to foster the implementation of hydrogen projects in the country.

3.1.3 Main uncertainties

The development of hydrogen is being undertaken with specific pilot projects across the country, both in terms of green hydrogen generation and uses in the final sectors. However, the future evolution of hydrogen will strongly depend on the ability of technologies and solutions to be effectively competitive in economic terms against other alternatives, mainly direct electrification. The development of hydrogen projects in Portugal may remain tightly bound to the success or failures of larger projects in bigger European countries, whose results may have a larger impact on the possibility of developing an international green hydrogen market.

3.2 Spain

3.2.1 Review of current trends

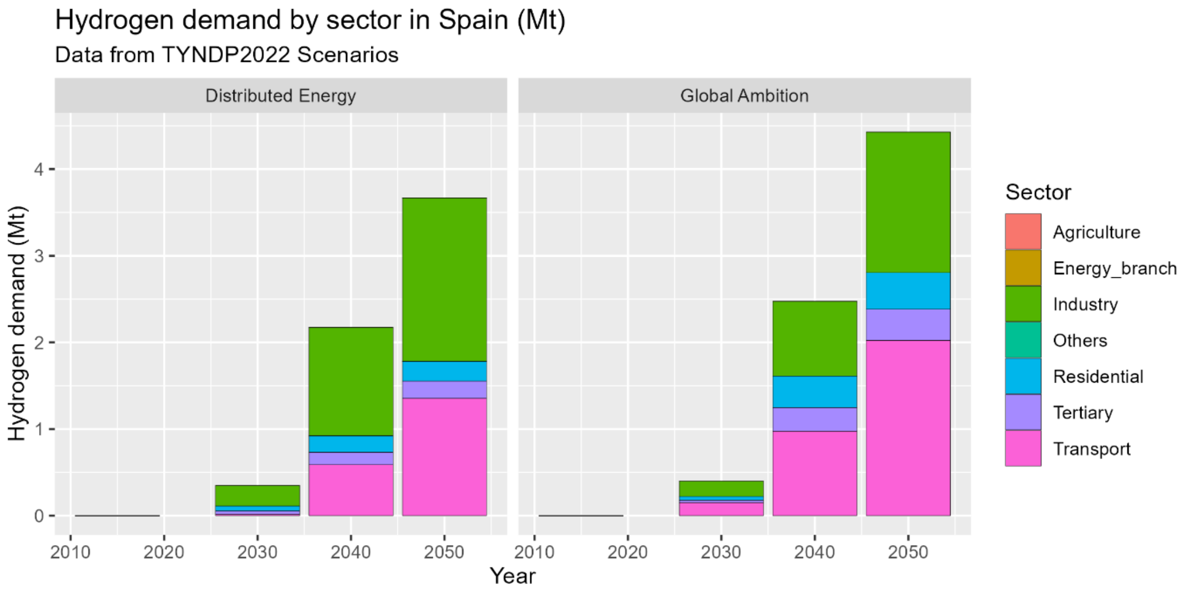
The current hydrogen demand in Spain is estimated to be around 555,000 tonnes per year, making it the fourth country in the EU-27 (data from FCHO, 2019). The main final use is in refineries, which account for 76% of the total demand, followed by ammonia (12%) and other chemicals (3%). Energy usages remain below 3% of the total, and transport use is almost non-existent.

3.2.2 Future trends

3.2.2.1 Existing strategies, quantitative objectives

The TYNDP scenarios expect between 3.7 and 4.4 million tonnes of hydrogen demand in Spain by 2050. When considering a power-to-gas perspective, 160 to 230 TWh of low-carbon electricity would be required for its generation. As a comparison, Spain generated around 125 TWh of electricity from renewables in 2021, mainly from wind (62 TWh), hydro (31 TWh) and solar (26 TWh). Thus, renewable electricity generation will need to be significantly upscaled to match green hydrogen demand, especially considering the increasing electrification rate in final uses and the need of increasing the low-carbon generation in the total electricity mix of the country.

The following chart shows the distribution of hydrogen demand across sectors in the two TYNDP-2022 scenarios.



In October 2020, the Spanish government has approved the "Hydrogen Roadmap: a commitment to renewable hydrogen", after a public consultation that received contributions from almost 80 different entities and individuals. A part of the funding of the Next Generation EU in Spain is allocated to hydrogen, with 1.5 billion euros to be spent in the sector by 2023.

The role of green hydrogen in Spain's Strategic Energy and Climate Framework is also highlighted in other documents, including the National Integrated Energy and Climate Plan ("PNIEC") 2021-2030, the Long-Term Decarbonisation Strategy 2050 and the Fair Transition Strategy.

The Spanish Hydrogen Roadmap relies on the national potential for renewable energy production (solar and wind) to become a technological leader in the generation and final use of green hydrogen. The Strategy defines some ambitious targets:

- Installation of at least 4 GW of electrolysers by 2030 (of which 300-600 MW by 2024);
- Share of 25% of renewable hydrogen on the total hydrogen consumption in industry.
- A total fleet of at least 150-200 renewable hydrogen fuel cell buses by 2030; specifically in cities with more than 100,000 inhabitants.
- At least 5,000-7,500 hydrogen fuel cell vehicles for freight transport by 2030.
- between 100 and 150 publicly accessible hydrogen stations installed by 2030.

In addition to fixing some targets by 2030 and providing some qualitative indications for the long-term development of hydrogen, the Hydrogen Roadmap aims to be a dynamic instrument that is updated every three years to monitor the evolution of the sector and define new actions that may be needed to reach the expected targets.

The leaders of France, Spain and Portugal have confirmed in October 2022 the intention of developing an underwater green energy corridor that will eventually transport hydrogen from Barcelona to Marseille, in substitution of a proposed natural gas pipeline connection.

3.2.2.2 Weak signals, possible disruption factors

Several Spanish firms are also involved in some Important Projects of Common European Interest (IPCEI) in the Hydrogen Technology Value Chain – "IPCEI Hy2Tech" and in the Hydrogen Value Chain – "IPCEI Hy2Use". Spanish firms will be working in hydrogen generation, end user technologies, infrastructure and applications in industry. The participants in these projects will closely cooperate with each other through numerous planned collaborations, and with over 300 external partners, such as universities, research organisations and SMEs across Europe. This could foster additional activities related to the development of the hydrogen supply chain in the country.

3.2.2.3 Levers and barriers

Spain has an interesting potential for green hydrogen generation, due different aspects:

- A well-developed renewables power sector, with both solar and wind power generation and potential.
- Well-developed natural gas transmission and distribution network in the country that could be refurbished to accommodate hydrogen.
- Existing LNG terminals that could be transformed in the future to be adapted to either export surplus green hydrogen or to import green hydrogen to be supplied via other EU countries.

At the same time, the connectivity to other European countries via pipelines remains limited, but there are some planned activities to develop connections with France.

3.2.3 Main uncertainties

Spain shows and interesting potential to become a green hydrogen producer, both for internal demand and for export to other European countries. However, the success of such a strategy will be tightly bounded to the effective creation of an international green hydrogen market in which the value of the commodity is priced at a sustainable level. In this perspective, the variability of carbon price over time could strongly limit private investment in green hydrogen, and the same effect may happen due to the competition against other promising technologies for the decarbonisation of the energy system.

3.3 France

3.3.1 Review of current trends

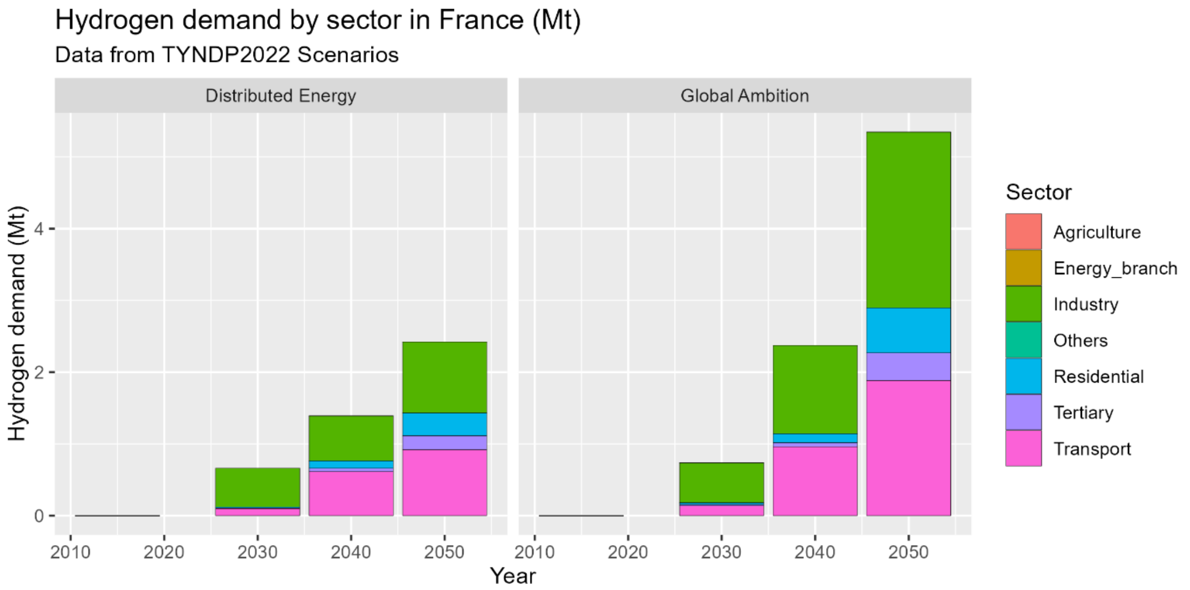
The current hydrogen demand in France is estimated to be around 487,000 tonnes per year, making it the seventh country in Europe (data from FCHO, 2019). The main final use is in refineries, which account for 48% of the total demand, followed by ammonia (30%) and energy (10%). Transport use is very limited, although there are some pilot projects, such as a fleet of taxis in Paris.

3.3.2 Future trends

3.3.2.1 Existing strategies, quantitative objectives

The TYNDP scenarios expect between 2.4 and 5.4 million tonnes of hydrogen demand in France by 2050. When considering a power-to-gas perspective, 105 to 275 TWh of low-carbon electricity would be required for its generation. As a comparison, France has produced 120 TWh from renewables in 2021, of which around half from hydro, and smaller shares from wind (37 TWh) and solar (15 TWh). However, it is well known that the country has a very large contribution of nuclear energy (380 TWh, around 70% of the total generation).

The following chart shows the distribution of hydrogen demand across sectors in the two TYNDP-2022 scenarios.



The French government has published a national hydrogen strategy in 2020, with the aim of supporting low-carbon hydrogen. Three main quantitative targets have been proposed:

- Installation of 6.5 GW of electrolysers by 2030 to support de decarbonization of the French economy;
- Support to hydrogen-based mobility, both for passengers and freight, aiming at reducing annual CO_2 emissions by 6 Mt in 2030;
- Development of a national supply chain for hydrogen, leading to the creation of 50,000-150,000 direct and indirect jobs in the sector.

The strategy considers a total of 7 billion € of financial aid by 2030, aiming at three main priorities: (1) industry decarbonisation through the development of a national hydrogen supply chain, (2) deployment of heavy mobility based on low-carbon hydrogen and (3) support research, development and capacity building.

Hydrogen is also among the objectives of the recent investment plan “France 2030”, which aims to strengthen the industrial competitiveness of France and to develop the technologies of the future. The government will devote 2.1 billion euros in aid to the development of 10 projects along the hydrogen supply chain, which will supplement the 3.2 billion euros of investment by private players. These projects will allow the construction of four gigafactories of electrolysers (representing up to 40% of the European market for electrolysers by 2030), hydrogen storage sites, fuel cells and vehicles for sustainable mobility and the production of the necessary materials.

The leaders of France, Spain and Portugal have confirmed in October 2022 the intention of developing an underwater green energy corridor that will eventually transport hydrogen from Barcelona to Marseille, in substitution of a proposed natural gas pipeline connection.

3.3.2.2 Weak signals, possible disruption factors

Several French firms are also involved in some Important Projects of Common European Interest (IPCEI) in the Hydrogen Technology Value Chain – "IPCEI Hy2Tech" and in the Hydrogen Value Chain – "IPCEI Hy2Use". French firms will be working in hydrogen generation technology, fuel cells technology, storage, transportation and distribution technology, end user technology and infrastructures. The participants in these projects will closely cooperate with each other through numerous planned collaborations, and with over 300 external partners, such as universities, research organisations and SMEs across Europe. This could foster additional activities related to the development of the hydrogen supply chain in the country.

3.3.2.3 Levers and barriers

Given the very high share of nuclear power generation, contributing to one of the lowest carbon intensities for electricity among large European countries, France is well positioned to develop a low-carbon hydrogen supply chain. The development of electrolysers at scale could then decrease their price and improve the economic conditions also for applications coupled with renewable energy generation.

3.3.3 Main uncertainties

The potential role of hydrogen produced from nuclear power in addition to renewables in decarbonizing the energy system may not be in line with strategies of other EU countries that have decided to avoid nuclear energy. This remains the biggest uncertainty in the future of the low-carbon hydrogen sector in France.

At the same time, the future evolution of the share of nuclear in the national power generation mix may vary compared to the current level, since the different 2050 scenarios recently developed by RTE (the French transmission grid operator) show that maintaining or even increasing the production of carbon-free electricity will depend on the political will and the economic and industrial capacity to accelerate the deployment of renewable production and the progressive and proactive renewal of the nuclear fleet.

3.4 Italy

3.4.1 Review of current trends

The current hydrogen demand in Italy is estimated to be around 519,000 tonnes per year, the fifth country in the EU-27 (data from FCHO, 2019). The main final use is in refineries, which account for 75% of the total demand, followed by ammonia (15%) and other chemicals (5%). Energy usages remain below 3% of the total, and transport use is almost non-existent.

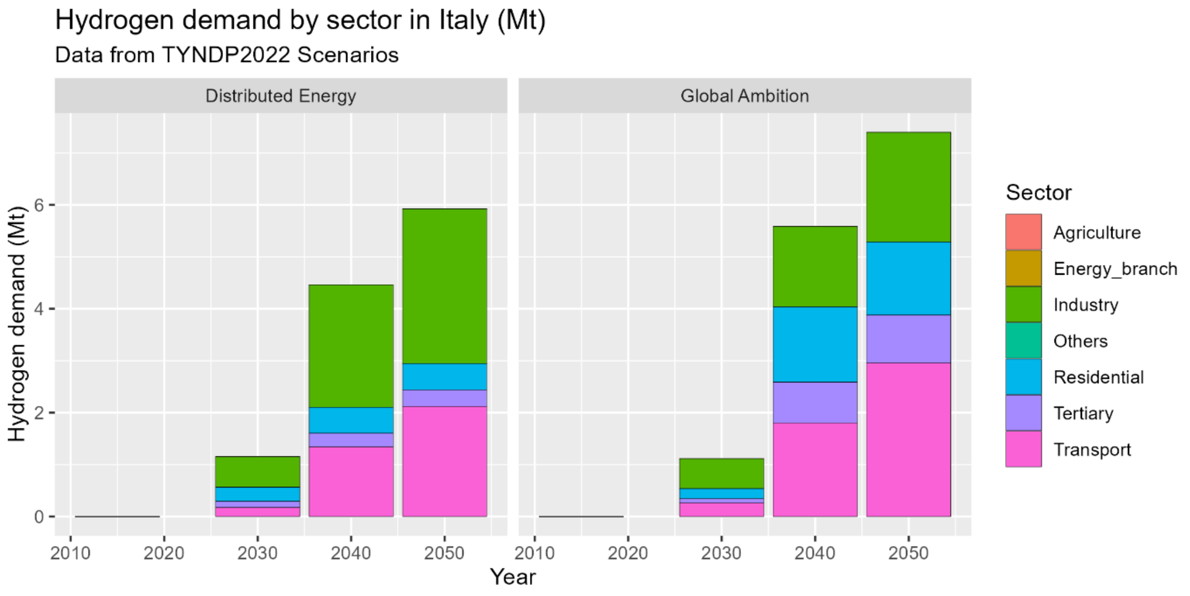
There have been some pilot projects of hydrogen for public transport, including hydrogen buses in some cities and some trains on non-electrified tracks.

3.4.2 Future trends

3.4.2.1 Existing strategies, quantitative objectives

The TYNDP scenarios expect between 5.9 and 7.4 million tonnes of hydrogen demand in Italy by 2050. When considering a power-to-gas perspective, 260 to 380 TWh of low-carbon electricity would be required for its generation. As a comparison, Italy has generated 117 TWh of renewable electricity in 2021, mostly from hydro (45 TWh), solar (25 TWh) and wind (21 TWh). Thus, the country would need to dramatically improve its generation capacity to meet the green hydrogen demand, and even more if its ambition includes the export towards other EU countries.

The following chart shows the distribution of hydrogen demand across sectors in the two TYNDP-2022 scenarios.



Italy has published a draft hydrogen strategy in November 2020, proposing some specific targets, although this has not yet been converted in a definitive strategy. This draft strategy aims at specific targets to be reached by 2030:

- 2% share of hydrogen in final energy demand;
- 5 GW of installed capacity of electrolysers;
- Up to 8 Mt of CO_2 emission savings;
- 10 billion € of investments for hydrogen projects (excluding investments for supporting RES), leading to a 27 billion € increase of GDP;
- Creation of 200.000 temporary jobs and 10.000 permanent jobs.

The draft strategy also reports that by 2050 hydrogen could represent 20% of final energy consumption in Italy, with a range of applications including long-distance transport, specific industrial sectors (refineries, chemicals, steel), electricity storage and buildings heating.

The strategy proposes different models of hydrogen generation and distribution, to be applied depending on the specific context. These models include: (1) local generation from on-site renewables, (2) distributed hydrogen generation based on grid-connected electrolysers (exploiting green electricity) and (3) centralized energy production in sites with high availability of renewables and distribution of hydrogen through pipelines or trucks.

Italy could also become a hydrogen hub for the European Union, connecting large production sites of green hydrogen in North Africa with the regions of high demand in Germany and other countries in Northern Europe.

Officials from Croatia, Italy and Slovenia have signed a letter of intent in 2022 to develop a cross-border hydrogen valley in the North Adriatic sea, with the aim of promoting hydrogen technologies, define a set of projects and find sources for their financing. The three countries will set up a joint working group to implement the letter of intent.

3.4.2.2 Weak signals, possible disruption factors

Several Italian firms are also involved in some Important Projects of Common European Interest (IPCEI) in the Hydrogen Technology Value Chain – "IPCEI Hy2Tech" and in the Hydrogen Value Chain – "IPCEI Hy2Use". Italian firms will be working in hydrogen generation technology, fuel cells technology, storage, transportation and distribution technology, end user technology and hydrogen applications in industry. The participants in these projects will closely cooperate with each other through numerous planned collaborations, and with over 300 external partners, such as universities, research organisations and SMEs across Europe. This could foster additional activities related to the development of the hydrogen supply chain in the country.

Other projects are currently being developed in Italy, and there is growing interest in hydrogen in specific applications with dedicated pilot projects, including urban buses, regional trains and industrial applications.

3.4.2.3 Levers and barriers

Italy has an important renewable potential, especially in the southern regions, where both solar and wind power generation are being deployed. However, the increase of renewable capacity needed to decarbonise the country will be very high, and even higher if green hydrogen generation is included. The country is already facing some issues related to the South-North power transmission network, which may not be able to accommodate the high increases of generation in the South and demand in the North, unless proper economic resources are allocated to network improvement. An alternative option may be to produce green hydrogen on-site where solar and wind power is available, and then transport it via pipeline to the usage sites.

Italy shows a very developed natural gas network, which could be potentially adapted to accommodate some hydrogen shares. The network operator, SNAM, has tested in some facilities the operation with hydrogen concentrations up to 10%, and it evaluated the possibility of gradually adapting its network to reach a 20% level. The concept of hydrogen valleys is being considered as an alternative option, with specific network sections to be fully converted to 100% hydrogen operations.

Italy also shows an interesting production of biogas, which is often being upgraded to biomethane, which could lead to carbon-negative hydrogen generation when coupled to carbon capture and sequestration. However, although this pathway is often considered as green hydrogen given the generation from biomass, it differs from the mainstream pathway that considers electrolysis coupled to renewable electricity.

A final barrier is represented by the bureaucracy of large projects in the country, which in the last decades has slowed down an important number of investments, both for natural gas infrastructure and renewable power plants. This aspect needs to be considered when evaluating future expansion plans, as longer times needed to implement projects may impact on the expected production targets.

3.4.3 Main uncertainties

As for other countries, the successful implementation of an international green hydrogen market will represent a big uncertainty for the development of projects in the country. Italy may represent a potential interesting hub connecting North Africa and northern EU countries (especially Germany), but the potential success of this proposal remains related to a large number of barriers and geopolitical choices.

Considering the national situation, the lack of a clear and durable long-term strategy, as already seen in other energy applications, could significantly affect the investment of industrial players, due to the incertitude of future business plans.

3.5 Slovenia

3.5.1 Review of current trends

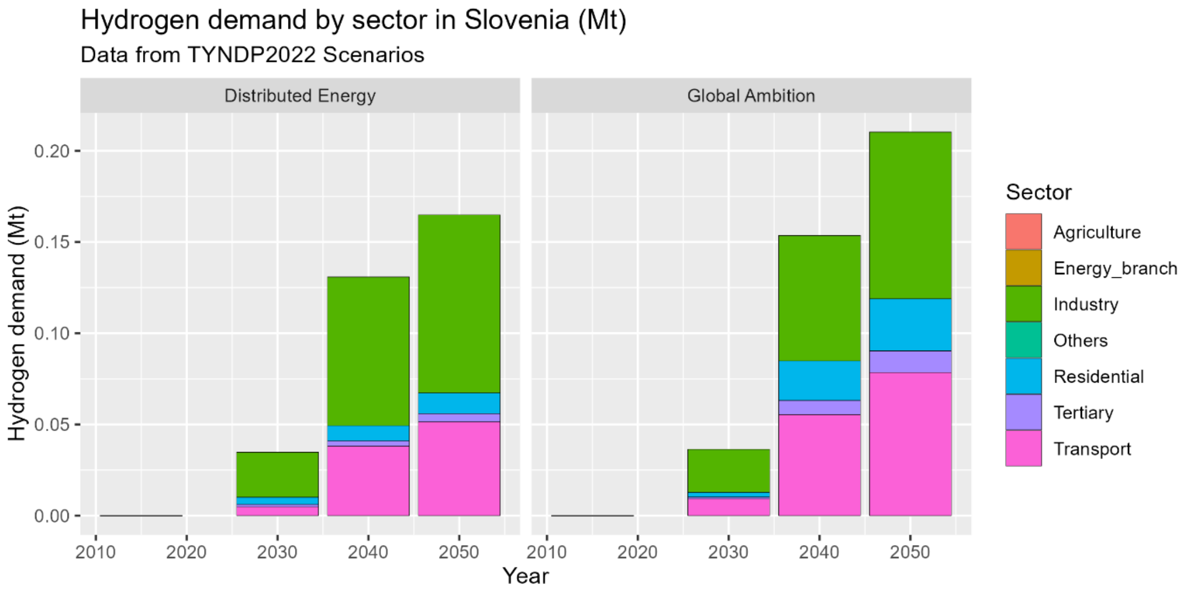
The current hydrogen demand in Slovenia is estimated to be around 2,000 tonnes per year (data from FCHO, 2019). The main final use is in production of chemicals (others than ammonia and methanol), representing almost 80% of the total demand, followed by energy with 19%.

3.5.2 Future trends

3.5.2.1 Existing strategies, quantitative objectives

The TYNDP scenarios expect between 0.16 and 0.21 million tonnes of hydrogen demand in Slovenia by 2050. When considering a power-to-gas perspective, 7 to 11 TWh of low-carbon electricity would be required for its generation. As a comparison, Slovenia produced in 2021 around 5 TWh of renewable electricity, almost all from hydropower. However, Slovenia has also produced 5.5 TWh of nuclear power in the same year. Both solar and wind remains marginal, although solar has been gradually increasing in the last years.

The following chart shows the distribution of hydrogen demand across sectors in the two TYNDP-2022 scenarios.



The National Energy and Climate Plan in Slovenia aims at a share of 10% of renewable hydrogen or methane in the grid by 2030. This figure will rise to 25% by 2040 and 100% by 2050. There is currently no specific hydrogen strategy, nor the government has indicated the intent of developing one.

3.5.2.2 Weak signals, possible disruption factors

Officials from Croatia, Italy and Slovenia have signed a letter of intent in 2022 to develop a cross-border hydrogen valley in the North Adriatic sea, with the aim of promoting hydrogen technologies, define a set of projects and find sources for their financing. The three countries will set up a joint working group to implement the letter of intent.

Slovenia is also implementing a cross-border cooperation with Austria for the development of hydrogen technologies. A roadmap was published in 2022 with an estimated demand of 10 ktoe of hydrogen by 2030.

3.5.2.3 Levers and barriers

Slovenia has a high rate of investment of R&D, especially in companies, and there is also an important ecosystem of research centres and supporting organizations, such as science parks, business incubators, NGOs and government agencies. Slovenia aims at becoming an innovation leader on environment and technologies in the next years, and hydrogen could be part of the solutions that will be developed.

There is some interest from industrial players in developing a hydrogen supply chain, but regulation needs to be adapted to properly support hydrogen pilot sites to be scaled up in different applications.

The cooperation between universities and industries remains quite weak, especially in a cross-border perspective with Austria, which can represent an important lever to develop a hydrogen economy. Strong partnerships across different sectors may also help the upscaling of hydrogen technologies.

3.5.3 Main uncertainties

There is the need of a long-term and stable regulatory environment, both nationally and at EU level, including no retroactive changes on regulation and the standardisation of the sector (e.g. by clearly defining green hydrogen and/or low-carbon hydrogen). Such a stability is of paramount importance for a sector that its at a very early stage of maturity and would need important investments to scale up the industry.

3.6 Croatia

3.6.1 Review of current trends

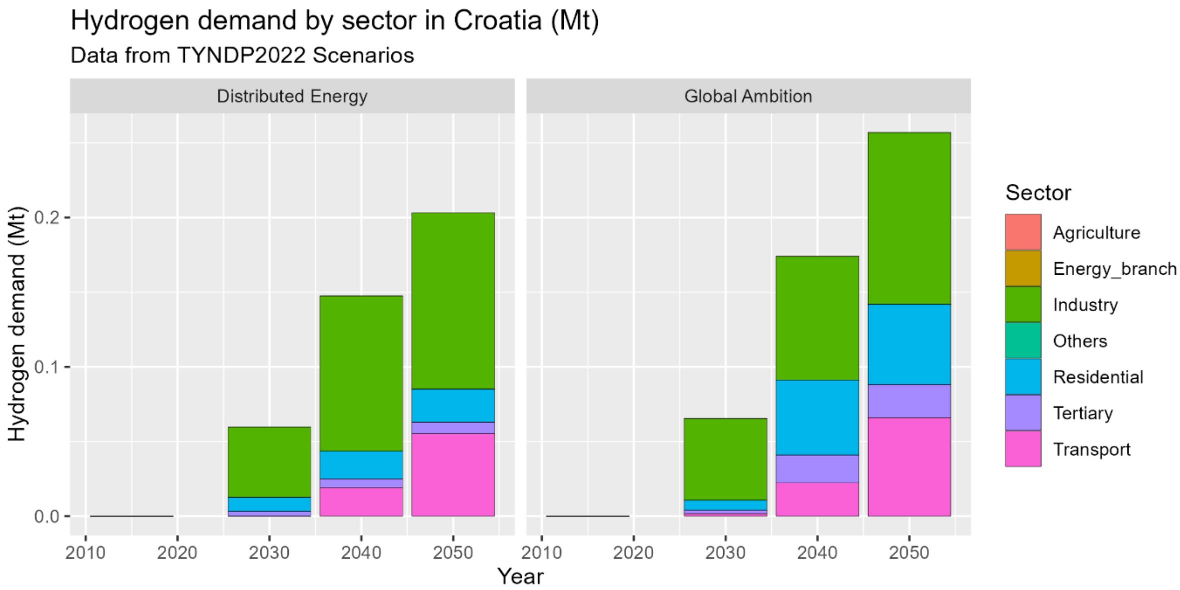
The current hydrogen demand in Croatia is estimated to be around 122,000 tonnes per year (data from FCHO, 2019). The total consumption is almost equally split between ammonia production (54%) and refining (46%).

3.6.2 Future trends

3.6.2.1 Existing strategies, quantitative objectives

The TYNDP scenarios expect between 0.20 and 0.26 million tonnes of hydrogen demand in Croatia by 2050. When considering a power-to-gas perspective, 9 to 13 TWh of low-carbon electricity would be required for its generation. As a reference, 10 TWh of renewable electricity have been generated in Croatia in 2021, of which almost 7 TWh from hydro and 2 TWh from wind. Green hydrogen would thus need a significant increase of renewable power capacity in the country, especially considering the potential threats of climate change on the hydro productivity.

The following chart shows the distribution of hydrogen demand across sectors in the two TYNDP-2022 scenarios.



Croatia has adopted a 2050 hydrogen strategy, with estimated total investments between 3.1 and 9.3 billion euro, depending on the scenario. In the framework of a development scenario that aims at climate neutrality by 2050, Croatia plans to install 70 MW of green hydrogen production facilities by 2030 and 2.75 GW by 2050. In parallel, hydrogen is expected to represent 0.2% of national energy consumption by 2030 and 11% by 2050. The strategy also presents an alternative scenario considering an accelerated development of a hydrogen economy in the EU, which could allow electrolysers capacity to increase to 1.27 GW by 2030 and 7,33 GW by 2050, and in parallel a hydrogen share in energy consumption of 3.75% in 2030 and 15% in 2050.

3.6.2.2 Weak signals, possible disruption factors

Current hydrogen generation in Croatia is almost totally relying on steam methane reforming, and the country could evaluate the possibility of developing carbon capture and storage solutions to shift towards blue hydrogen, in addition to the green hydrogen potential related to renewable electricity upscaling. However, green hydrogen remains the most interesting solution to exploit the potential of the country, given the important future strategies of renewable power capacity deployment.

Considering the short-term applications, the Strategy is considering transportation and industry sectors, in particular refineries and ammonia production. There are already some advanced projects in the transportation sector, according to the National Hydrogen Strategy.

3.6.2.3 Levers and barriers

The planned increase of renewable power capacity in the following years may represent an interesting opportunity to develop green hydrogen production in the country, provided that this should not conflict with other specific goals of renewable electricity use.

Croatia has a well-developed gas transmission and distribution network (more than 2,500 km and 18,000 km respectively), which could represent an important asset for hydrogen transport. The Strategy envisions to consider hydrogen blending in the short term in some specific sites, and then to evaluate the possibility of refurbishing existing infrastructure to transport either hydrogen or carbon dioxide, depending on the least cost principle.

The development of green hydrogen use in industries will likely require important infrastructure investments, including on the gas grid for its supply or on the electricity grid if hydrogen is to be produced directly in the industrial sites that need it.

The National Hydrogen Strategy also highlights the importance of raising the public awareness about the advantages of green technologies and hydrogen economy, through dedicated communication campaigns.

3.6.3 Main uncertainties

Green hydrogen will be in direct competition with other alternative uses of renewable electricity in the country, and this is already reported in the Hydrogen Strategy that has been published. Thus, it is likely that the new renewable capacity that will be installed based on the national decarbonization goals will be used in the most effective way to shift away from fossil fuels. Thus, the success of hydrogen in final uses will also depend on its economics, especially considering that the current hydrogen pathways are often way less efficient compared to other technologies in most of the final sectors. Thus, hydrogen may remain limited to specific hard-to-abate applications where no other options are available.

3.7 Montenegro

3.7.1 Review of current trends

There are currently no data of hydrogen use in the country.

3.7.2 Future trends

3.7.2.1 Existing strategies, quantitative objectives

Hydrogen has not yet been considered in the energy plans of Montenegro. There is no publicly available information related to potential hydrogen initiatives.

3.7.2.2 Weak signals, possible disruption factors

Montenegro has currently no natural gas uses, nor it has any project for transmission and distribution network deployment. However, the future potential implementation of such a network, either through pipeline connection with other countries or through an LNG terminal, may also represent the opportunity of developing it by considering the potential future adaptation to hydrogen. However, at this stage these options seem rather remote.

3.7.2.3 Levers and barriers

Final energy sectors in the country, given the lack of natural gas, are strongly dependent on oil products and electricity (mostly generated from hydro and coal). However, a few large industrial sites are currently importing LNG or CNG on trucks for their operations, often from very far locations abroad. Although there is no public information on their potential interest to incorporate hydrogen use, a green hydrogen generation in the country (or in the region) could become competitive in the future.

Some specific industrial sectors may be more favorable to hydrogen use, such as ammonia production, refineries and steel production. These sectors are currently playing a marginal role in the national industry. Considering industrial energy consumption in Montenegro, iron and steel represents 6% of the total, while chemicals and petrochemicals (including ammonia production and oil refining) represents 2%.

3.7.3 Main uncertainties

As discussed above, hydrogen development in Montenegro is very hard to estimate due to the already very limited use of natural gas in the country. A future combined development of both energy carriers may provide some benefits in terms of economic sustainability, but the important investments required for the infrastructure may represent an important barrier.

3.8 Albania

3.8.1 Review of current trends

There are currently no data of hydrogen use in the country.

3.8.2 Future trends

3.8.2.1 Existing strategies, quantitative objectives

There are no specific hydrogen strategies in the country. Albania has approved a Natural Gas Masterplan in 2016, but without any specific mention of hydrogen integration.

3.8.2.2 Weak signals, possible disruption factors

Although Albania has currently a very limited natural gas distribution network, it is currently expanding its international connections, which may help increasing natural gas use in the future. The Trans-Adriatic Pipeline (TAP) connecting Azerbaijan to Italy is passing through Albania, and it is expected to boost natural gas both in final sectors and power generation.

3.8.2.3 Levers and barriers

Almost all electricity production is currently relying on hydropower, which poses potential problems of supply given the variability of generation and the increasing risk related to climate change. On the other hand, the significant solar and wind potential in the country could also represent a key asset for green hydrogen generation.

Hydrogen could also play a role in Albania's natural gas expansion plan, which will be developed in the next years. The role of hydrogen could be related to a possible blend in the network, with hydrogen-ready new infrastructure that can represent a favourable situation compared to other countries with existing natural gas infrastructure. The same logic may be applied to natural gas storage sites, that can become interesting for hydrogen blending or future hydrogen storage.

Industrial players that may benefit from green hydrogen availability include refineries (which handle a high proportion of the domestic oil production), ammonia production and iron and steel. Some industries that are currently relying on oil and electricity have expressed interest to be connected to the natural gas network, which could lead to potential future hydrogen uses.

3.8.3 Main uncertainties

Albania may be in a favourable position in the event of a development of an international green hydrogen market, due to the possibility of deploying a hydrogen-ready gas network, including storage facilities, and being located on a potential connection path towards large European hydrogen consumers. However, as already noted for other countries, the success of such an international market is depending on a number of technical, economic and geopolitical aspects and barriers that need to be properly addressed. The main issue is probably the green hydrogen effectiveness in decarbonization strategies compared to other technologies and solutions.

3.9 Greece

3.9.1 Review of current trends

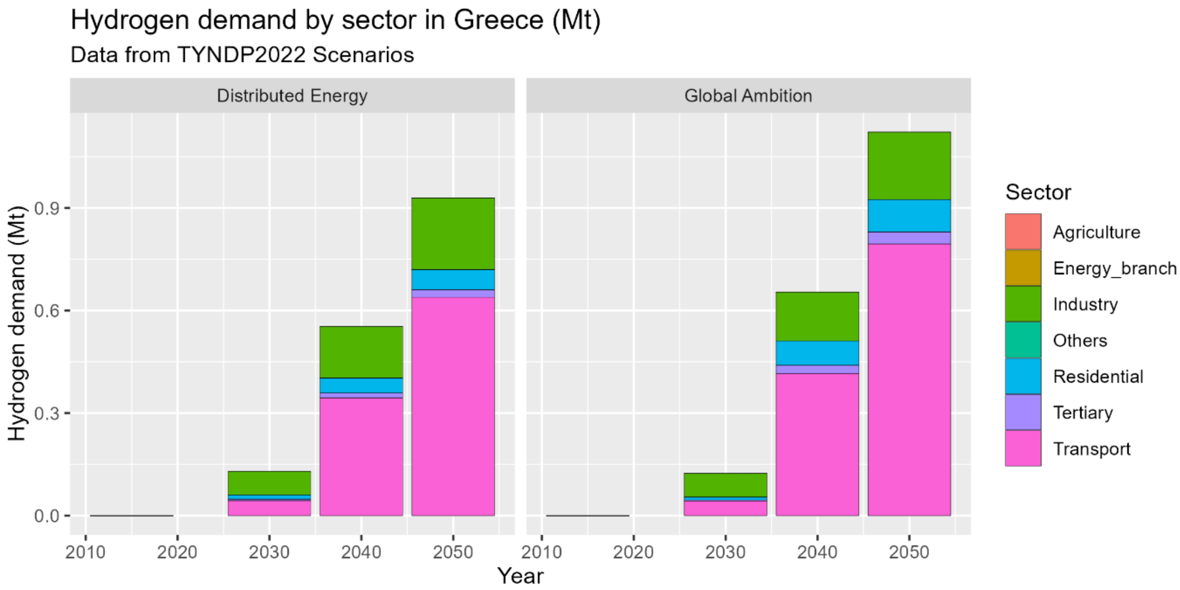
The current hydrogen demand in Greece is estimated to be around 329,000 tonnes per year (data from FCHO, 2019). The main final use is in refineries, which account for 93% of the total demand, followed by ammonia (7%).

3.9.2 Future trends

3.9.2.1 Existing strategies, quantitative objectives

The TYNDP scenarios expect between 0.9 and 1.1 million tonnes of hydrogen demand in Greece by 2050. When considering a power-to-gas perspective, 40 to 60 TWh of low-carbon electricity would be required for its generation. As a comparison, 22 TWh of renewable power have been produced in Greece in 2021, of which around half by wind and one quarter each by hydro and solar. Thus, green hydrogen generation would need a significant upscale of renewable capacity in the country, even more if Greece want to become a leader in green hydrogen exports.

The following chart shows the distribution of hydrogen demand across sectors in the two TYNDP-2022 scenarios.



A draft "National Strategy for the Promotion of Technologies – Applications of Hydrogen and Renewable Gases" has been studied by a 20-member Committee[12]. The strategy estimates a domestic production of 3.5 TWh of green hydrogen in 2030, thanks to a capacity of 750 MW of electrolysers, supported by 3 GW of renewable power (80% solar PV and 20% wind). The aim of the hydrogen is to replace natural gas and oil in refineries, industry and transport sectors. The Committee estimates that hydrogen development could save in 2030 up to 500 ktoe of gas and oil imports (which represent 10% of the total), reducing carbon dioxide emissions by 750 kt. From an economic perspective, a total investment of 3 to 4 billion euros could create 3000-4000 jobs along the value chain and increase the domestic added value by 90-110 million euro.

After 2030, Greece is also estimating to become a potential exporter of green hydrogen to supply the demand in other countries of the EU. Greece could produce around 3 Mtoe of green hydrogen in 2040, of which 1 Mtoe will be available for export. By 2050, green hydrogen generation could rise to 7.4 Mtoe, and exports to 2.3 Mtoe, with an estimated export value of 1.6 billion euros (and 0.9 billion euros in 2040). The total turnover of the hydrogen supply chain in 2050 is estimated around 10 billion euros. The RES capacity required to support it will reach 30 GW in 2040 and 60 GW by 2050.

[12] Source: https://www.ot.gr/2022/06/07/english-edition/greek-hydrogen-strategy-domestic-production-of-3500-gwh-in-2030/

3.9.2.2 Weak signals, possible disruption factors

Three Greek firms are also involved in some Important Projects of Common European Interest (IPCEI) in the Hydrogen Technology Value Chain – “IPCEI Hy2Tech” and in the Hydrogen Value Chain – “IPCEI Hy2Use”. Greek firms will be working in hydrogen generation technology, fuel cells technology, storage, transportation and distribution technology and hydrogen applications in industry. The participants in these projects will closely cooperate with each other through numerous planned collaborations, and with over 300 external partners, such as universities, research organisations and SMEs across Europe. This could foster additional activities related to the development of the hydrogen supply chain in the country.

3.9.2.3 Levers and barriers

Greece could become an important energy hub in the medium- and long-term through future dedicated hydrogen pipelines connecting hydrogen production sites in the Middle-East countries to European consumption spots. Moreover, thanks to its worldwide renowned shipping industry, Greece could position itself in the short-term as an important player in the shipping of low-carbon ammonia produced from green hydrogen, to be supplied to existing industrial sites that are already requiring ammonia as a feedstock for different processes.

3.9.3 Main uncertainties

As for other similar countries, the possibility for Greece to become an important hydrogen hub in an international market is tightly related to the emergence of such a market. The effectiveness of green hydrogen in becoming a commodity to support the decarbonization of national economies will depend on a set of economic, technological and geopolitical aspects, most of which will be well beyond the control of any action taken in a single country.

3.10 Cyprus

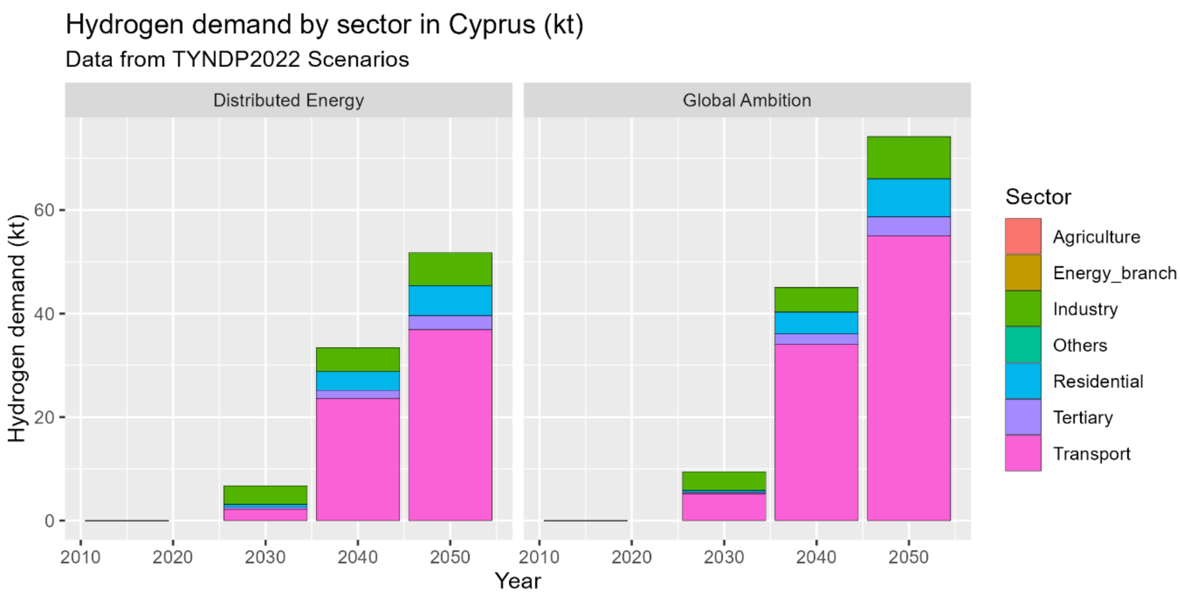
3.10.1 Review of current trends

There is currently no hydrogen demand in Cyprus (data from FCHO, 2019).

3.10.2 Future trends

3.10.2.1 Existing strategies, quantitative objectives

The TYNDP scenarios expect between 50 and 70 thousand tonnes of hydrogen demand in Cyprus by 2050. When considering a power-to-gas perspective, 2 to 4 TWh of low-carbon electricity would be required for its generation. The renewable power generation in Cyprus in 2021 reached 0.8 TWh (mostly from solar and wind), meaning that a green hydrogen economy would require an important upscale of the generation capacity. The following chart shows the distribution of hydrogen demand across sectors in the two TYNDP-2022 scenarios.



However, there is currently no hydrogen strategy in Cyprus, and no plans to develop a roadmap in the nearest future[13].

3.10.2.2 Weak signals, possible disruption factors

The industrial sector seems to suggest a potential interest in developing a hydrogen supply chain. In the context of the Cyprus Employers and Industrialists Federation (OEB), the Cyprus Hydrogen Association was founded on March 2021, with the aim of evaluating the possibility of developing hydrogen generation and use in the country, specifically considering the industrial and the transportation sector.

3.10.2.3 Levers and barriers

The country has currently no gas networks in operation, which could complicate the development of a hydrogen supply chain given the need of building new distribution infrastructure.

3.10.3 Main uncertainties

An effective future deployment of hydrogen solutions in Cyprus may depend on the success stories demonstrated in other countries that are expected to adopt them earlier. If hydrogen proves to be an effective and economically sustainable option to decarbonise some specific sectors, it can become also a solution for insulated countries that are currently heavily relying on imported oil products.

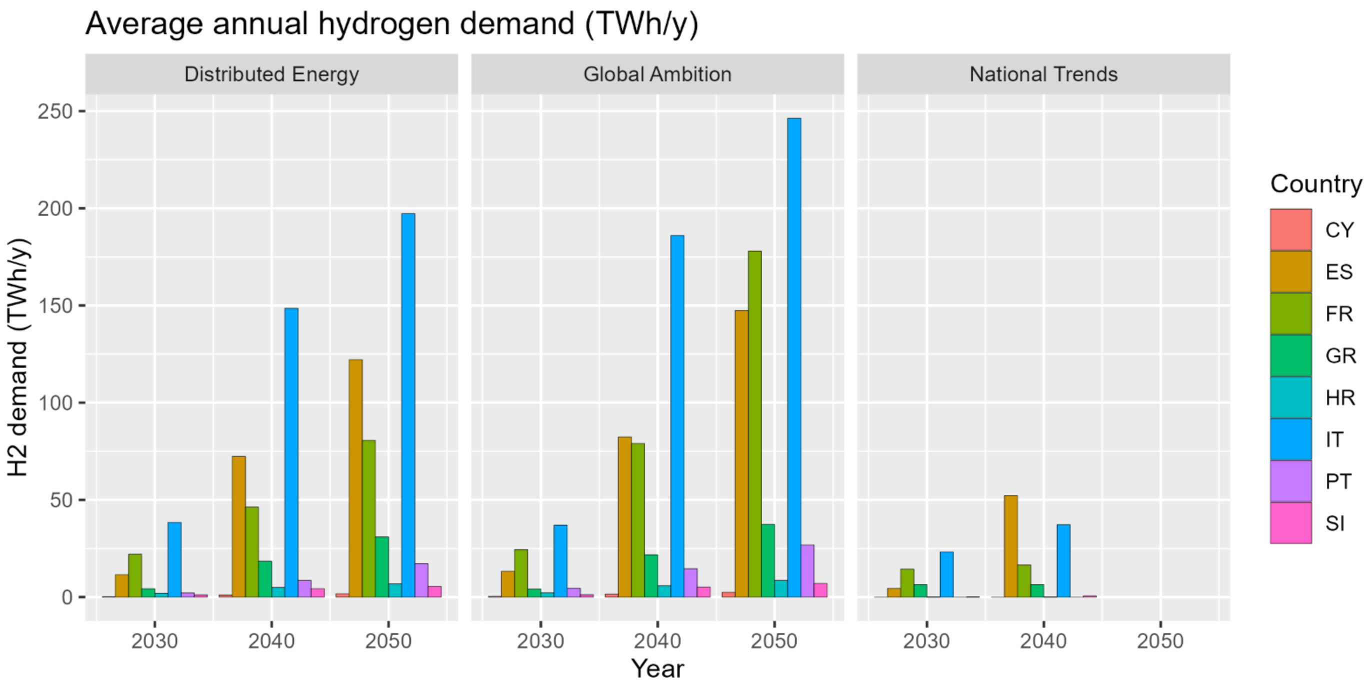
[13] Source: https://fleishmanhillard.eu/wp-content/uploads/sites/7/2022/02/FH-National-Hydrogen-Strategies-Report-2022.pdf

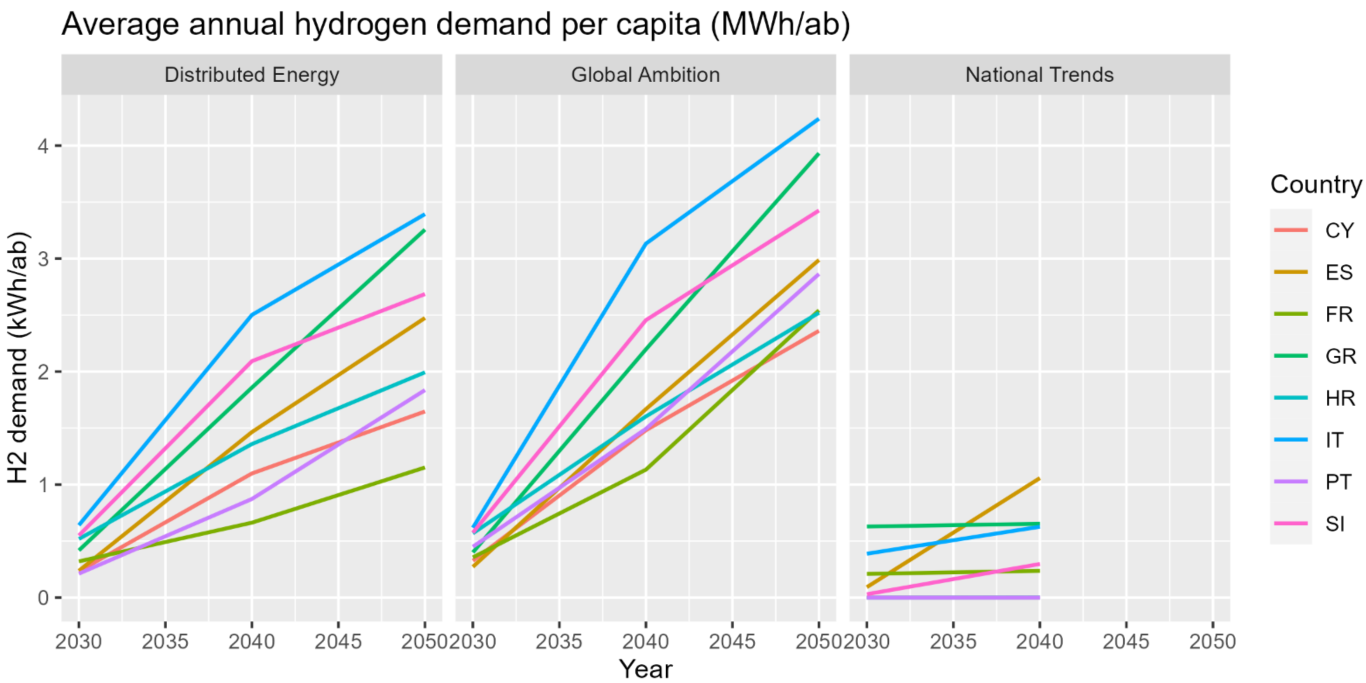
4 Conclusion

The countries considered in the analysis show a different level of interest towards hydrogen development. In general, low-carbon hydrogen is seen as a potential solution to help decarbonizing the economy, in line with net-zero strategies by 2050.

The following charts show the comparison of estimated of hydrogen demand in the different countries in the TYNDP2022 scenarios. In absolute terms, Italy, Spain, and France are the countries in which hydrogen demand will represent the biggest potential. However, when considering per-capita statistics, Italy, Greece, and Slovenia are the three countries with the highest consumption.

In general, the countries of southern Europe that are analysed in this report can all play a potential role in connecting the high-potential production sites in the Mediterranean with other demand hubs in the EU, which may not be able to match their hydrogen needs with their domestic productions alone. In this perspective, the effectiveness of an international (green) hydrogen market will depend on several aspects that include economics, technology, and geopolitics. The combined efficiency of the entire hydrogen supply chain remains quite low, especially considering compression, liquefaction of chemical transformation to transport it over long distances. Carbon pricing and national or international decarbonization policies and strategies will also be key drivers to support the economic effectiveness of low-carbon technologies, including pure hydrogen or other hydrogen-based fuels. However, experts agree that hydrogen may prove to be competitive with other low-carbon technologies, and its transportation over long distances may prove to be successful, only if its generation can be achieved at a very low cost.


Average annual hydrogen demand (TWh/y)
Distributed Energy
Global Ambition
National Trends
H2 demand (TWh/y)
0
50
100
150
200
250
2030
2040
2050
Year
Country
CY
ES
FR
GR
HR
IT
PT
SI


Average annual hydrogen demand per capita (MWh/ab)
Distributed Energy
Global Ambition
National Trends
H2 demand (kWh/ab)
0
1
2
3
4
2030
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2050
Year
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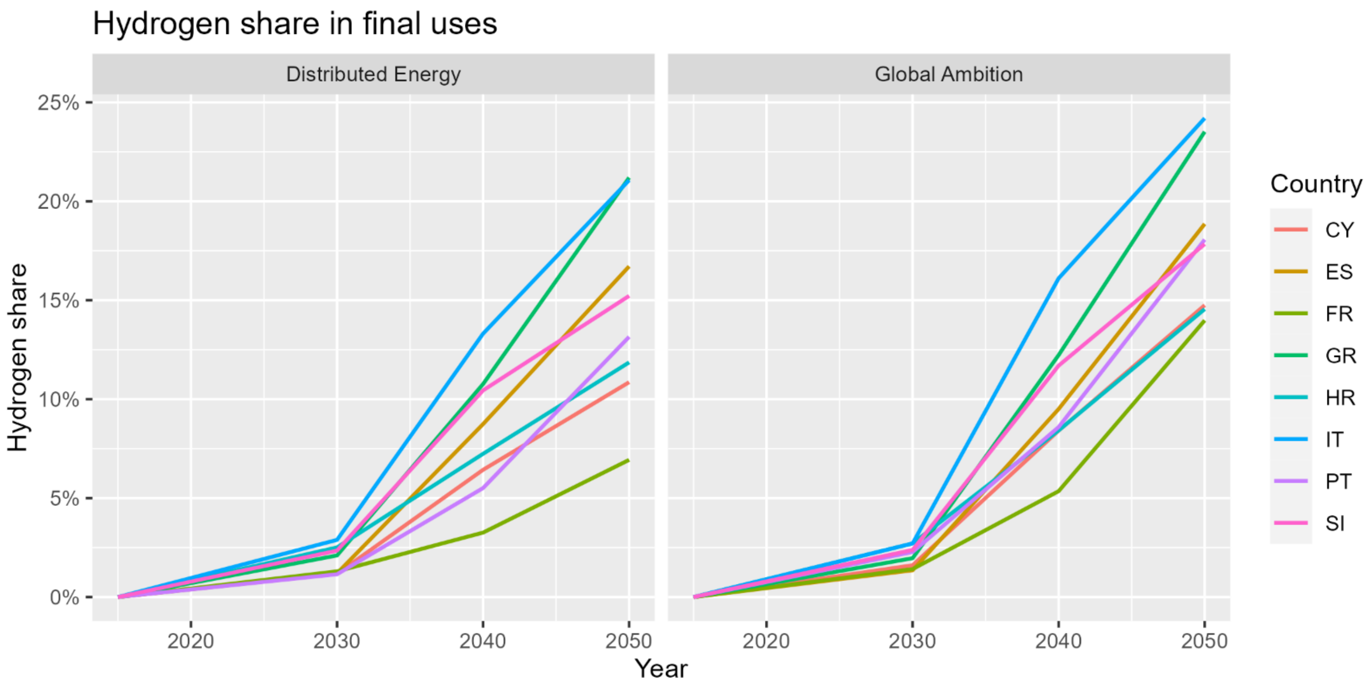
Hydrogen share in final uses
Distributed Energy
Global Ambition
Hydrogen share
25%
20%
15%
10%
5%
0%
2020
2030
2040
2050
Year
Country
CY
ES
FR
GR
HR
IT
PT
SI

5 Appendix

Appendix 1 – Bibliography – European countries

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Appendix 2 – Scenarios of hydrogen demand

Hydrogen demand in TYNDP2022 Scenarios by country and sector (data in TWh).

Country	Scenario	Year	Industry	Residential	Tertiary	Transport	Total
Cyprus	Distributed Energy	2030	0.1	0.0	0.0	0.1	0.2
Cyprus	Distributed Energy	2040	0.2	0.1	0.1	0.8	1.1
Cyprus	Distributed Energy	2050	0.2	0.2	0.1	1.2	1.7
Cyprus	Global Ambition	2030	0.1	0.0	0.0	0.2	0.3
Cyprus	Global Ambition	2040	0.2	0.1	0.1	1.1	1.5
Cyprus	Global Ambition	2050	0.3	0.2	0.1	1.8	2.5
Spain	Distributed Energy	2030	7.9	1.9	1.3	0.5	11.6
Spain	Distributed Energy	2040	41.7	6.3	4.8	19.6	72.3
Spain	Distributed Energy	2050	62.8	7.6	6.6	45.1	122.1
Spain	Global Ambition	2030	5.9	1.4	0.9	5.0	13.3
Spain	Global Ambition	2040	28.7	12.1	9.1	32.4	82.4
Spain	Global Ambition	2050	54.0	14.1	12.0	67.4	147.4
France	Distributed Energy	2030	17.9	0.5	0.3	3.2	22.0

Country	Scenario	Year	Industry	Residential	Tertiary	Transport	Total
France	Distributed Energy	2040	20.9	3.4	1.5	20.4	46.3
France	Distributed Energy	2050	33.0	10.6	6.5	30.6	80.6
France	Global Ambition	2030	18.5	0.9	0.5	4.6	24.5
France	Global Ambition	2040	41.0	4.2	1.8	32.0	79.0
France	Global Ambition	2050	81.6	20.9	12.8	62.7	178.0
Greece	Distributed Energy	2030	2.3	0.4	0.1	1.5	4.3
Greece	Distributed Energy	2040	5.0	1.4	0.5	11.5	18.4
Greece	Distributed Energy	2050	7.0	2.0	0.7	21.3	30.9
Greece	Global Ambition	2030	2.3	0.3	0.1	1.4	4.1
Greece	Global Ambition	2040	4.8	2.4	0.8	13.8	21.8
Greece	Global Ambition	2050	6.6	3.1	1.2	26.5	37.4
Croatia	Distributed Energy	2030	1.6	0.3	0.1	0.0	2.0
Croatia	Distributed Energy	2040	3.5	0.6	0.2	0.6	4.9
Croatia	Distributed Energy	2050	3.9	0.7	0.3	1.8	6.8
Croatia	Global Ambition	2030	1.8	0.2	0.1	0.1	2.2
Croatia	Global Ambition	2040	2.8	1.7	0.6	0.7	5.8
Croatia	Global Ambition	2050	3.8	1.8	0.7	2.2	8.6
Italy	Distributed Energy	2030	19.6	9.0	4.0	5.8	38.4
Italy	Distributed Energy	2040	78.5	16.6	8.7	44.7	148.5
Italy	Distributed Energy	2050	99.2	16.9	10.6	70.6	197.2
Italy	Global Ambition	2030	19.1	6.4	2.9	8.7	37.1
Italy	Global Ambition	2040	51.6	48.3	26.2	60.0	186.0
Italy	Global Ambition	2050	70.3	46.9	30.7	98.4	246.3
Portugal	Distributed Energy	2030	1.9	0.1	0.1	0.1	2.1
Portugal	Distributed Energy	2040	4.7	0.2	0.1	3.6	8.5
Portugal	Distributed Energy	2050	6.8	0.2	0.2	9.9	17.0
Portugal	Global Ambition	2030	3.3	0.1	0.1	1.0	4.5
Portugal	Global Ambition	2040	6.9	0.8	0.7	6.2	14.6
Portugal	Global Ambition	2050	12.1	0.9	1.0	12.9	26.9
Slovenia	Distributed Energy	2030	0.8	0.1	0.0	0.2	1.2
Slovenia	Distributed Energy	2040	2.7	0.3	0.1	1.3	4.4
Slovenia	Distributed Energy	2050	3.2	0.4	0.2	1.7	5.5
Slovenia	Global Ambition	2030	0.8	0.1	0.0	0.3	1.2
Slovenia	Global Ambition	2040	2.3	0.7	0.3	1.8	5.1
Slovenia	Global Ambition	2050	3.0	1.0	0.4	2.6	7.0

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