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Hydrogen Business Guide

Bilateral energy partnerships in developing countries and emerging economies

giz

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Contents

Abbreviations

BMWK ... German Federal Ministry for Economic Affairs and Climate Action
CAPEX ... Capital Expenditures
CO_2 ... Carbon dioxide
RE ... Renewable energy
EU ... European Union
FCEV ... Fuel Cell Electric Vehicle
GIZ ... Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
GW ... Gigawatt
H_2 ... Hydrogen
IEA ... International Energy Agency
IRENA ... International Renewable Energy Agency
kWh ... Kilowatt hour
LCOE ... Levelised Cost of Electricity
LCOH ... Levelised Cost of Hydrogen
LNG ... Liquefied Natural Gas
MoU ... Memorandum of Understanding
MW ... Megawatt
NDC ... Nationally Determined Contributions
PPA ... Power Purchase Agreement
PJ ... Petajoule
PtL ... Power-to-Liquid
PtX ... Power-to-X
PV ... Photovoltaics
TWh ... Terawatt hour
WACC ... Weighted Average Cost of Capital

Introduction

The impacts of climate change and the resulting need to act on climate protection are global topics which governments worldwide have to address. Extreme weather phenomena are becoming more frequent, causing destruction, flooding, drought and humanitarian crises. The German Government has set ambitious goals to address these developments, ensure long-term climate action and stop global warming. These goals are based on the Paris Agreement of 2015 and the goal of achieving climate neutrality by 2045 by massively expanding renewable energy, strengthening energy efficiency, and phasing out coal-fired power generation by 2030. To enable a fossil fuel- and emission-free future and permit the energy transition to be fully implemented, one key pillar of the German Government's strategy is the use of -green hydrogen produced with renewable energy. Particularly in industrial and transport sectors which cannot be decarbonised with conventional technologies or electricity, the aim is to use green hydrogen as a gaseous or liquid energy carrier and fuel to make all sectors climate neutral. In June 2020, the National Hydrogen Strategy was presented to achieve this goal.

With the National Hydrogen Strategy, Germany plans to import large quantities of green hydrogen in the medium to long term. After all, the quantities required will greatly exceed Germany's green hydrogen generating capacity. The strategy provides for 21 to 96 TWh of green hydrogen to be imported in 2030. To meet this demand, the German Government will utilise international cooperation arrangements and partnerships in the European Union (EU) and beyond.

To support the market ramp-up for green hydrogen and its derivatives at European and global level, the German Government has launched numerous funding programmes including H2Global, the funding guideline for international hydrogen projects and H2-Uppp. The market ramp-up for green hydrogen also offers new business opportunities for German companies. Targeted support measures for the private sector aim to allow the potential of hydrogen technologies to be fully exploited and improved while simultaneously promoting the competitiveness of the sector in the international context.

In Measure 34 of the National Hydrogen Strategy, the German Government's bilateral energy partnerships also play a major role in cooperating with strategic export and import countries. The bilateral energy partnerships are also a key instrument in the German Government's foreign energy policy, in which it combines energy policy dialogue at the government level with practical and goal-oriented project work and engagement with the German private sector as an integral part of the partnerships. This will strengthen the promotion of future-oriented energy strategies and the advancement of private sector innovation worldwide and will serve as impetus for energy-efficient innovations and cooperation arrangements on the path to a global energy transition.

At present, Germany maintains 23 energy partnerships and dialogues throughout the world, 11 of which are implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the German Ministry for Economic Affairs and Climate Action (BMWK), including Algeria, Brazil, Chile, China, Ethiopia, India, Jordan, Mexico, Morocco, South Africa and Tunisia. Germany (Federal Foreign Office and BMWK) conducts the other 12 energy partnerships with Angola, Australia, Japan, Kazakhstan, Nigeria, Norway, Russia, South Korea, Turkey, the United Arab Emirates, the United States and Ukraine.

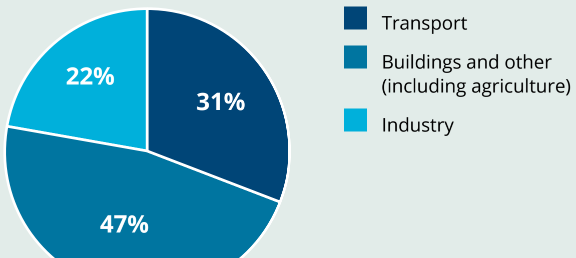
As part of the global energy transition, green hydrogen is also playing an increasingly important role in bilateral energy partnerships, which offer a dialogue platform for BMWK and the partner ministries on their respective hydrogen policies. They also offer advice on different aspects of the development of green hydrogen (including strategic development, regulatory frameworks, certification, sustainability standards and transport) and conduct corresponding workshops on green hydrogen. In this context, the bilateral energy partnerships have also supported the development of hydrogen potential analyses and hydrogen strategies in various countries.

This Hydrogen Business Guide presents the initial results and findings of the potential analyses for Algeria, Brazil, Chile, Mexico, Morocco, South Africa and Tunisia. The guide aims to give German businesses orientation regarding the hydrogen potential and current energy-policy developments in these countries. These are snapshots of a situation that is in a constant state of flux in the countries as a result of the worldwide dynamics. The guide also provides an overview of the countries' respective electricity and energy mix, their respective renewable energy potentials and goals and the current planning status for green hydrogen.

Algeria

Energy data

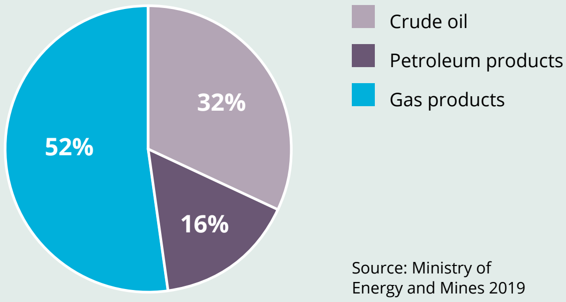
Energy consumption by sector



Source: Ministry of Energy and Mines 2019

The transport and industrial sectors account for more than half of Algeria's energy consumption.

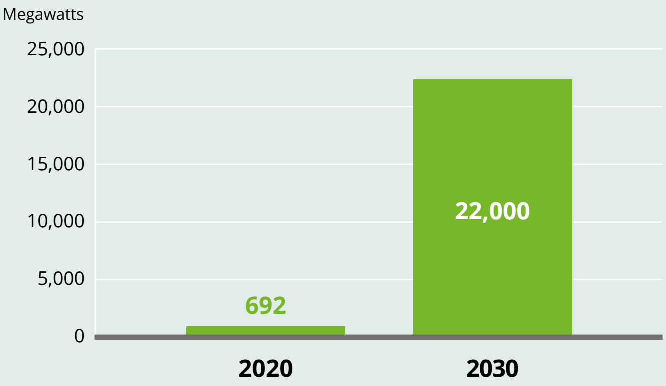
Energy exports



Source: Ministry of Energy and Mines 2019

Algeria is an important exporter of petroleum and natural gas and has petroleum reserves amounting to 12.2 billion barrels and 4.51 trillion cubic metres of natural gas reserves. Algeria's energy exports amounted to 92 million tonnes of crude oil units in 2019.

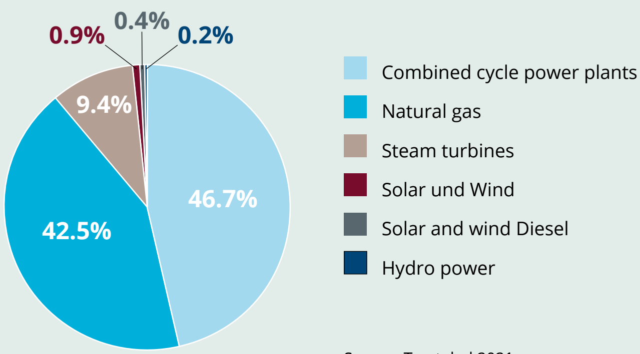
Installed and planned solar, wind and hydro power capacity



Source: Ministry of Energy and Mines 2021

With the Algerian Renewable Energy and Energy Efficiency Development Plan, Algeria has made a sustainable energy supply a national priority. This plan aims to ensure that 15,000 MW is generated from renewable sources by 2035.
Goal: to save at least 240 billion cubic metres of natural gas and thereby avoid 200 million tonnes of carbon.

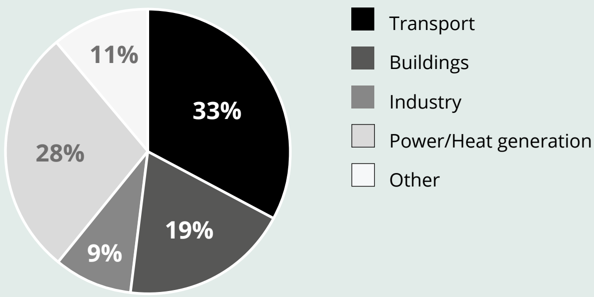
Electricity generation by energy source



Source: Tractebel 2021

Combined cycle power plants and gas turbines contribute by far the most to electricity generation. PV and wind accounted for 0.9% of the national electricity generation.

Carbon emissions by sector



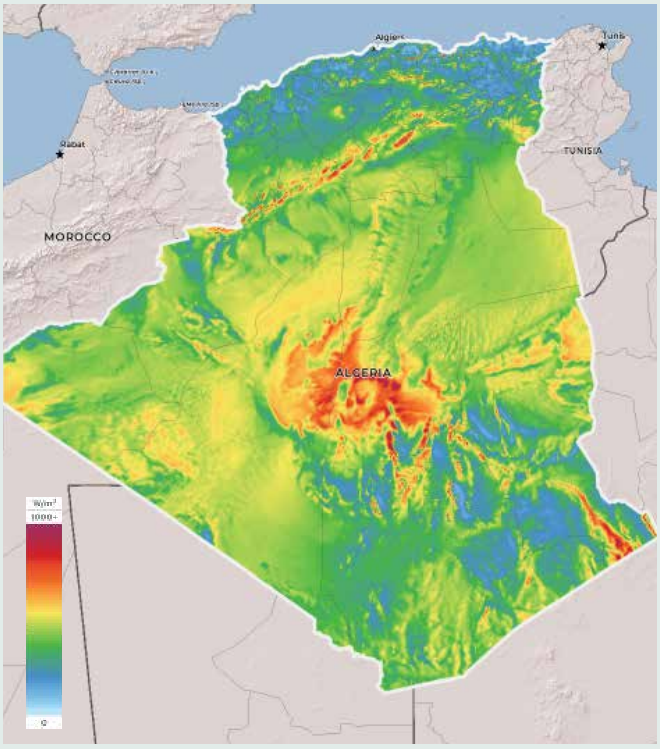
Source: IEA 2018

The transport sector is responsible for around one third of the country's emissions.

Renewable energy potential

Production conditions for green hydrogen and its derivatives

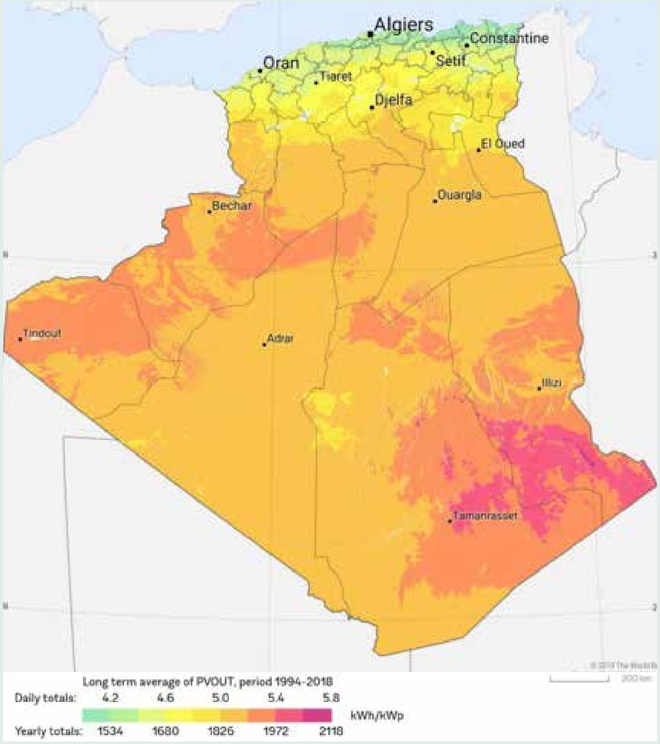
Wind speeds



Source: Global Wind Atlas 2021

Wind conditions are best in the centre of Algeria.

Solar irradiance



Source: Solargis 2021

The PV potential is especially promising in the south of Algeria.

WIND

Wind potential: **35 TWh/year**
Wind speed in the windiest region: **avg. 8.71 m/s**

SOLAR

PV potential: **13.9 TWh/year**
Annual solar irradiance: **2,000 kWh/m²**

Source: Tractebel 2021

WATER

Hydropower potential: **0.5 TWh/year**

Source: Tractebel 2021

The Algeria Renewable Energy Program was revised again for 2020. It aims to install 16,000 MW of photovoltaic capacity alone by 2035. As a consequence, solar electricity generation will increase from around 0.4 GW today to around 30 GW by 2050. It is assumed that wind energy will increase to 2 GW in 2050. The prevailing direct current technology will continue to be expanded until capacity eventually reaches 41 GW in 2050.

The comparison of the overall potential for PV-based hydrogen production with production from onshore wind energy shows that PV production potential is ten times that of onshore wind energy.

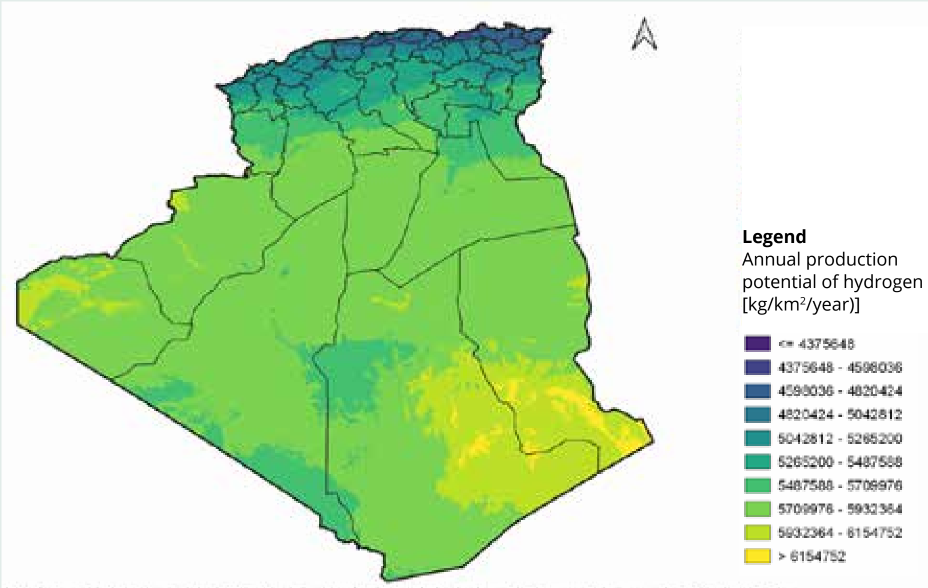
Hydrogen potential

The greatest potential for specific PV-based hydrogen production is in the south-east region of Algeria in the Ahaggar and Tassili-n'Ajjer mountains, in the provinces of Illizi and Tamanrasset. The lowest potential for specific PV-based hydrogen production is in the north-eastern Mediterranean region between Bejaia and Annaba.

Potential of green hydrogen production from PV electricity

Geographical overview of technical annual production potential

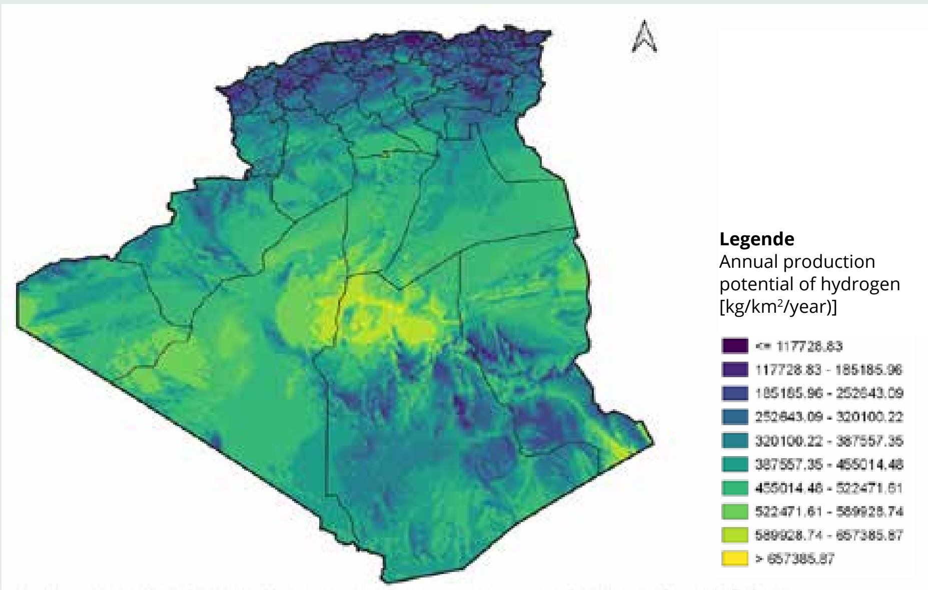
The total technical overall potential for the production of green hydrogen from PV electricity in Algeria is estimated at 6,650 million tonnes per year in 2030.



Potential of green hydrogen production from onshore wind electricity

Geographical overview of technical annual production potential

The total technical potential for the production of green hydrogen from onshore wind electricity in Algeria is estimated at 994 million tonnes per year in 2030.



Source of all graphics: Tractebel 2021

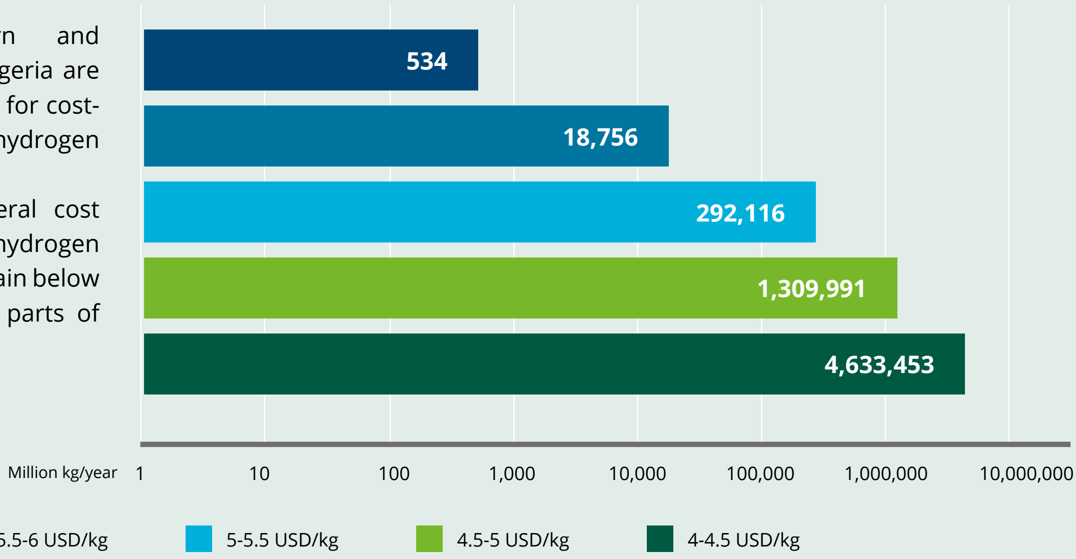
Required renewable energy capacity for green hydrogen

The renewable electricity generation capacity additionally required is between 8 and 519 GW.
Depending on the choice of renewable energy sources, 10 to 519 GW of PV generating capacity or 8 to 195 GW of onshore wind generating capacity will be needed.

Hydrogen production costs

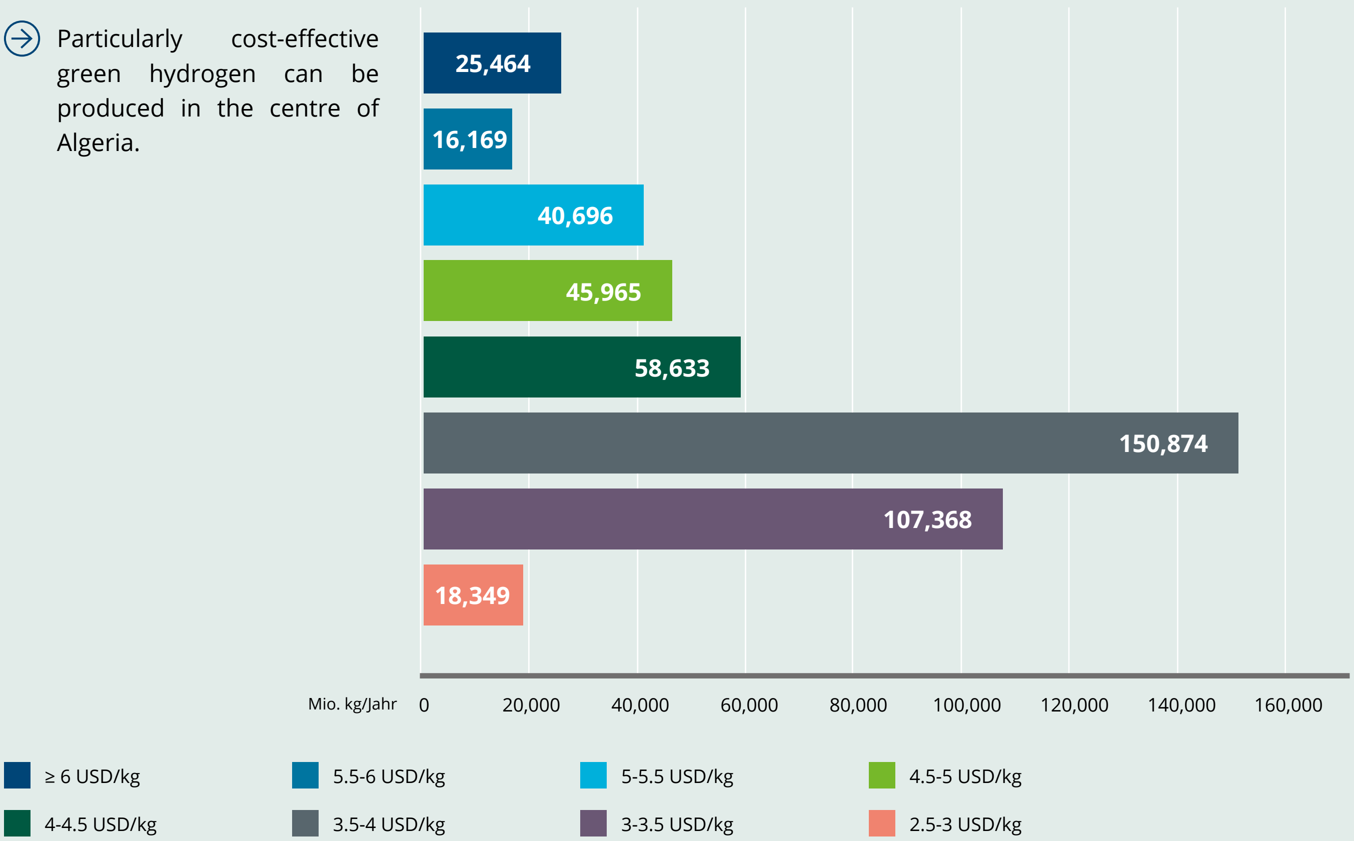
Annual hydrogen production of different LCOH levels (PV) up to 2030

The south-eastern and western parts of Algeria are particularly suitable for cost-effective PV-based hydrogen production.
However, the general cost of PV-based hydrogen production will remain below USD 5/kg in many parts of Algeria.



Annual hydrogen production of different LCOH levels (onshore wind) up to 2030

Particularly cost-effective green hydrogen can be produced in the centre of Algeria.



Source of all data: Tractebel 2021

Cost of hydrogen production (LCOH)

- The expected LCOH fluctuates between USD 2.50/kg and USD 5.40/kg for industrial-scale applications.
- The cost of hydrogen production from onshore wind energy is (on average) around USD 1/kg lower than from photovoltaics.
- The most important cost components are renewable energy (29-65% of LCOH) and electrolysis (21-65% LCOH).
- The transport cost of hydrogen pipelines (renovation and new construction) is between USD 0.17/kg (local supply) and USD 0.7/kg (export).
- The cost of maritime transport is between USD 0.02/kg (local supply) and USD 0.07/kg (export). For long distances the cost of transporting hydrogen is twice the cost of desalination based on the LCOH.
- Desalination and hydrogen transport together account for less than USD 0.2/kg of the LCOH.

Source: Tractebel 2021

Water supply

The investment cost of producing pure water accounts for only a few per cent of the total investment cost of an electrolysis-based facility for the generation of green hydrogen; the impact on the standardised cost of hydrogen generation (LCOE) is also very low.

Water desalination

The cost of desalination in Algeria is between USD 0.62 and USD 1.11/m^3. The additional need for (tap) water required for hydrogen production is between 5 and 279 million m^3/year.

Source: Tractebel 2021

Local and international demand for green hydrogen and its derivatives

Green hydrogen in Algeria: demand and required capacity

Hydrogen demand
- The potential domestic demand in Algeria (118-285 TWh) is low compared with the potential export demand (481-665 TWh).
- For industrial-scale usage, potential hydrogen demand varies between 85 and 665 TWh/year.

Electrolysis capacity
- The required electrolysis capacity varies between 8 and 519 GW depending on the renewable source.
- At least 8 GW of electrolysis capacity is required for the partial decarbonisation of existing domestic industries (ammonia production).

Land use
- The total land area needed for hydrogen production (renewable energy + electrolysis) is estimated at 0.1 to 1.2 million hectares.
- The specific land use of onshore wind-based hydrogen supply chains is higher than that of PV-based supply chains.
- The specific land use per annual hydrogen production amounts to around 490-1200 km2/TWh for onshore wind energy and 70-100 km2/TWh for photovoltaic solar energy.

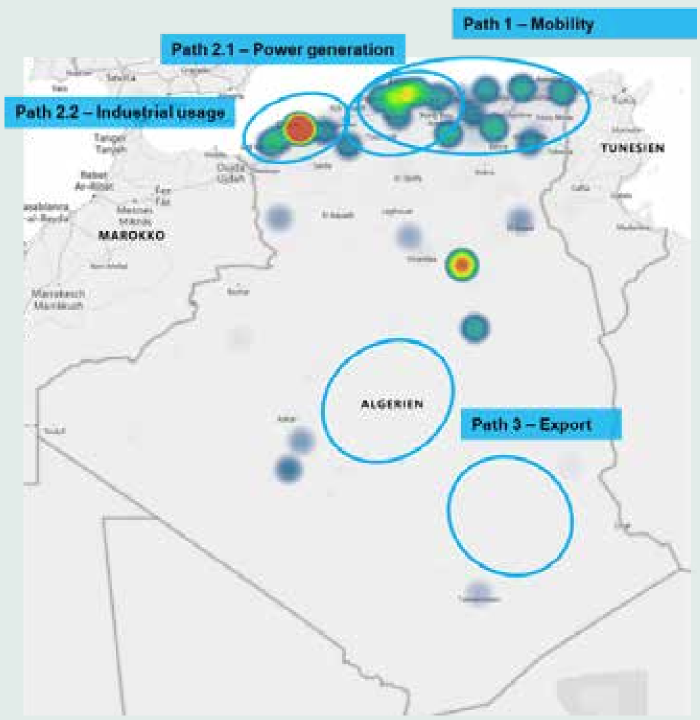
Medium- to long-term areas of application:
1. The country has experience in particular in the production of ammonia, methanol and petrochemicals, and in refining. Algeria has high petroleum reserves that are processed in oil refineries. The clean production of hydrogen is a key prerequisite for substantially reducing emissions from refinery operations.
2. Electricity generation: 100% conversion of natural gas to green hydrogen
3. Mobility (buses, trucks): green hydrogen and synthetic fuels based on green hydrogen are especially well-suited for aviation, sea transport, rail transport and heavy-load vehicles such as buses and trucks.

Potential green hydrogen demand of selected industry locations

Demand is greatest in the north, while the south has great potential for hydrogen production.

Hydrogen demand (100% conversion) (t/year)

1,700 — 327,332

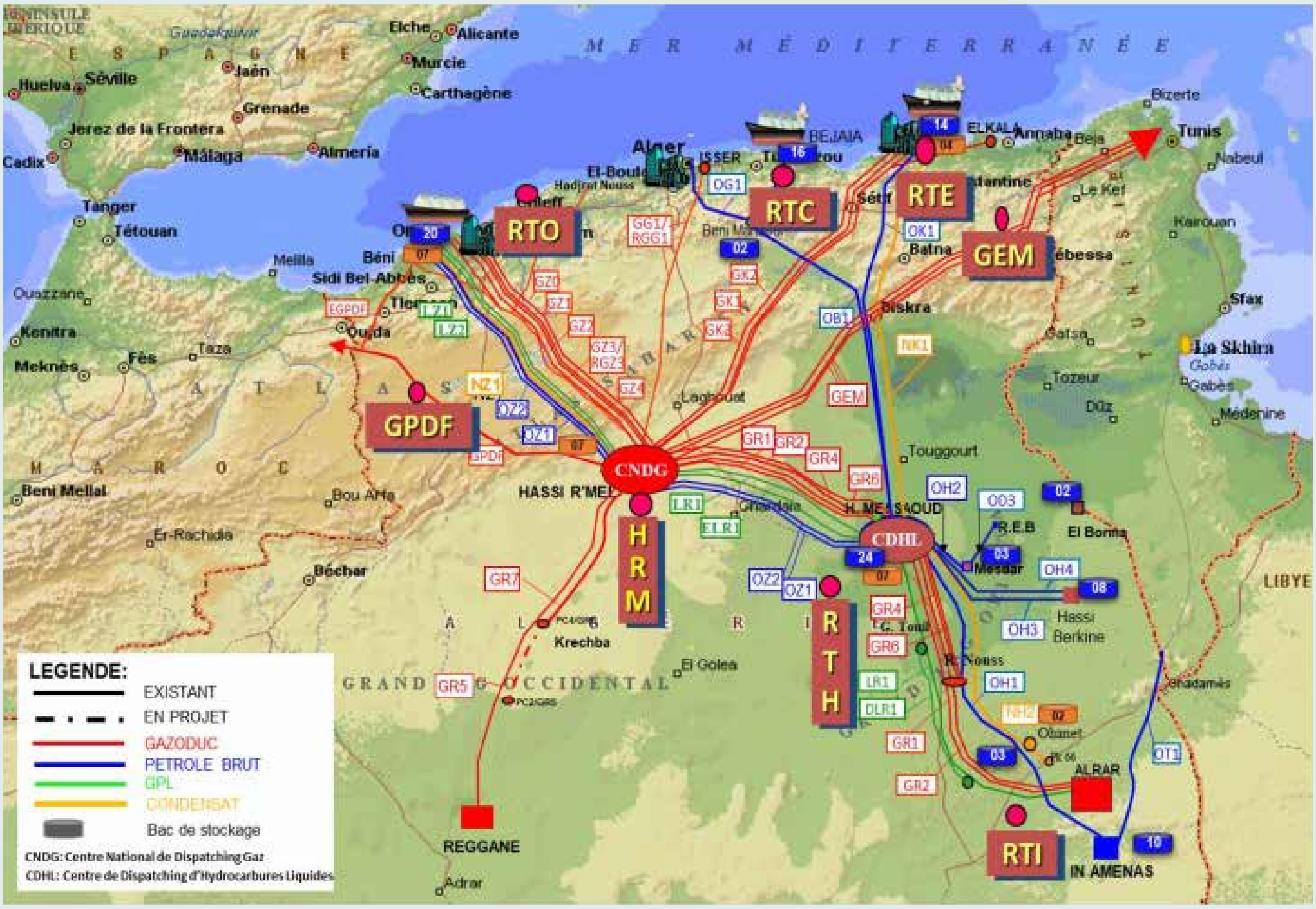


Source of all graphics: and data: Tractebel 2021

Hydrogen transport

Existing infrastructure

Transport network



Sources: Algerian Ministry of Energy and Mining, Sonatrach 2021

The gas pipeline network grew from 6,105 km in 2005 to 19,258 km in 2016 and will increase to 27,291 km by 2027. In 2021 the gas pipeline network measured 20,705 km and had a total capacity of 404,342 mtpa (million tonnes per annum).

Natural gas networks in Northern Africa

There are currently three gas pipelines from Algeria to Europe. A fourth pipeline, to Nigeria, is under construction.

Algeria has two LNG terminals in the cities of Arzew and Skikda on the Mediterranean coast.

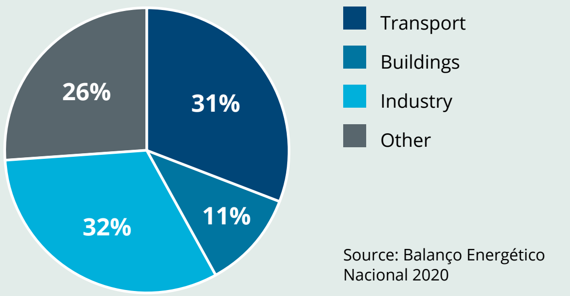
Pipelines	Enrico-Mattei gas pipeline	Duran-Farell gas pipeline	Medgaz (west)	Galsi (east)
Network	Algeria-Italy via Tunisia and Sicily	Algeria-Spain via Morocco	Hassi R'mel, Beni Saf (Algeria) Et Almeria (Spain)	Hassi R'mel, ElKala (Algeria), Cagliari, Olbia (Sardinia) and CD Pecaia (Italy)
Length	550 km	716 km	747 km	1,470 km
Capacity	25 Gm^3/year	12 Gm^3/year	8-10 Gm^3/year	8-10 Gm^3/year (NG)

Source of all graphics and data: Tractebel 2021

Brazil

Energy data

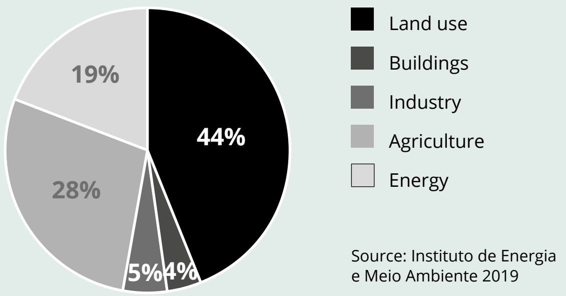
Energy consumption by sector



Source: Balanço Energético Nacional 2020

Industry and transport are responsible for around 65% of energy consumption.

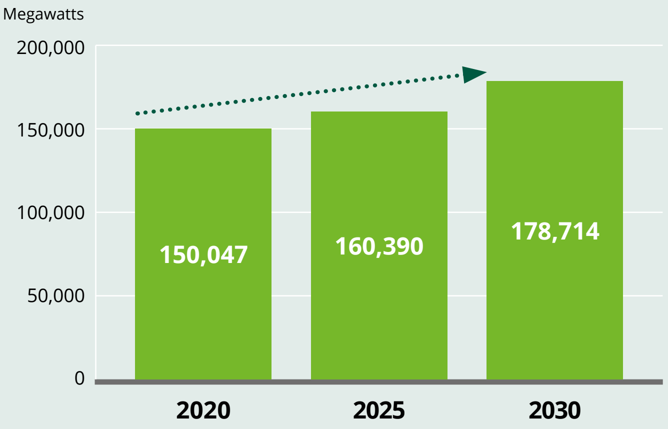
Carbon emissions by sector



Source: Instituto de Energia e Meio Ambiente 2019

Nearly half the carbon emissions are attributed to land use. Brazil aims to achieve climate neutrality by 2050.

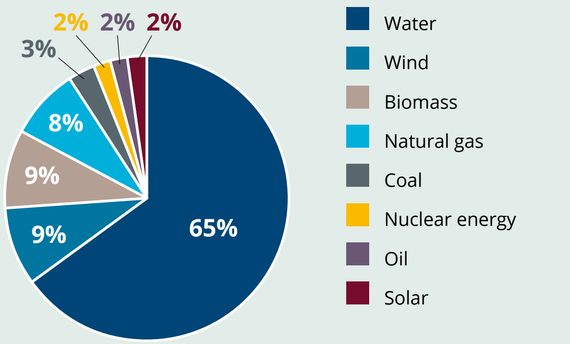
Installed and planned renewable energy capacity



Source: Ministério de Minas e Energia/Empresa de Pesquisa Energética 2021

Expanding the share of renewables is part of Brazil's long-term energy planning. The country is a global pioneer and its share of renewables in the energy mix (45.3%) is well above the OECD average (10.6%).

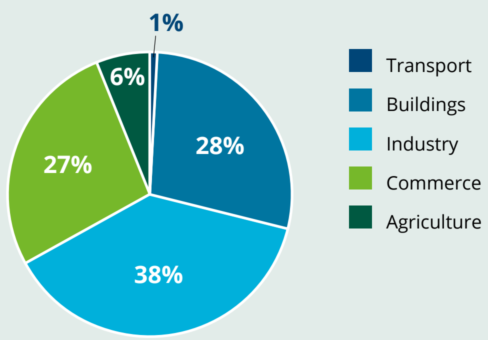
Power generation by energy source



Source: Empresa de Pesquisa Energética 2021

The share of renewable energy in the power mix is a high 85%.

Power consumption by sector



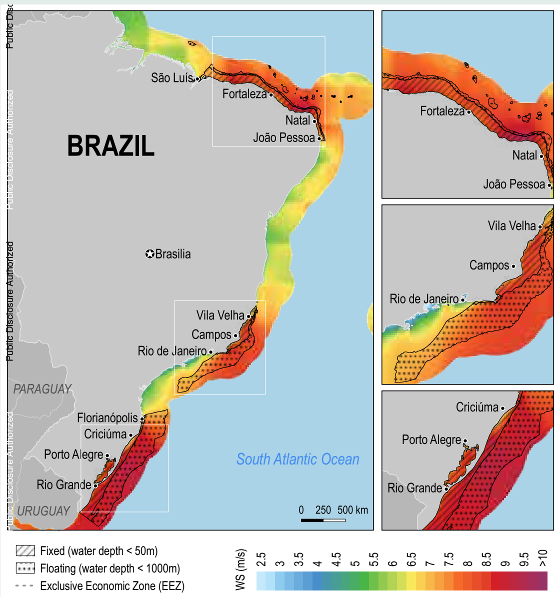
Source: IEA 2019

The industrial sector accounts for greatest share of total electricity consumption.

Renewable energy potential

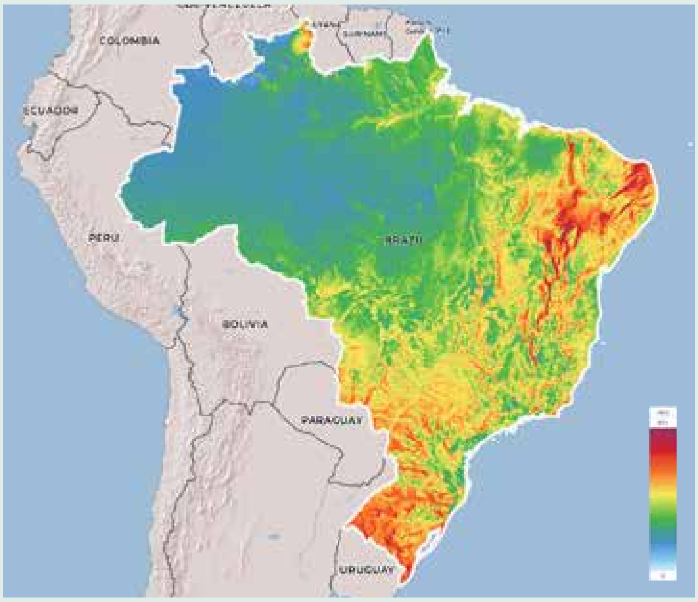
Production conditions for green hydrogen and its derivatives

Wind speeds: Offshore



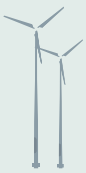
Source: Global Wind Atlas 2021

Wind speeds: Onshore



WIND

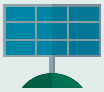
Wind potential: 721 TWh/year
Wind speed in the windiest area at an altitude of 100 m: 7.02 m/s



The north-east region of Brazil offers ideal conditions for hydrogen production due to its high solar irradiation and wind potential.

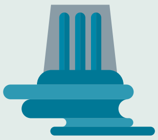
SOLAR

Solar energy potential: 65 TWh/year
Average solar irradiation (theoretical): 5.39 kWh/m²/day



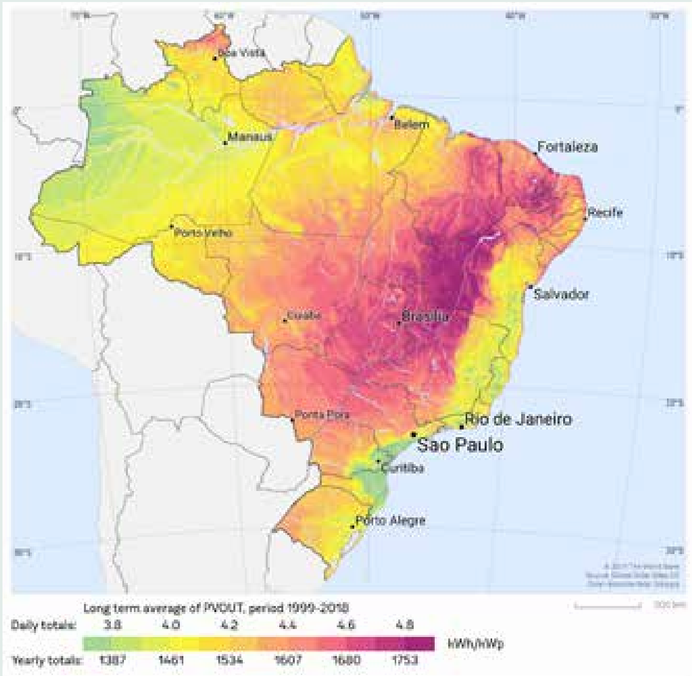
WATER

Hydropower potential: 172 GW



Sources: Empresa de Pesquisa Energética (EPE), Fundação Estadual do Meio Ambiente 2014, Global Wind Atlas 2021, Solargis 2021

Solar energy potential



Source: Solargis 2021

Hydrogen potential

Green hydrogen strategy

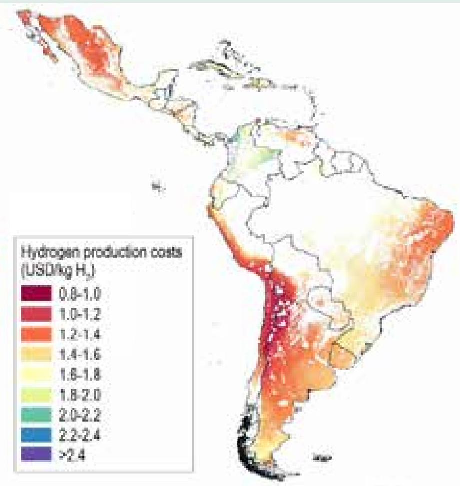
2005	Already in **2005**, the Brazilian Ministry of Mines and Energy (MME) coordinated its first Roadmap for the Structuring of the Hydrogen Economy in Brazil. The roadmap focused on the use of hydrogen in industry and included hydrogen production from renewable energy.
2020	In the National Energy Plan 2050 (PNE 2050) of **December 2020**, hydrogen is described as a disruptive technology and mentioned as a strategic element in the context of decarbonisation of the energy matrix and energy storage.
2021	In **late February 2021** the Energy Research Office (EPE) published a working paper on the principles of consolidation for a Brazilian hydrogen strategy that analysed fundamental aspects for a Brazilian hydrogen strategy. The document explicitly mentions the cooperation with Germany and with the German-Brazilian Energy Partnership. In March 2021, the Brazilian National Council for Energy Policy (CNPE) also pointed out that green hydrogen will be one of the priority topics for research and development in the country and announced public support for it. In **June 2021** Brazil submitted to the United Nations an Energy Compact for strengthening research, development and innovation policies for the development of a hydrogen market. In **mid-April 2021** the CNPE resolved to create guidelines for a National Hydrogen Programme. A proposal for the guidelines was published in **August**. It contains a comprehensive vision of the challenges and opportunities of developing a hydrogen industry and a hydrogen market in Brazil. The MME is currently preparing the final version of the hydrogen programme (PNH2), which is to be published in the first half of 2022.

Source: Empresa de Pesquisa Energética (EPE), Ministério de Minas e Energia (MME), Conselho Nacional de Política Energética (CNPE) 2021

Hydrogen production costs

According to a McKinsey study, Brazil is one of the world's most competitive countries for the production of green hydrogen. The study reports that the cost of Brazilian green hydrogen (LCOH) will be around USD 1.50/kg in 2030, which is on a par with that of the top locations in the United States, Australia, Spain and Saudi Arabia.

According to a study by IRENA, green hydrogen in Brazil could already be cheaper than blue hydrogen by 2024.



Sources: IEA 2021, McKinsey & Company 2021, IRENA 2022

Water supply

Brazil has one of the largest supplies of freshwater in the world. But the north-east, the region with the greatest renewable energy potential, has areas which suffer from year-long periods of drought. According to a study by IRENA, Brazil has a low water stress level for the production of green hydrogen. Brazil will most likely also have to rely on the use of desalination plants in some regions.

Sources: GTAI 2020, GIZ 2021, IRENA 2022

Local and international demand for green hydrogen and its derivatives

Local demand

In 2019, most hydrogen production was used for crude oil refineries and around 20% on the basis of ammonia for fertiliser production. However, the fertiliser industry is operating below installed capacity, so that in 2019 capacity underutilisation necessitated the import of fertiliser to meet the needs of the agricultural sector.
According to the International Energy Agency (IEA), demand for hydrogen in Brazil amounts to 0.4 Mt/year. Demand for hydrogen is also expected to increase in the chemical, iron and steel industries and in mobility, aviation and heavy goods transport.
Brazil has a national ethanol production and distribution infrastructure. At present, specific research projects are under way for producing hydrogen from ethanol and developing alternative drive systems for mobility based on ethanol fuel cells.

Source: IEA 2021

Selection of current and planned pilot (projects):

- University of Rio de Janeiro: production of hydrogen-powered buses, prototype production to be launched in early 2022.
- The University of Itajubá (UNIFEI) in Minas Gerais has plans to build a pilot plant for the production of green hydrogen for applied research with industry partners. The pilot project provides for the installation of an electrolyser with an output of 1 MW. The unit is to be powered with electricity from a PV plant already installed on the campus. The hydrogen is to be used in the metropolitan buses in Itajubá.
- The city of Fortaleza (population 2.7 million) has announced that it would use city buses that run on green hydrogen via fuel cell technology in future. The federal state of Ceará and Neoenergía, which belongs to the Spanish Iberdrola Group, signed a Memorandum of Understanding to this end.
- Furnas project: in December 2021 the first Furnas pilot plant for the production of green hydrogen was inaugurated at the Itumbiara hydropower plant. This is a research and development project of the Brazilian electricity regulator Aneel with the participation of SMA and the University of Braunschweig. It aims to develop energy storage units for lithium and green hydrogen batteries using solar energy (1,000 kWp).
- The fertiliser producer Unigel plans to produce green hydrogen starting in 2023. The plant in the federal state of Bahia aims to achieve a production capacity of 200,000 tonnes per year, which will require 300 MW of energy.
- Hytron and EDP: in early September 2021 the Portuguese energy company EDP announced R$ 41.9 million (around EUR 7 million) in investment for a production site of 250 Nm3/h of green hydrogen in the industrial complex of the port of Pecém. The company Hytron, which had just been acquired by the Neuman & Esser Group at the end of 2020, was awarded the contract for a 1.3 MW electrolyser powered by solar and wind electricity. The green hydrogen produced in this way is to reduce the emissions from a coal-fired power plant operated by EDP.

International demand

Brazil is a highly sought-after location for foreign enterprises. Some 1,300 German companies, in particular, have settled in Brazil.

- High presence of companies along the hydrogen value chain: Linde, Messer, MAN, Siemens, Thyssen-Krupp, etc.
- 95% of the members of the Global Hydrogen Council have subsidiaries in Brazil.
- The proximity and good connection to Europe make Brazil a promising hydrogen location for the future. The Brazilian port infrastructure and logistics are conducive to exporting hydrogen.
- Memoranda of understanding for hydrogen projects in Brazil amounted to USD 22 billion already in mid-2021.

Source: H_2 Bulletin 2021

Hydrogen transport

Existing infrastructure

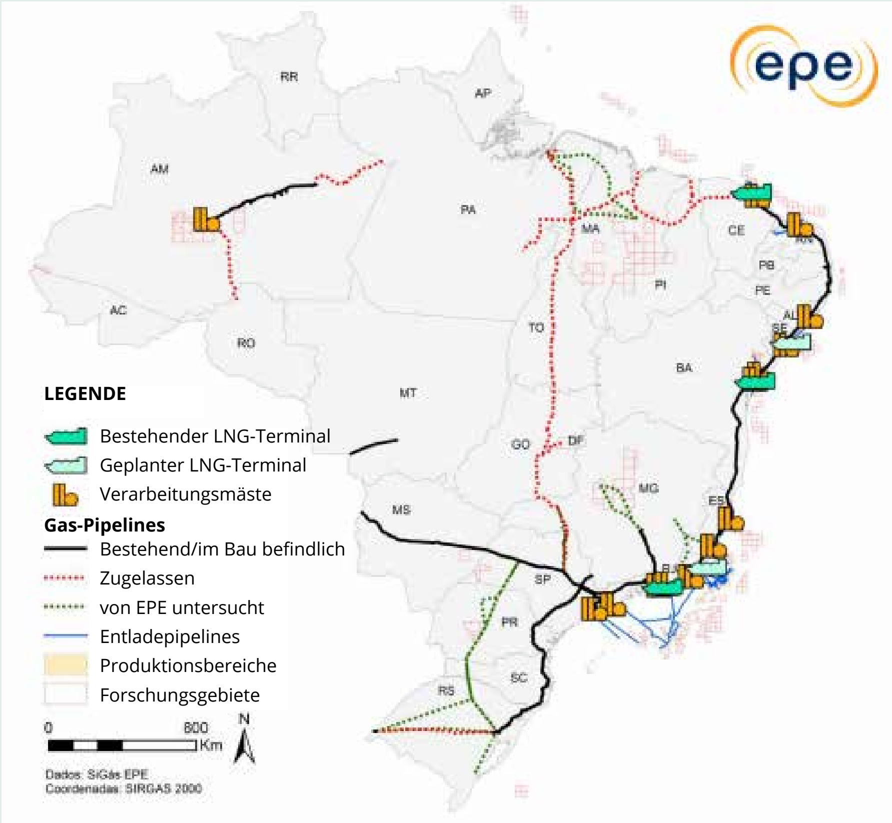
Gas grid

The Brazilian gas grid extends mainly along the Brazilian coastal region from the federal state of Ceará to Rio Grande do Sul. In the Amazon region a natural gas pipeline has also existed since 2009, connecting Urucu with Manaus. The natural gas grid is being continuously expanded.

Source: EIA 2021

Electricity grid infrastructure

Brazil has an extensive and integrated electricity grid that connects large parts of the country. The 85% share of renewables in electricity generation means that renewable electricity generation and hydrogen production can be separated geographically while still allowing for low-carbon hydrogen to be produced.



Source: Empresa de Pesquisa Energética 2019

Important ports for hydrogen export

Ports play a major role for green hydrogen. In Brazil, 36 ports are publicly operated. The country also has private ports, and its inland ports are also relevant for the local market.

Porto de Peçém (federal state of Ceará in the north-east of Brazil)

- The Port of Rotterdam Authority has a 30% stake in the port.
- Very favourable location for export to Europe and keen interest in PtX export.
- Certified for hydrogen handling, extensive complex including a hub for hydrogen diverse industries.

Porto de Açu (federal state of Rio de Janeiro)

- 98% of the port belongs to Prumo, a logistics company, partnership with the port of Antwerp.
- Keen interest in PtX export.

Porto Suape (federal state of Pernambuco)

- Ideal location thanks to good strategic location for terminals, logistics, services and industry for the international hydrogen market.

Porto Central (federal state of Espírito Santo)

- A port which is under construction, with plans to export PtX and host strategic business sectors such as oil and gas, energy generation, agriculture, mining, etc.
- Porto Central is being developed as a new deep water multi-purpose industrial port complex with access to motorways, future railway lines and other types of infrastructure.

Porto Santos (federal state of São Paulo)

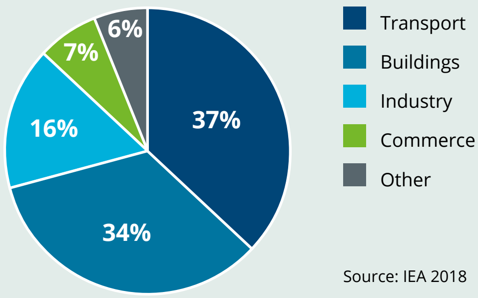
- Brazil's largest industrial port
- Structure and certification for ammonia import and export

Sources: Argusmedia 2021, Neoenergía 2021, bnamericas 2021, Porto do Açu 2021, AmmPower 2021

Chile

Energy data

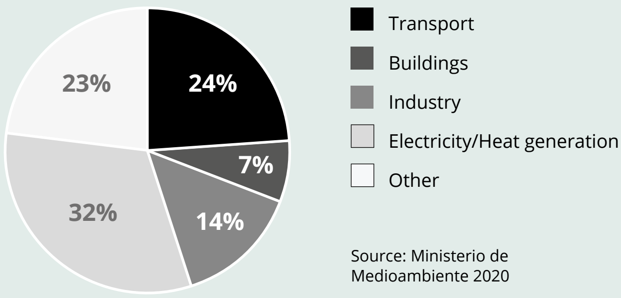
Energy consumption by sector



Source: IEA 2018

Industry (including mining) and transport are responsible for 70% of energy consumption.

Carbon emissions by sector

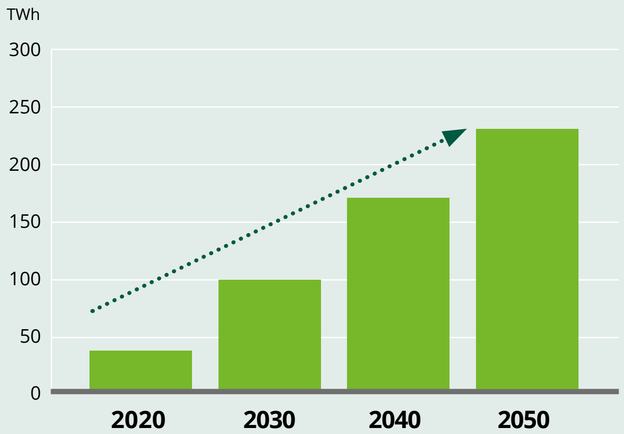


Source: Ministerio de Medioambiente 2020

In Chile the energy sector is responsible for 78% of carbon emissions.

Installed and planned solar, wind and hydropower capacity

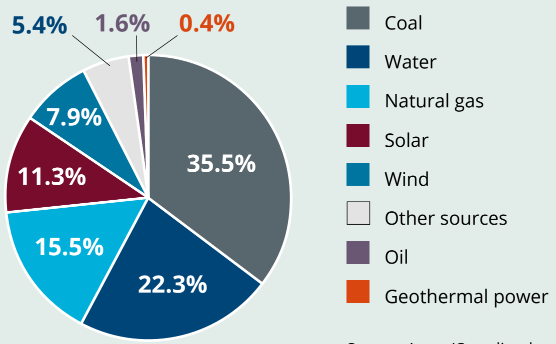
Planned electricity generation up to carbon neutrality



Source: Ministerio de Medioambiente 2021

Chile aims for the electricity mix to be based on around 70% renewables by 2030 and for climate neutrality to be reached by 2050.

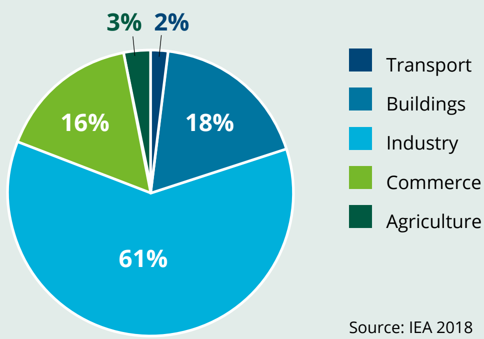
Power generation by energy source



Source: Acera/Coordinador Eléctrico Nacional/Generadoras de Chile 2021

In 2020-2021, fossil sources accounted for around 55% of the electricity mix, and renewable energy made up 45% of the electricity mix (including large-scale hydropower).

Power consumption by sector



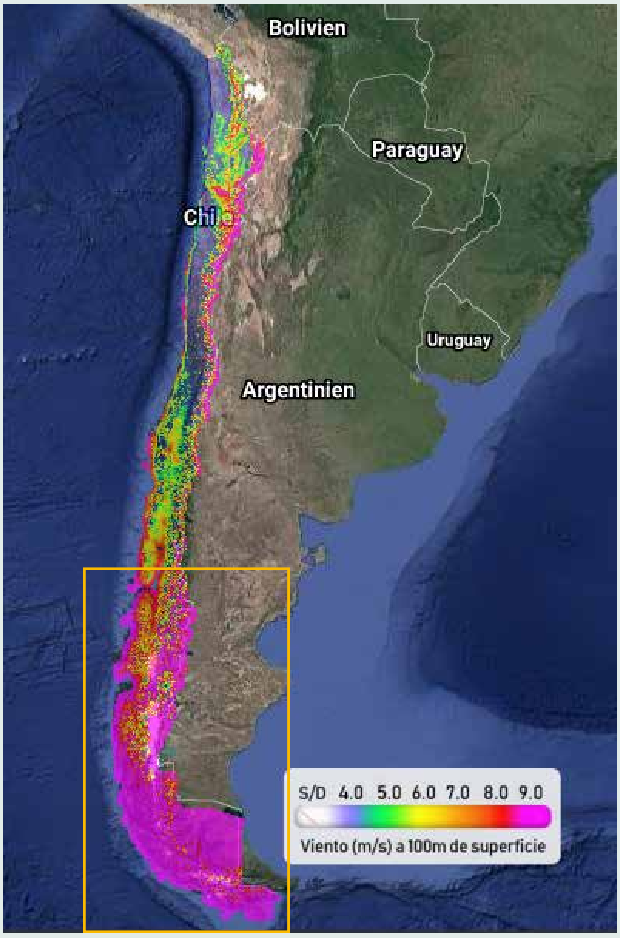
Source: IEA 2018

The industrial sector consumes over two thirds of total electricity.

Renewable energy potential

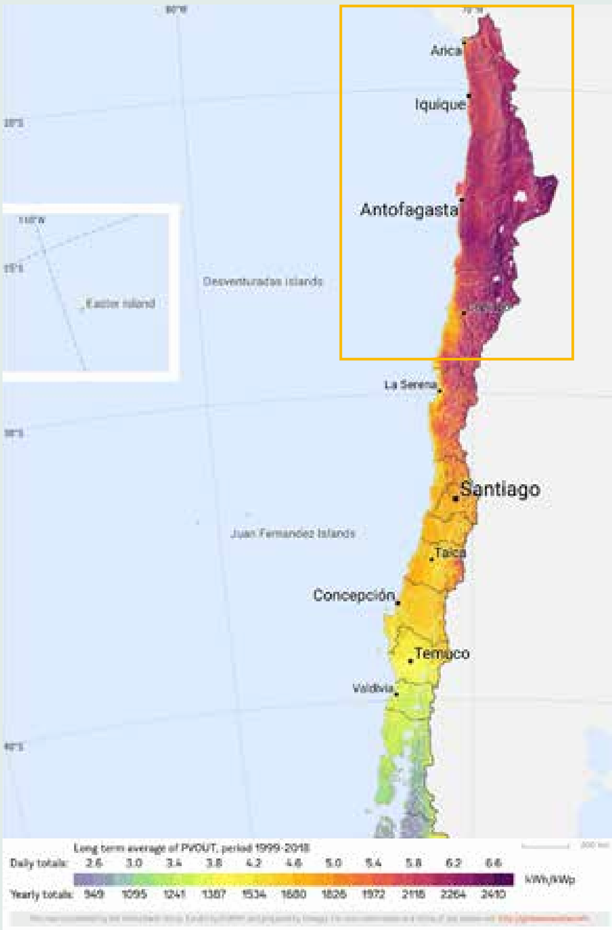
Production conditions for green hydrogen and its derivatives

Wind speeds



Source: Ministerio de Energía 2021

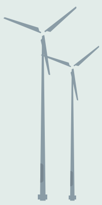
Solar irradiance



Source: Global Solar Atlas 2019

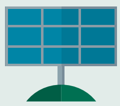
WIND

Wind speed: **avg. 7.3 m/s**
At locations in the south of Chile, wind speeds reach >14 m/s, > 60% full load



SOLAR

Solar energy potential: **avg. 5.36 kWh/kWp**
Solar irradiance:
>7.5 kWh/m²/day in the Atacama desert is the highest worldwide!



→ Worldwide, the strongest direct solar irradiance can be found in the north of Chile. Patagonia in the south is known for its outstanding wind potential.

Additionality of renewable energy for hydrogen production

With the renewable energy projects currently being introduced by private project developers, renewable energy generation capacity of up to 67 GW can be installed in the coming years, far more than the current installed capacity of the Chilean energy system of slightly more than 27 GW. Even if all coal capacities are phased out (currently still 4.9 GW installed capacity), sufficient surplus renewable energy generation units are available for hydrogen production, for meeting local needs and for the export market. According to GIZ calculations, hydrogen production in 2030, 2040 and 2050 will require installed capacity of 9.59 GW and 98 GW of wind and solar energy, respectively. In line with the ambitious long-term energy planning model PELP, electricity generation will increase four-fold by 2050, with around half of the energy generated (150 TWh) available for hydrogen production.

Source: GIZ, Ministerio de Energía (PELP) 2021, CNE 2021

In August **2021, 145 renewable energy projects** with a total capacity of **4,733 MW** were under construction, of which **71%** were solar (PV) systems and 25% were wind farms.

Source: CNE, Chile 2021

Already in **2019**, the Chilean coal commission from the private sector and policymakers set out its path for phasing out coal for power generation. **Five coal-fired power plants were removed from the grid by August 2021. By 2025, 65% of the coal-fired power plants are to be shut down** and wherever possible, converted to other uses, for example energy storage. The challenges for the energy transition include further expanding the transmission grid, the declining output of hydroelectric power plants as a result of climate change, and maintaining grid security. **Establishing appropriate energy storage capacity and starting up the first CSP plant with base-load capacity** in the Atacama Desert will aim to address these challenges.

Source: GIZ, Chile 2020

Electricity generation from solar and wind energy has **increased five-fold** in the past six years in Chile. By **2030**, at least **70%** of the energy mix will be able to be provided by renewables. Chile plans to **achieve climate neutrality by 2050 at the latest**. The use of 'green' hydrogen is to account for **24%** of the mix. Chile is thus strengthening its resolve to continue its path towards achieving a climate-friendly energy transition.

Source: Ministerio de Energía (PELP)/GIZ, 2021

Chile's renewable energy potential is **80 times greater** than the currently installed capacity. **5,000 TWh/year is possible**.

Source: Ministerio de Energía/GIZ 2021

In August 2021, **16,680 MW of renewable energy generation capacity** was installed (including large-scale hydropower). That amounts to **56%** of the power plant fleet.

Source: Acera, Chile 2021

In the most recent technology-neutral tenders of August **2021**, an average of **USD 23.78/Mwh was offered for 15-year PPAs**. The lowest offers for a combination of photovoltaic solar generation and storage were below **USD 15/MWh**.

Source: Ministerio de Energía 2021

Hydrogen potential

Hydrogen roadmap

The National Green Hydrogen Strategy has been under implementation in Chile since November 2019. The development of hydrogen production in Chile is planned to take place in three phases:

2019–2025

5 GW electrolysis capacity in operation

- The focus is on the local green hydrogen industry in order to accelerate production of green hydrogen. This primarily involves developing know-how, providing infrastructures and securing funding. These activities will aim to ensure that the course is set for successful export to third countries.

2025–2030

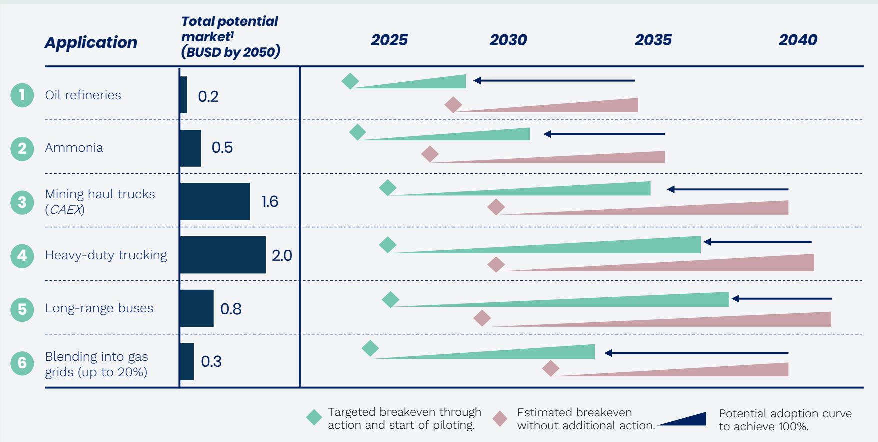
Production of the world's cheapest green hydrogen and 25 GW electrolysis capacity

- A number of exports are to be introduced. In particular, green ammonia is to be exported to Europe and parts of Asia. Funding is also to be secured for the long term.

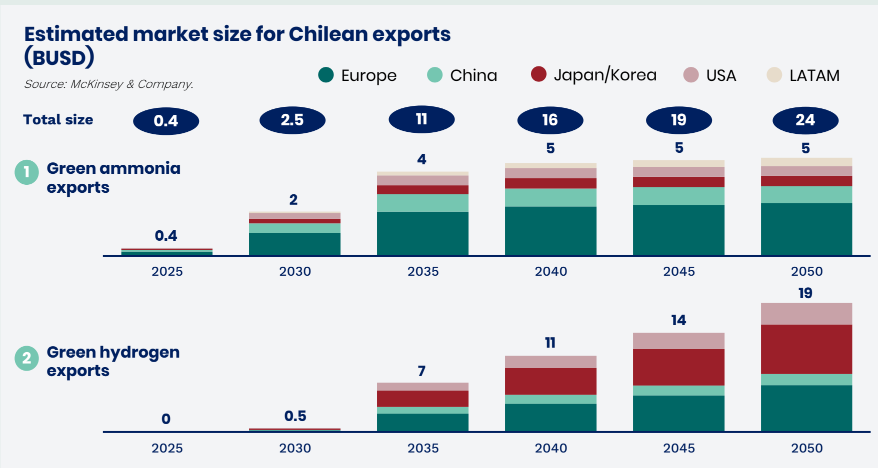
2030–2040

Top 3 of the main exporters of green hydrogen

- While green ammonia continues to be the top export, a large market for green hydrogen is already planned in the importing countries from 2035.



1. Annual sales. Considers the full transition to hydrogen of the energy demand in each application.
Source: Based in analyses from McKinsey & Company.



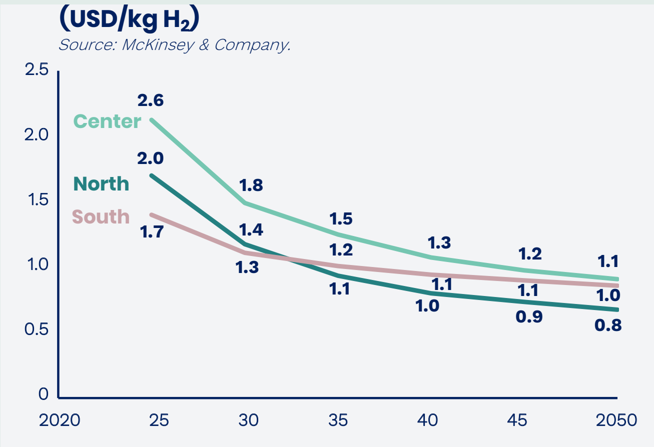
Source: Ministerio de Energía, Chile 2019

Production costs

Levelised cost of green hydrogen (LCOH)

The current cost of green hydrogen production is USD 4-4.50/kg. However, it is predicted that it could drop to USD 2.50 to 1.50 by 2030. To put this in perspective: a production cost of USD 1.50/kg makes green hydrogen competitive with grey hydrogen from natural gas. Achieving a production cost of USD 1/kg would make green hydrogen competitive with natural gas as fuel.

Goal: Chile aims to produce the world's most cost-effective green hydrogen.



Source: Ministerio de Energía, Chile 2019

Water supply

Central and northern Chile are basically desert and semi-desert regions. Climate change is also leading to a further reduction in rainfall. However, relatively little water is required for the production of green hydrogen, and the cost of hydrogen accounts for around 2% of the total hydrogen production cost. Nearly all of the hydrogen projects now being planned will obtain their water from seawater desalination plants.

Desalination plants

Chile already has 83 desalination plants of various sizes and capacities (most of them for seawater). Nearly 30 more plants are currently in planning or under construction. Demand for desalination plants is already very high, which means that the production of green hydrogen can be integrated without any problem. The new seawater desalination projects are designed first and foremost to serve to supply the local population but are also intended to secure the supply of water for agriculture and mining.

Source: Ministerio de Energía, Chile 2019

Local and international demand for green hydrogen and its derivatives

National demand

Green hydrogen

In Chile there is demand in oil refineries, especially for hydrocracking and desulphurisation. Green hydrogen is also used in the food industry for the hydration of fats, as well as in the glass industry. The cooling of thermoelectric turbines can also benefit from green hydrogen.
In future the decarbonisation of the mining sector will be advanced through the use of green hydrogen, particularly in transport applications (fuel cells, synthetic fuels).

Ammonia

Demand for green ammonia is especially high as fertiliser in agriculture, for making explosives in mining, as ammonium nitrate and for coolants.

Methanol

The cement and other industries have expressed interest in supplying inevitable carbon emissions for synthetic fuels.

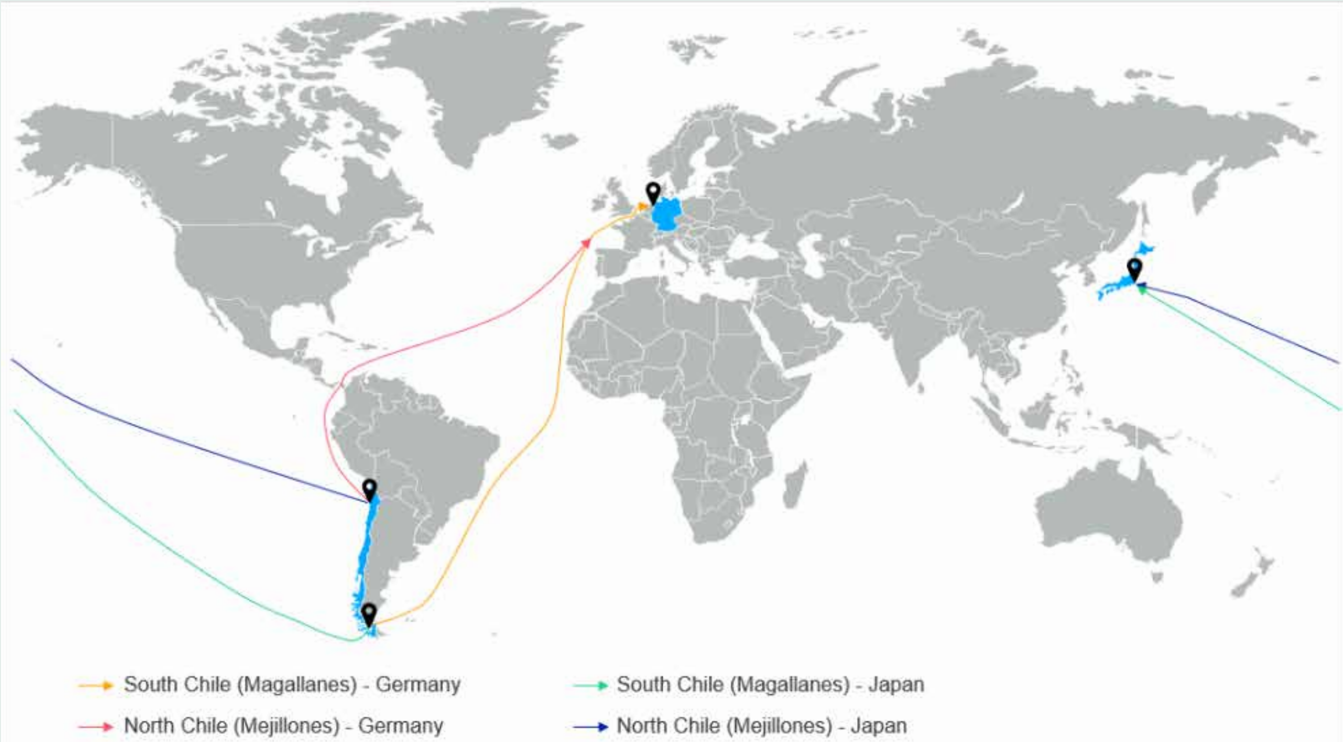
Key areas of demand

Oil refineries, ammonia production, mining haul trucks, heavy load trucking, long-distance buses, feeding into existing gas networks, as well as other industrial applications. Demand for green hydrogen is high among oil refineries alone; today's market requires 58,500 tonnes of hydrogen per year, 99% of which is consumed by the oil industry.

Sources: Ministerio de Energía in cooperation with the Comité solar e innovación ener-gética, Chile 2019 and Ministerio de Energía in cooperation with GIZ, Chile 2019

Hydrogen transport

Example of export routes to Europe and Japan



Source: Ministerio de Energía In cooperation with GIZ 2021

Export and export costs

Shipping hydrogen derivatives such as methanol and ammonia is currently more cost-effective than transporting green hydrogen. In general, the cost of transporting green ammonia or methanol accounts for around 5% of the cost of the end product.
Climate-neutral ship propulsion technologies (powered by ammonia, methanol or direct hydrogen) are still under development. Shipping to Germany/the EU is somewhat more cost-effective than to Japan.
Transport synergies can be used by transporting chemicals on the return trip to Chile in order to guarantee efficiency and reduce long-term transport costs. In 2018, around 16% of chemical imports came from Germany, which is why there is a potential market in this sector.

Source: GIZ 2021

Potential (liquefied natural gas) terminals and ports in Chile

In the north:
- LNG Mejillones S.S Terminal Puerto Angamos: four available ports for various types of goods ENAEX uses the port for importing ammonia

In central Chile:
- LNG Quintero in the Valparaíso region can be developed in future
- Talcahuano (BíoBío region)

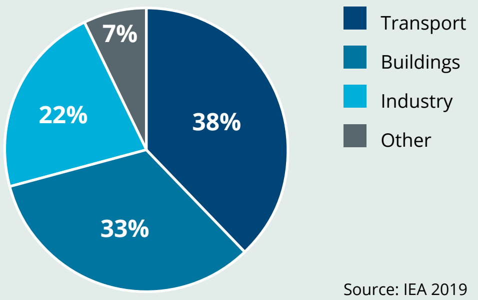
In the south:
- Cabo Negro terminal: has the infrastructure required to handle propane, butane, diesel and petrol and can also ship green hydrogen out of the country across the Pacific or the Atlantic. In addition, METHANEX, a methane production company, has a nearby site with possible capacities for interim storage.
- Additional ports are under development.

Source: GIZ 2021

Morocco

Energy data

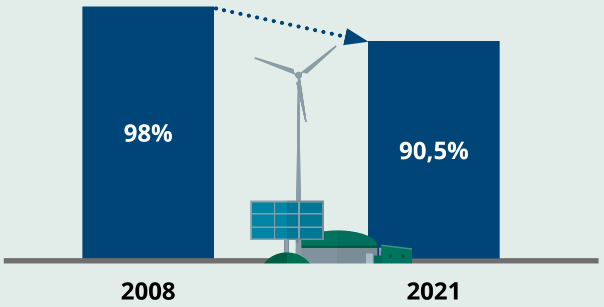
Energy consumption by sector



Source: IEA 2019

More than 60% of total energy consumption in Morocco is attributed to the transport and industry sectors.

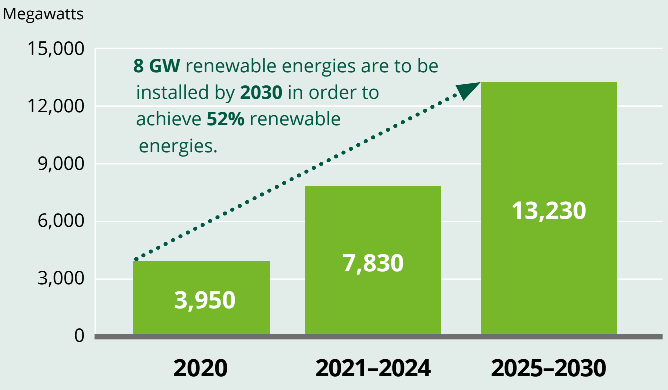
Energy dependency rate in 2021



Source: IEA 2021

Morocco is pursuing an ambitious programme to reduce its dependency on imports of fossil energy.

Installed solar and wind energy capacity

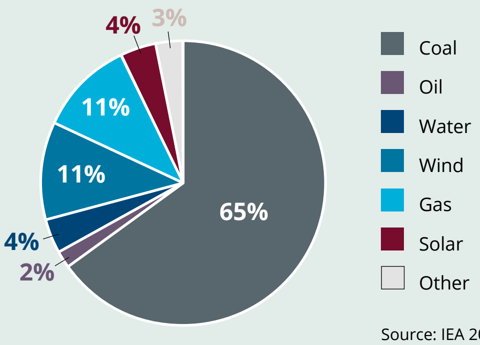


Source: Ministry of Energy, Mines, and Sustainable Development 2021

The installed solar, wind and hydropower capacity is currently 37% and is planned to grow to at least 52% by 2030.

Large-scale renewable energy projects are enabling Morocco to rapidly expand its share of renewables by 20% of the energy mix compared with 2009. This expansion has been the fastest in the region to date.

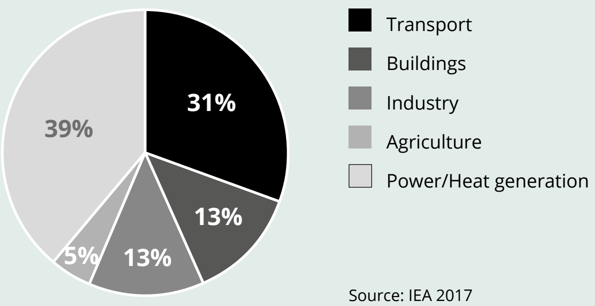
Power generation by energy source



Source: IEA 2018

Renewables account for around 20% of the electricity generation mix. The majority of electricity generation is coal-based.

Carbon emissions by sector



Source: IEA 2017

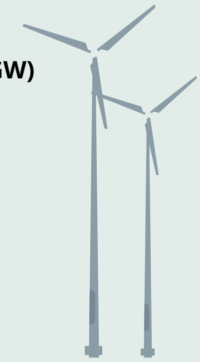
Carbon emissions in Morocco amount to nearly 60 million tonnes (2017) and are based mainly on petroleum products.

Renewable energy potential

Production conditions for green hydrogen and its derivatives

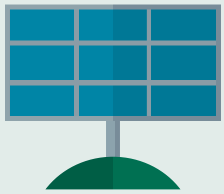
WIND

Wind potential: 5,000 TWh/Jahr (1,250 GW)
Wind speeds: avg. 9 m/s, onshore
avg. 10–11 m/s, offshore



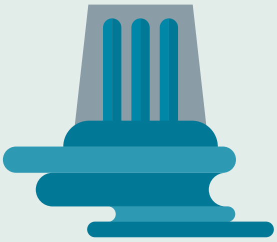
SOLAR

Solar energy potential: 40,000 TWh/Jahr (17,000 GW)
Solar irradiance: avg. 5 kWh/m²/day



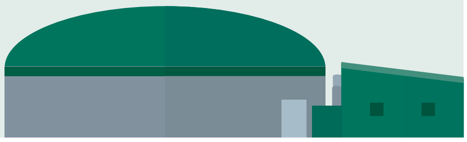
WATER

Hydropower potential: > avg. 5,000 GWh/year



BIOMASS

avg. 11.5 (MWh/year)



Hydrogen potential

Morocco's green hydrogen strategy

The Moroccan green hydrogen strategy was published in November 2021. The German-Moroccan Energy Partnership (PAREMA) closely supported the content of the strategy with a key study and ongoing advice. The German-Moroccan Hydrogen Alliance was founded in 2020.

The flanking studies are already showing great potential for green hydrogen. Morocco could meet around 2-4% of the global Power-to-X (PtX) demand (972-6,180 TWh, Fraunhofer ISE 2019) by 2030. To reach this goal, an additional 9 GW of renewable energy would be required.

There is a new trend towards standalone projects, which provide for direct provision of hydrogen production through renewables. Two European developers are currently planning to develop projects with 20 GW of solar energy capacity.

Three pillars:

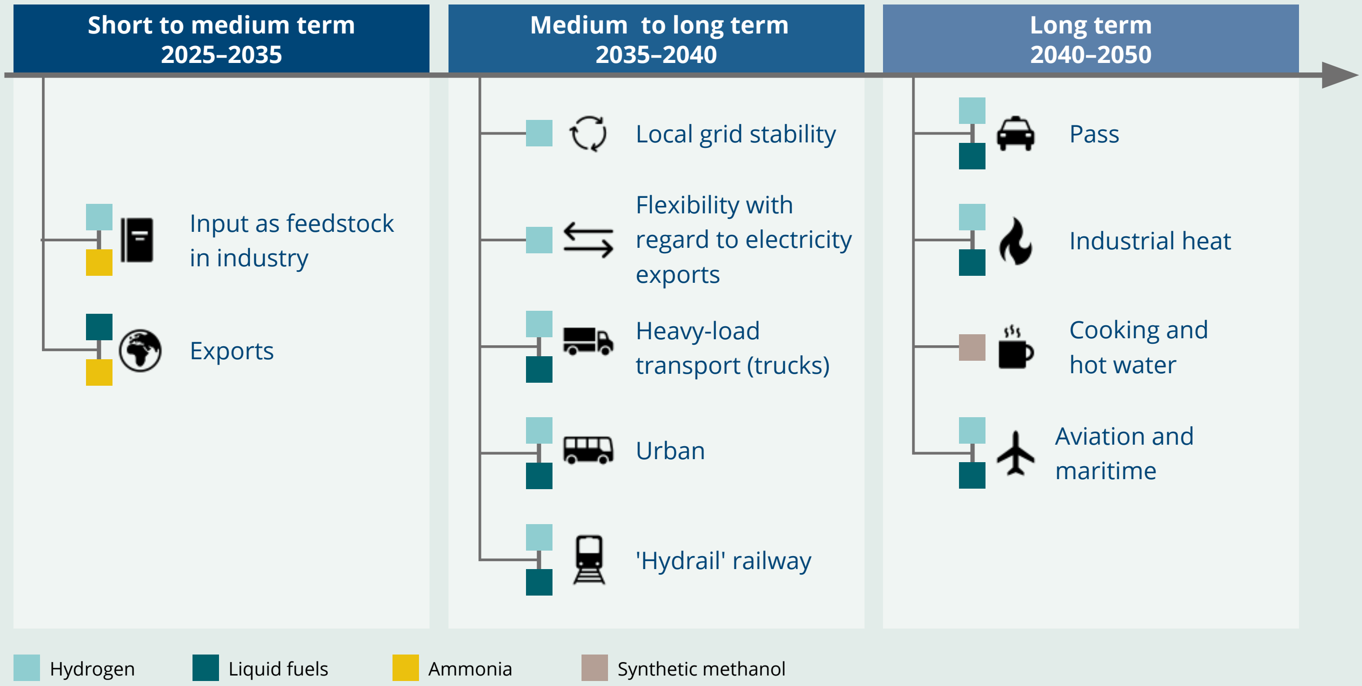
- **Technologies**, including technological developments and cost savings
- **Investments and supply**, including setting up an industry cluster and developing an appropriate infrastructure master plan
- **Markets and demand** are related to the realisation of demand opportunities that lead to new markets

Action plan up to 2050:

1. **Reducing costs** along the value chain
2. **R&D:** Developing **a Moroccan** and **regional research cluster**
3. Measures for **local industrial integration** (human capital, know-how)
4. Developing an industrial cluster and an **infrastructure master plan**
5. **Securing funding** by strengthening international cooperation
6. Creating favourable conditions for **export** (especially to the EU)
7. Developing a national **storage plan**
8. Developing a **national market**

Short-term 2020–2030	Medium term 2030–2040	Long term 2040–2050
• Local use of green hydrogen as feedstock in industry • Export of green hydrogen products • Exploring natural hydrogen storage locations	• Developing initial economically viable projects • Exporting synthetic liquid fuels • Green hydrogen as energy storage	• Increased production capacity for the export of green ammonia, hydrogen and synthetic fuels • Local use of green hydrogen in industry, for generating heat, in residential buildings, in urban mobility and in aviation

Green hydrogen production capacities and LCOE for green hydrogen and its derivatives



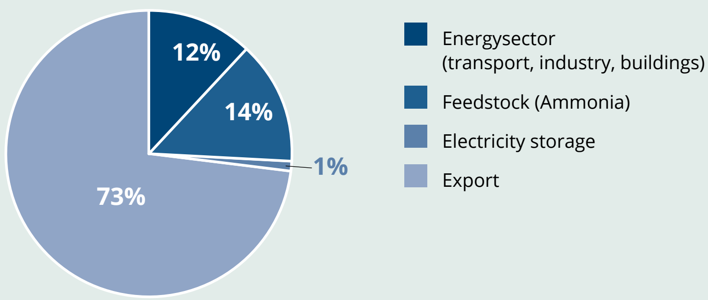
Water supply

In order to address the issue of sourcing fresh water for hydrogen production, desalination plants can be built at the site of the electrolyser in Morocco. The total cost of water desalination amounts to around EUR 0.80/m3, which adds EUR 0.007/kg to the cost of hydrogen production. The cost for water (purification, desalination and transport) would account for less than 2% of the total cost of hydrogen production and the energy consumption for water desalination only around 1% of the total energy requirements for hydrogen production.

Local and international demand for green hydrogen and its derivatives

Estimate of the potential hydrogen demand 2050: 150 TWh

Morocco is a world leader in the production of ammonia-based fertilizers and imports about 2 million tons of ammonia annually. The demand is expected to increase in the future and offers the potential to export synthetic ammonia.



Morocco's H2 export potential is particularly large.

Source of all graphics: Frontier Economics 2020

Green H2 Maroc Hydrogen Cluster

Vision: The Green H2 Maroc Hydrogen Cluster has been in place since March 2021. Its vision is to create a national, regional and international cooperation platform dedicated to the development of the hydrogen/PtX industry, in particular through shared innovations, industrial integration, capacity development, knowledge transfer and market development.

Hydrogen transport

Existing infrastructure

Locations for renewable energy sources, industry and ports in northern Morocco

Morocco has a well-developed port infrastructure, especially in the north of the country. The ports can serve as hubs for shipping products such as green hydrogen, ammonia, or methanol to third countries.

Ports with facilities for the energy trade

- Tangier West Med Port
- Nador West Med Port
- Casablanca Port
- Jorf Lasfar Port
- Laayoun Port

Maghreb-Europe-Gaspipeline (MEG)

Source: Frontier Economics 2020

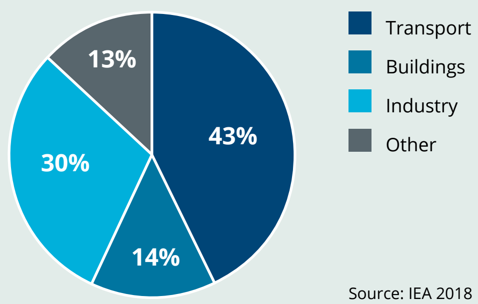
The Maghreb-Europe gas pipeline (MEG; also known as the Pedro Duran Farell pipeline) is a natural gas pipeline that connects the Hassi-R'mel field in Algeria to Cordoba in Andalusia, Spain, via Morocco. However, long-term contracts have not been renewed by Algeria. This could offer the potential to convert the existing Maghreb-Europe gas pipeline for possible hydrogen supplies for export to Europe.

Mexico

1
2
FUEL CELL
CARS ONLY
H2
Gasoline & Diesel
Not Available
FUEL CELL
CARS ONLY
H2

Energy data

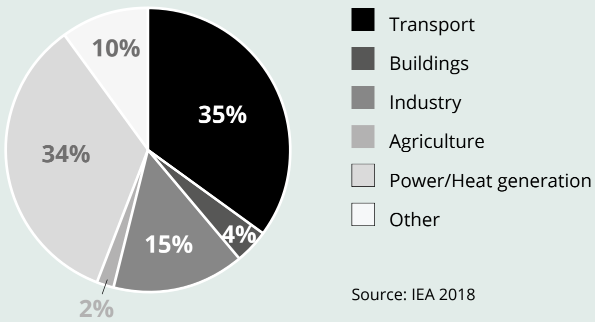
Energy consumption by sector



Source: IEA 2018

Industry and transport are responsible for around 70% of energy consumption.

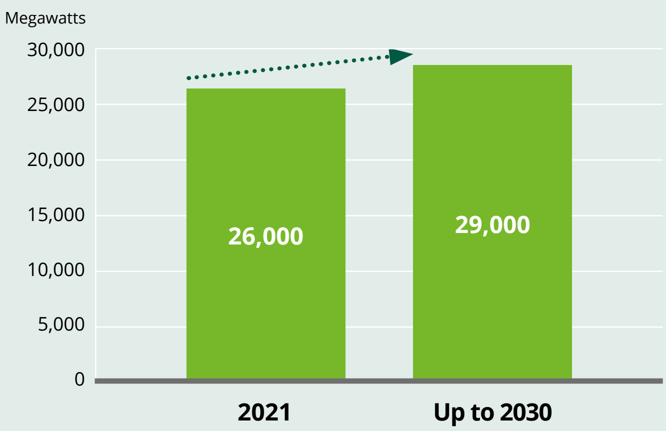
Carbon emissions by sector



Source: IEA 2018

Most of the carbon emissions are produced by the building and transport sector. Green hydrogen could avoid nearly 300 Mt of carbon by 2050.

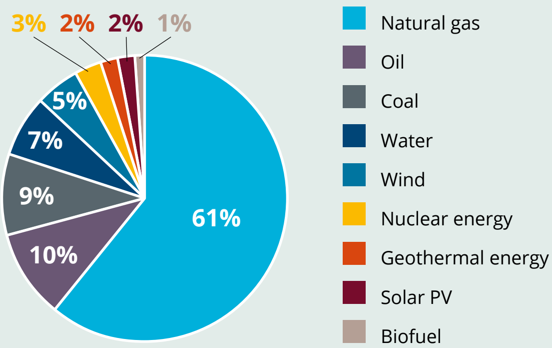
Installed and planned solar, wind and hydropower capacity



Source: IRENA 2021

Mexico plans for an additional 3,000 MW of renewable energy to be fed into the energy mix by 2030.

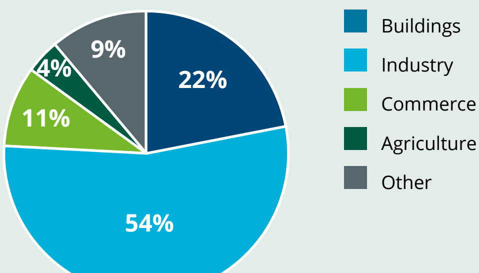
Power generation by energy source



Source: IEA 2019

Over two thirds of electricity is generated from natural gas.

Power consumption by sector



Source: IEA 2018

The industrial sector consumes over half of the total electricity.

Renewable energy potential

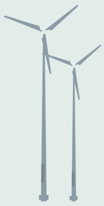
Production conditions for green hydrogen and its derivatives

Renewable energy infrastructure in Mexico

→ Renewable energy facilities in Mexico are relatively homogeneously distributed.

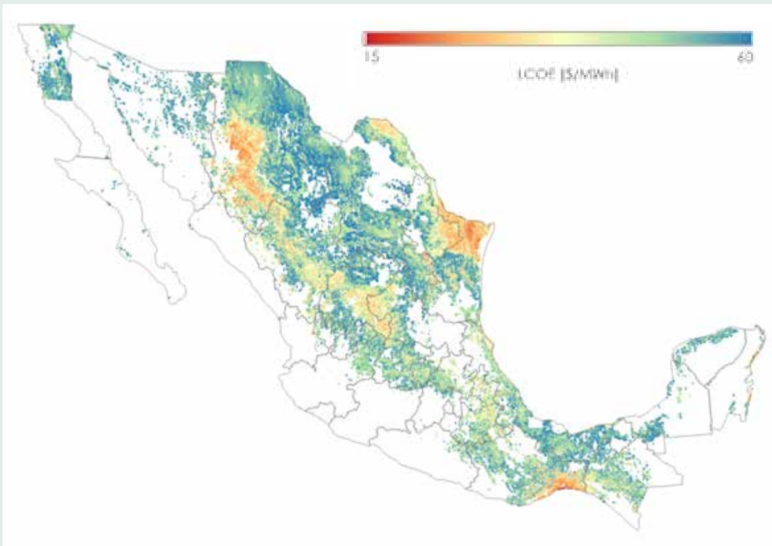
WIND

Wind potential: 6,300 TWh/year
Wind speed in the windiest region: 7.1 m/s



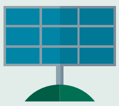
Sources: GIZ/Hinicio 2021, Global Wind Atlas 2021

Onshore wind potential



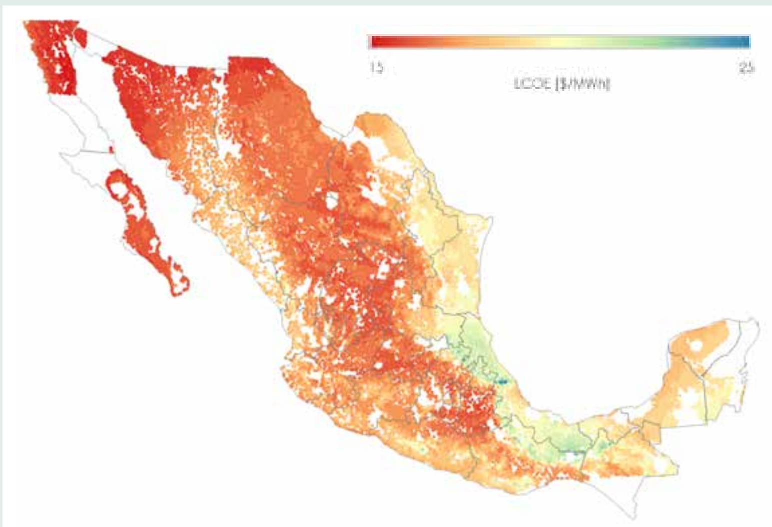
SOLAR

Solar energy potential: 6,900 TWh/year
Solar irradiance (theoretical): avg. 5.77 kWh/m²/day



Sources: GIZ/Hinicio 2021, Solargis 2021

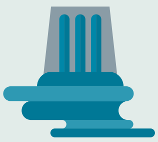
Solar energy potential



WATER

Hydropower potential (up to 10 MW): 3.2 GW
Large-scale hydropower plants: 17 GW

Source: IRENA 2015



Both wind and solar energy have the potential to meet the entire current energy requirements by 2050 for less than USD 30/MWh. The potential of solar energy is up to 100 times higher than that of wind energy.

Source of all graphics: GIZ/Hinicio 2021

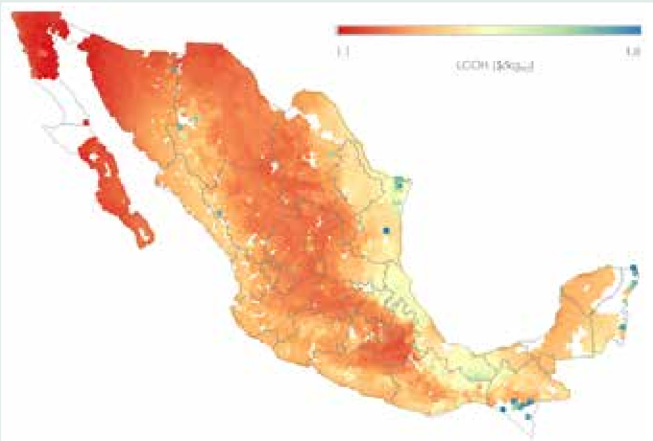
Hydrogen potential

Mexico has a well-developed energy infrastructure that would be able to promote the development of green hydrogen. The country has a number of international seaports, robust electricity and gas transmission grids, hydropower, solar, wind power and other renewable energy plants.
The regions with the highest renewable energy potential in Mexico correspond to the locations for potential hydrogen use, with the greatest potential in the north-western part of the country. The community of Mulegé in Baja California is a special case with a high solar irradiance ratio, copper mines and an isolated electricity grid.

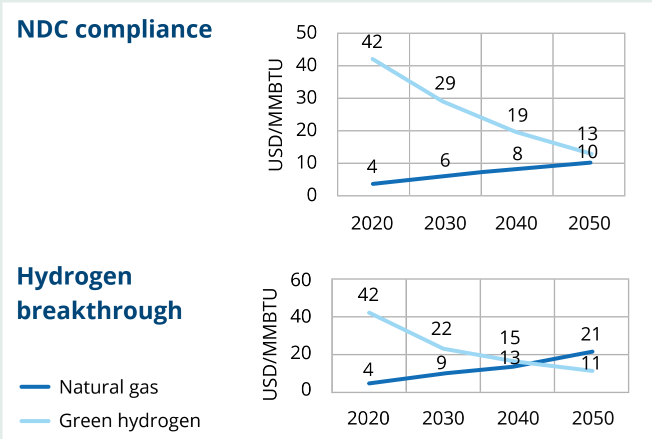
Hydrogen production cost

Mexico has suitable potential to install up to 22 TW of electrolyser capacity nationwide in order to produce green hydrogen at an average hydrogen cost (LCOH) of USD 1.40/kg in 2050 with energy mainly generated from PV.

LCOH with hybrid wind-PV production



LCOH scenarios



The map shows that the most cost-effective green hydrogen can be produced in the regions with the highest solar and wind energy potential.

The levelised cost of green hydrogen will be able to compete with natural gas by 2050.

The potential study assumes two scenarios: NDC compliance and hydrogen breakthrough. In the conservative scenario, it is anticipated that green hydrogen will become competitive for most applications only slowly in Mexico and will not increase until the final years prior to 2050. This gives rise to forecast demand of less than 60 kilotonnes of green hydrogen per year by 2047, which is likely to increase to over 120 kilotonnes by 2050.

Source of all graphics: Hinicio 2021

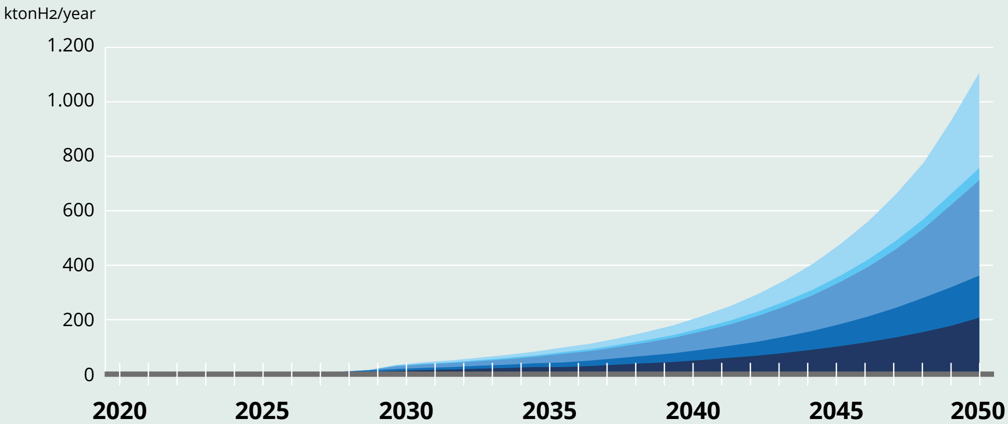
Water supply

The need for water for hydrogen production per region is insignificant in comparison with overall water consumption. In all cases, water consumption for hydrogen production would account for 0.01% or less of total water consumption in the region.
In regions in which the resource is scarce and sea water is available, for example on the Baja California peninsula, water desalination is required for green hydrogen production. Additional investments for desalination would mean an increase of less than 1% of the CAPEX per MW required for electrolysis.

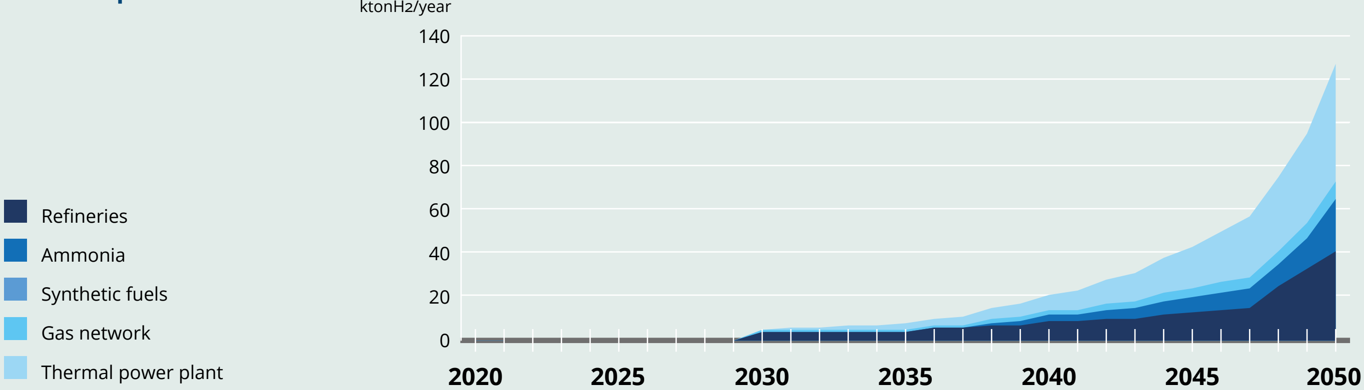
Local and international demand for green hydrogen and its derivatives

Potential national green hydrogen demand until 2050

Hydrogen breakthrough scenario



NDC Compliance Szenario



Source of all graphics: Hinicio 2021

Demand for all applications will increase sharply under both scenarios, especially from 2040 onward. In the NDC Compliance scenario, H_2 will play a major role especially in refineries and in thermal power plants from 2040 onwards play.

Potential green hydrogen demand in refineries

In a hydrogen breakthrough scenario, hydrogen demand in refineries will already increase continuously from 2030. E-fuels will be used by 2050 particularly in aviation, in maritime In the NDC compliance scenario, this trend would not be anticipated until 2045.

Potential of green hydrogen demand for gas infrastructure

The use of green hydrogen in the gas grid is highly significant. Up to one fifth of natural gas consumption can be replaced by green hydrogen.

Potential green hydrogen demand for synthetic fuels

E-fuels will be used by 2050 particularly in aviation, in maritime, in transport and in railway transport.

Potential green hydrogen demand for thermal power plants

Green hydrogen will be able to compete with natural gas as fuel for thermal power by 2042, which will foster its use by 2050.

Potential hydrogen use in Mexico

Green hydrogen in industry

Existing industrial sectors such as metal processing, production of industrial gases, aerospace and the automotive industry form the basis for the country's future competitiveness in hydrogen technologies.

The greatest potential for green hydrogen in industry exists in the mining sector, where demand could reach 500,000 tonnes annually by 2050. With 50% of this demand, 1,500 mining vehicles could be powered with fuel cells, 42% would be used for extracting one quarter of the iron ore for steel production and 8% would provide 4.3 PJ of energy for thermal applications for industry. The total volume would meet more than 80% of the demand of the private non-transport sector by 2050.

In 2050, the cumulative requirement for green hydrogen will reach 580,000 tonnes per year for all industries studied. This corresponds to a need for 6,750 MW of electrolyser capacity.

Source: GIZ/Hinicio 2021

Hydrogen transport

H2-Export costs in Mexico – European Union (2030)

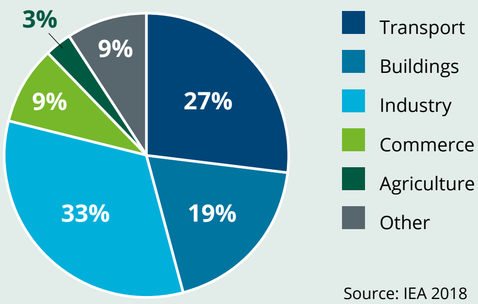
Mexico is a competitive exporter of green H2 over long distances to Europe and Asia. The projected production costs of green H2 are very low due to good renewable resources and its privileged geographic location and with access to the Atlantic and Pacific oceans at a northern latitude. In 2030, green H2 from Mexico could be delivered to Europe at a price of about 6 USD/kg and to the neighboring U.S. states by pipeline at a price of 2.5 USD/kg.

Source: GIZ/Hinicio 2021

South Africa

Energy data

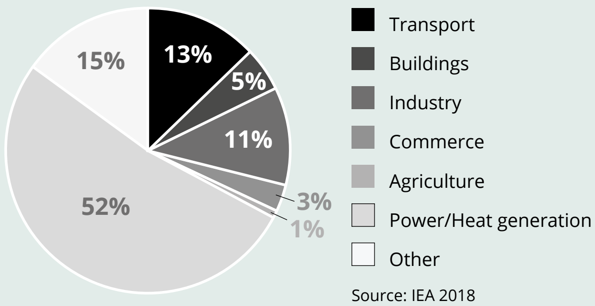
Energy consumption by sector



Source: IEA 2018

Industry and transport are responsible for around 60% of energy consumption.

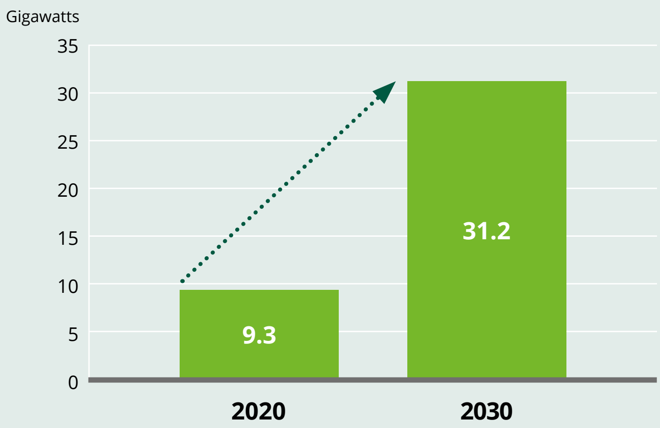
Carbon emissions by sector



Source: IEA 2018

The use of renewable energy in the electricity sector would save 40-45% of total carbon emissions and the use of hydrogen can lead to a reduction of around 75% of carbon emissions by 2050. Source: IHS Markit 2021

Installed and planned solar, wind and hydropower capacity

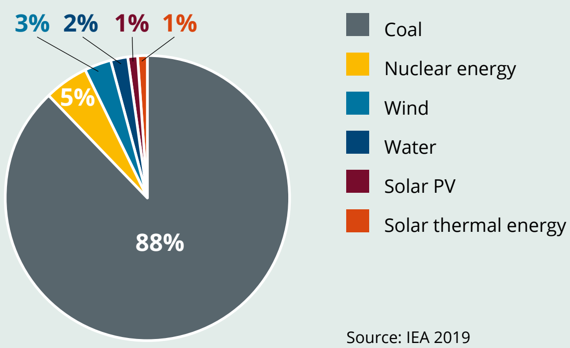


Source: IRENA 2021, IRP 2019

According to the expansion plans of the responsible ministry (DMRE) from 2019, solar, wind and hydropower capacity will account for 39.65 per cent (31.2 GW) of total installed capacity in 2030. An update of the IRP 2019 including ambitious expansion plans is expected.

Source: IHS Markit 2021

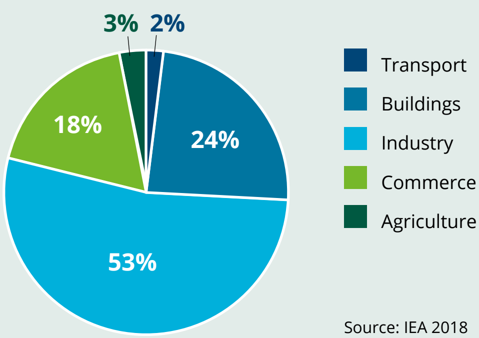
Power generation by energy source



Source: IEA 2019

Nearly 90% of electricity is generated from coal.

Power consumption by sector



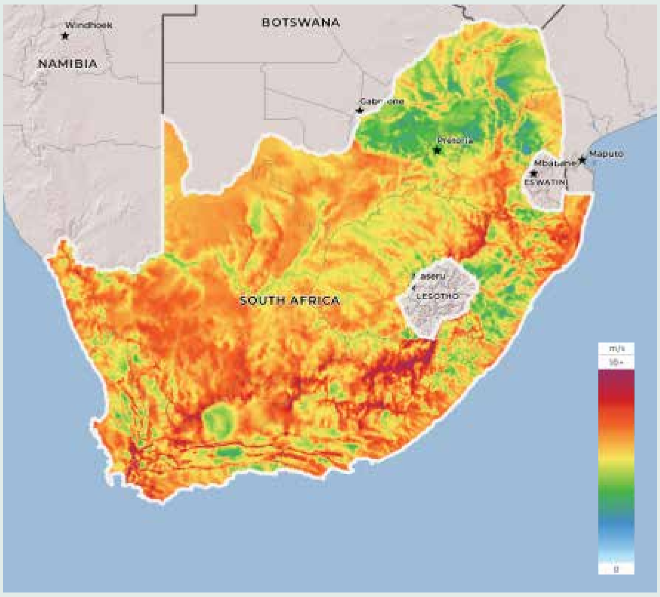
Source: IEA 2018

The industrial sector is responsible for more than half the total electricity consumption (2019: 224.56 TWh).

Renewable energy potential

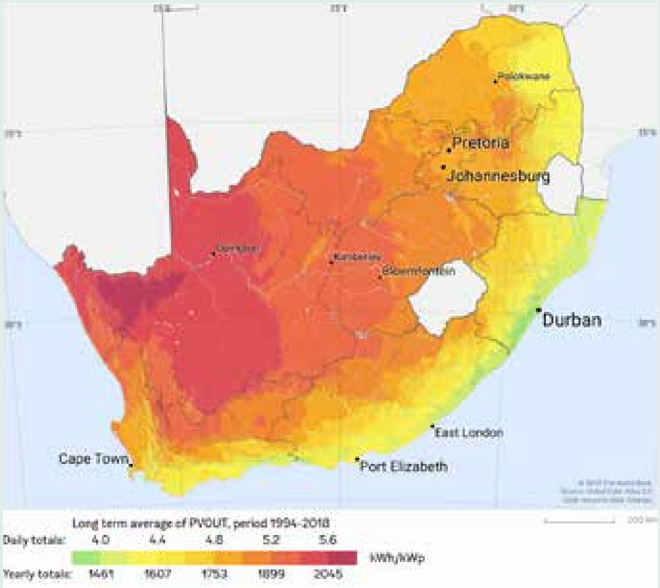
Production conditions for green hydrogen and its derivatives

Wind speeds



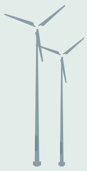
Source: Global Wind Atlas 2021

Solar irradiance



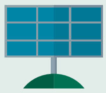
Source: Solargis 2021

WIND



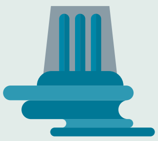
Wind potential: 6,787 GW (22,000 TW/h)
Wind speed: avg. 5.88 m/s

SOLAR



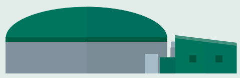
Solar energy potential: 292 GW (550 TWh)
Solar irradiance: avg. 6,64 kWh/m²/day

WATER



Hydropower potential: 747 MW

BIOMASS



241 MW

Sources: IHS Markit 2021, Global Wind Atlas 2021, Fraunhofer IWES 2016, Solargis 2021, IRENA 2021

Hydrogen potential

As a contribution to the use of platinum resources in the country, the Ministry of Research launched the HySa strategy in 2008 with the aim of expanding the development and steering of innovations along the hydrogen and fuel cell technology value chain. For February 2022, the publication of the Hydrogen Society Roadmap has been announced in which the Ministry of Research presents guidelines for the development of the market up to 2050 for relevant interest groups of the hydrogen industry.

High potential for green hydrogen:

- Optimal renewable energy resources (after Atacama in Chile, South Africa has the best solar potential)
- Sufficient land for implementing renewable energy
- Despite local water scarcity, sufficient water supply forecast in conjunction with desalination technology

High potential for ammonia:

- Large-scale air-separation plants for the supply of nitrogen
- Access to green hydrogen

Large platinum reserves:

- The focus tends to be on the export of processed platinum products, such as fuel cells, rather than on exporting hydrogen (goal: market share of 25%)
- Available know-how and plants (especially SASOL) for manufacturing hydrogen-based petrochemical liquids such as green fuels

Source: National Business Initiative (NBI) 2021,
German-South African Energy Partnership

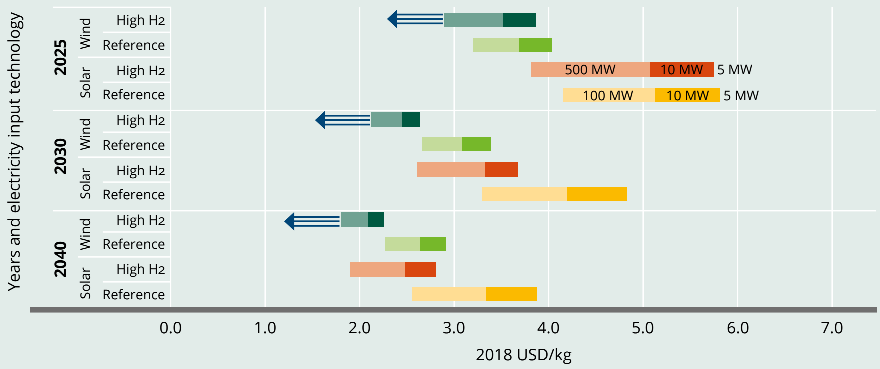
With good economic and political conditions, South Africa could produce 3.8 million tonnes of green hydrogen by 2050.

Source: IHS Markit 2021

Hydrogen production cost

Future cost of continuous (and fluctuating) green hydrogen

This diagram shows two scenarios: the ambitious 'high case scenario' and the 'reference scenario' with an electrolyser unit size of 5-500 MWe and 5-100 MWe. It is anticipated that the cost of green hydrogen will fall well below USD 3.00/kg for continuous hydrogen by 2030 and to below USD 2.00/kg by 2040.



Source: IHS Markit

Water supply

While South Africa suffers from water scarcity, the cost of sea water desalination is less than USD 0.02/kg.

Source: Council for Scientific and Industrial Research (CSIR) 2021

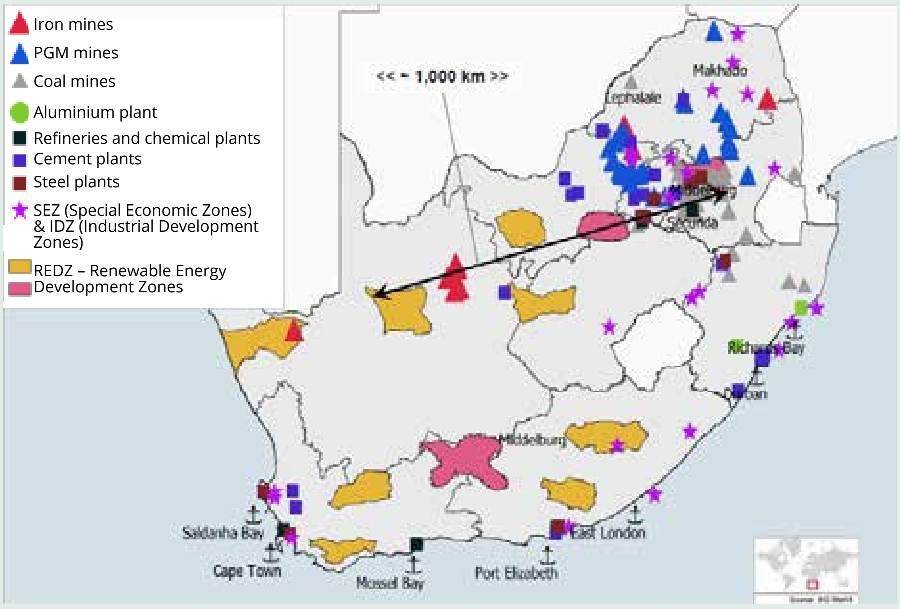
Local and international demand for green hydrogen and its derivatives

Local demand

Centres of potential hydrogen production and demand

Demand for and production of hydrogen is greatest in north-eastern South Africa. However, the country will focus on exporting green hydrogen.

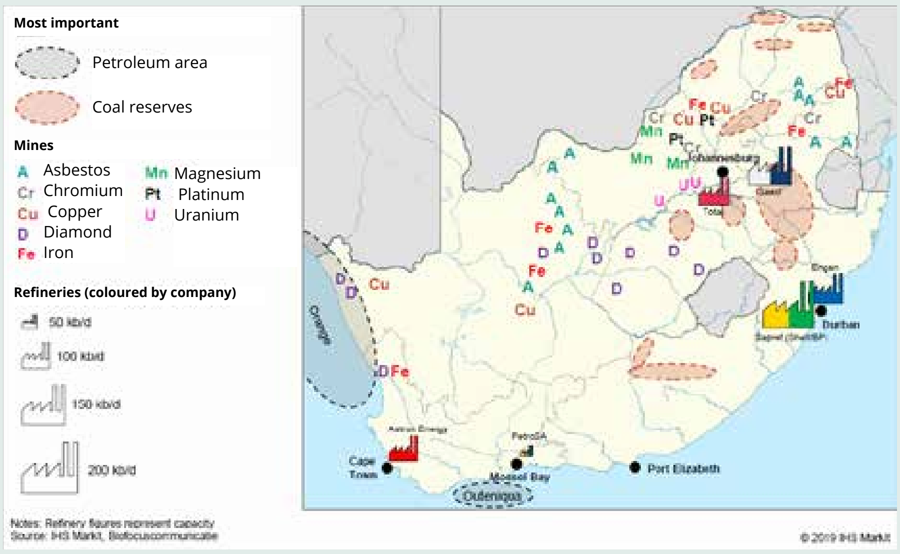
Source: Council for Scientific and Industrial Research (CSIR) 2021



There is local demand in the aviation industry, the chemical industry, from companies working with fuel cells, public transport (hydrogen fuel cell buses) and in the steel and cement industry.

Refineries and industrial demand areas

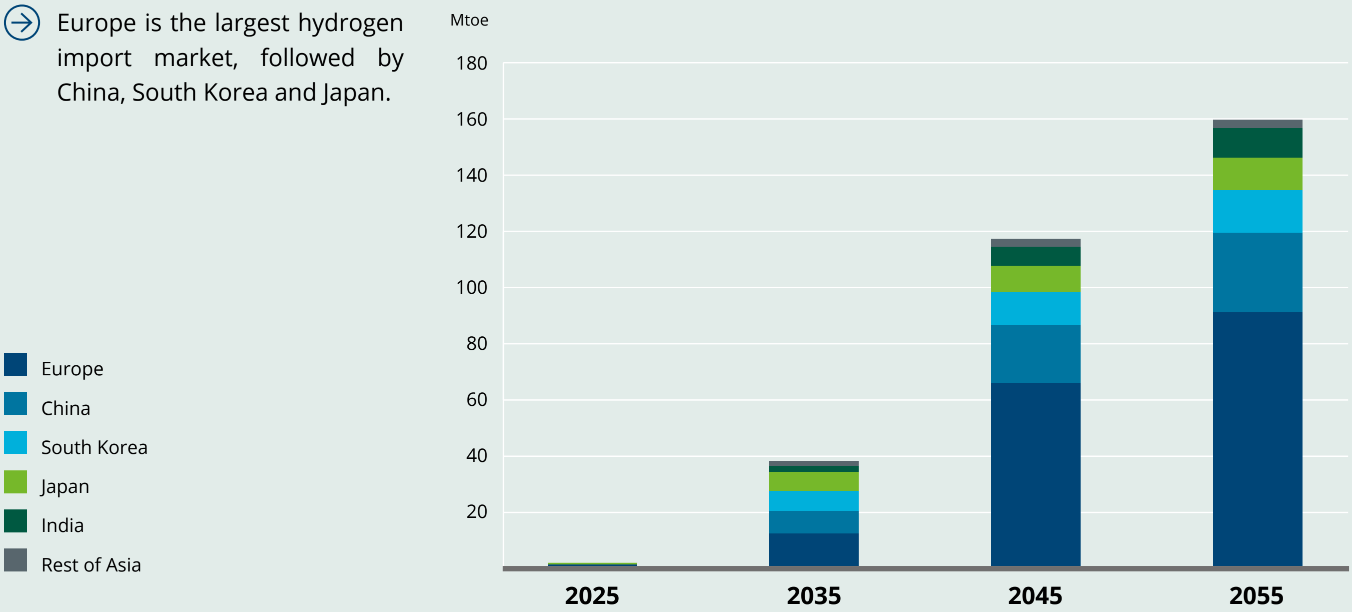
PetroSA, Astron Energy, Engen, Total, Sasol und Sapref (ShellBP) are the main refineries in South Africa. They are located in the port cities and in the vicinity of Johannesburg; hydrogen demand is therefore greatest in these areas.



Source of all graphics: IHS Markit 2021

International demand

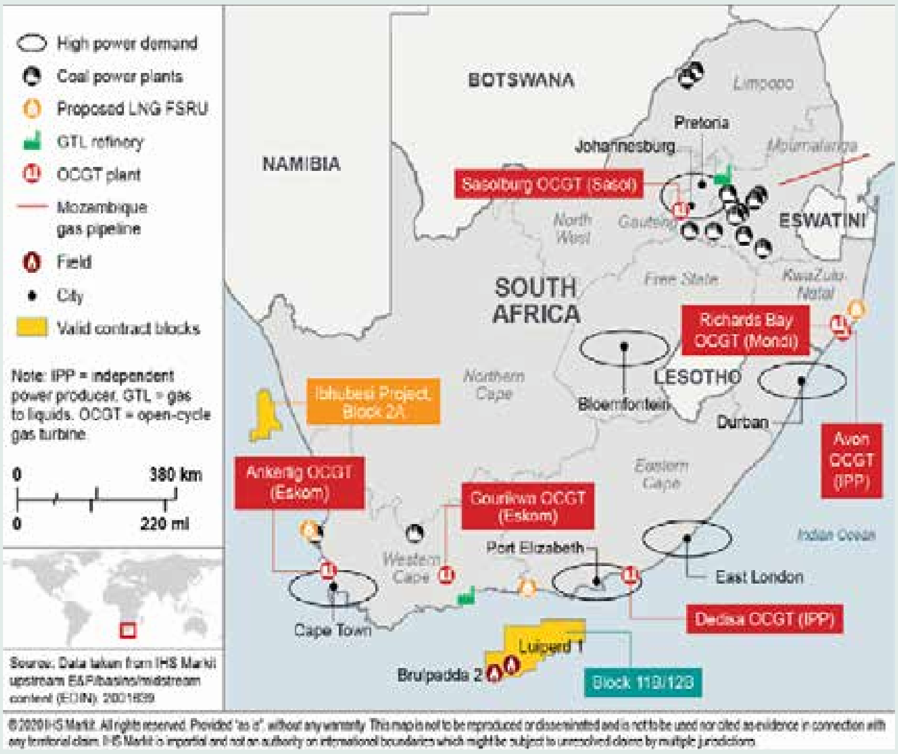
Europe is the largest hydrogen import market, followed by China, South Korea and Japan.



Source: IHS Markit 2021

Hydrogen transport

Existing infrastructure



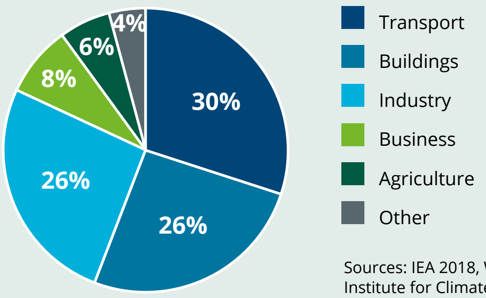
Some obstacles remain regarding the transport of green hydrogen in gaseous form. The compression of green hydrogen requires more energy than the compression of natural gas (up to four times more). Hydrogen leaks are also more likely compared with more dense gases. Today, shipping liquid hydrogen does not yet play a role in South Africa.

Source: IHS Markit 2021

Tunisia

Energy data

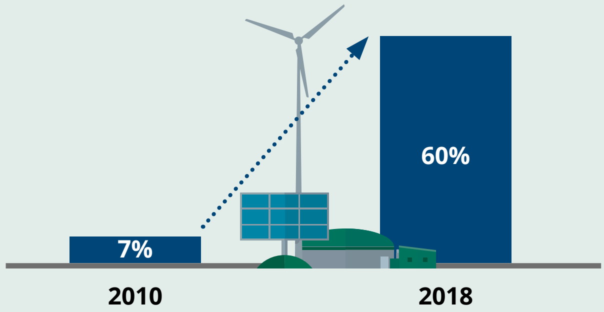
Energy consumption by sector



Sources: IEA 2018, Wuppertal Institute for Climate, Environment and Energy 2021

The building, transport and industry sectors dominate energy consumption.

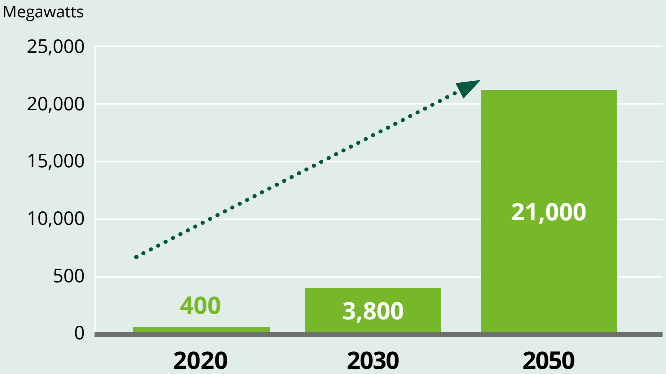
Energy dependency rate



Source: Irena 2021

The energy dependency rate has rapidly increased in recent years.

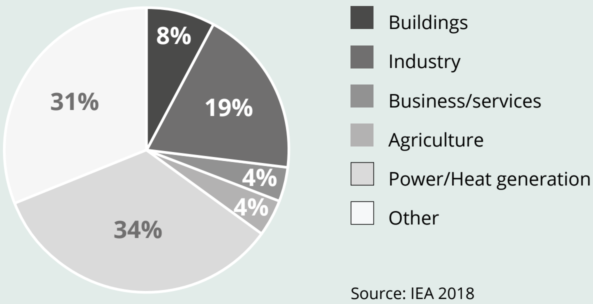
Installed and planned solar, wind and hydropower capacity



Source: Wuppertal Institute for Climate, Environment and Energy 2021

The Tunisian Solar Plan (PST) provides for 30% of Tunisia's electricity to be generated from renewable energy by 2030 and around 80% by 2050.

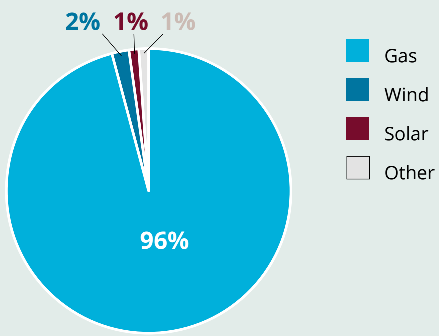
Carbon emissions by sector



Source: IEA 2018

The electricity, heating and transport sectors in particular are responsible for more than half the carbon emissions.

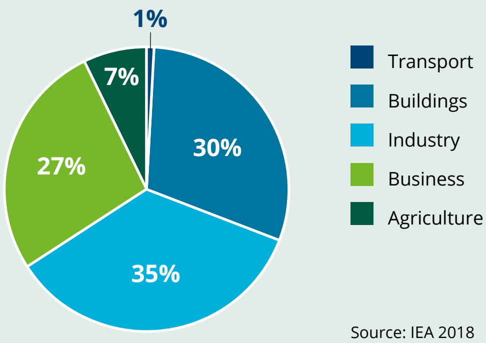
Electricity generation by energy source



Source: IEA 2018

Tunisia's electricity mix is dominated by natural gas.

Electricity consumption by sector



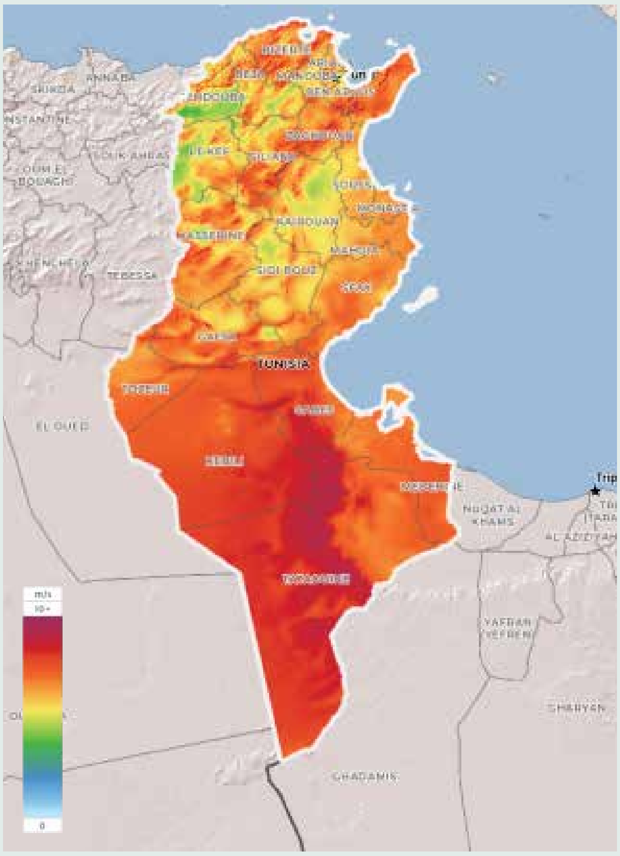
Source: IEA 2018

The industry, building and business sectors are chiefly responsible for energy consumption.

Renewable energy potential

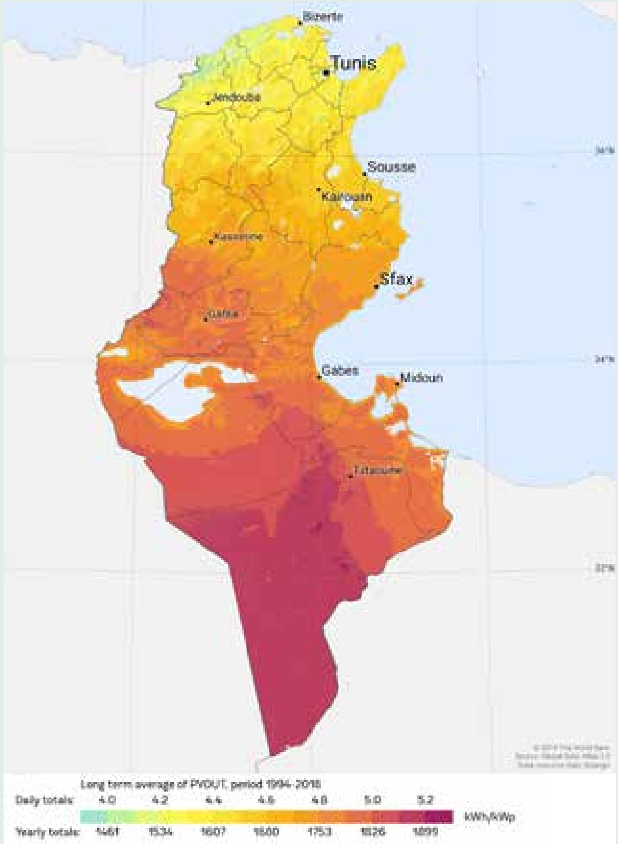
Production conditions for green hydrogen and its derivatives

Wind speeds



Source: Global Wind Atlas 2019

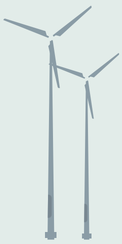
Solar irradiance



Source: Global Solar Atlas 2019

WIND

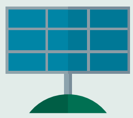
Wind onshore potential: 110 GW
Wind offshore potential: 250 GW



Source: Wuppertal Institute for Climate, Environment and Energy 2021

SOLAR

Solar PV potential: 840 GW
Solar CSP potential: 1000 GW
Sunshine hours: 3,000 hours per year
Solar irradiance in the south:
> 2,000 kWh/m² per year



Source: Wuppertal Institute for Climate, Environment and Energy 2021

Tunisia has favourable conditions for wind energy, especially in the north-east, in the central west and in the south-west. These regions have a total area of around 18,000 square kilometres (11% of the land area in Tunisia). Regions suitable for using the potential measure 1,700 square kilometres with around 10,000 MW.

Hydrogen potential

Northern Africa's proximity to Europe means it will play a major role as a potential future producer and exporter of green hydrogen. This also applies to Tunisia because the land has great solar and wind energy potential and its climatic and geographical conditions offer promising technical and economic potential for developing a national PtX sector.

Local and international demand for green hydrogen and its derivatives

The technical potential of renewable energy is enough to meet domestic demand and produce green hydrogen for export. By 2050, the greatest demand may come from the industrial sector, followed by the energy and transport sectors. In the initial phase up to 2030, demand could develop primarily in the transport sector, followed by the energy sector. In the energy sector, hydrogen could offset the increasing share of intermittent renewables and contribute to decarbonising gas-fired power generation through feeding into the gas grid. In this scenario, demand in the industrial sector will rise sharply from 2040.

Overview of Power-to-X opportunities in Tunisia's industrial sector

	Current use of hydrogen	Today's relevance for Tunisia	Long-term development potential in Tunisia
Refining	Desulphurisation and upgrading of heavy crude oil through • hydrocracking • hydrotreating	The country has a refinery without a processing plant, so that currently there is no demand for green hydrogen for refining in Tunisia.	New refineries or additional processing plants could create demand in future. However, these options are associated with risks such as lock-in effects or stranded investments.
Iron and steel	Direct reduction of iron (DRI) in primary steel production	Tunisia has a steel plant with secondary steel production from waste in an electric arc furnace. This process does not require hydrogen.	It is rather unlikely that a new steel industry will be established with DRI and a corresponding demand for hydrogen, especially because Tunisia has only limited iron ore reserves.
Chemicals	• Ammonia production • Methanol production • Other chemical processes	Tunisia produces no ammonia or methanol but imports both raw materials. Only indirect demand for hydrogen.	Green ammonia and methanol could be produced in Tunisia from hydrogen through renewables for domestic consumption and export.
High temperatures and heat	No current use, but possible in future	Tunisian industry does not use hydrogen for heat .	No potential short-term or medium-term uses in Tunisia. Long-term development of demand is possible, but direct use of concentrated solar heat could be a better option.

Source: Wuppertal Institute for Climate, Environment and Energy 2021

There is local demand in the aviation industry, the chemical industry, from companies working with fuel cells, public transport (hydrogen fuel cell buses) and in the steel and cement industry.

Overview of Power-to-X opportunities in Tunisia's transport sector

	PtX applications	Development status	Long-term development potential in Tunisia
Aviation	• Production of PtL (aircraft fuel) by means of the Fischer-Tropsch process or methanol synthesis • Hydrogen-powered aircraft	Feasibility studies and pilot projects are planned	Efforts to decarbonise the aviation industry and potentially increasing costs for emissions could generate interest in producing PtL in Tunisia.
Maritime transport	• Ammonia as fuel • Hydrogen-powered ships	Research and pilot projects. Companies expect ammonia-powered ships to be on the market before 2030.	The efforts on the part of the IMO and EU to decarbonise shipping could influence potential demand for ammonia as fuel. The possibility of using the existing infrastructure for handling ammonia in the port of Gabès must be explored.
Railway transport	• Hydrogen-powered trains • PtL as a drop-in fuel for diesel locomotives	The first hydrogen-powered trains are already running in several countries. Several companies are working on bringing these trains to market.	Only a small percentage of routes is already electrified. However, hydrogen-powered trains could become an alternative for long-distance and freight transport routes in order to also decarbonise the railway sector. Opportunity to focus investments on green technologies in order to prevent lock-in effects.
Road transport	• FCEV passenger vehicles • FCEV trucks • FCEV buses • PtL as fuel	Light commercial FCEVs are available on the market. For heavy FCEVs, projects are already under way with growing demand.	Greatest potential for heavy commercial vehicles with high daily mileage on set routes and central refuelling. The national bus transport system could also be a potential area for introducing state-supported hydrogen use early on.

Source: Wuppertal Institute for Climate, Environment and Energy 2021

In future Tunisia will use Power-to-X applications in order to decarbonise the transport sector.

Hydrogen production costs

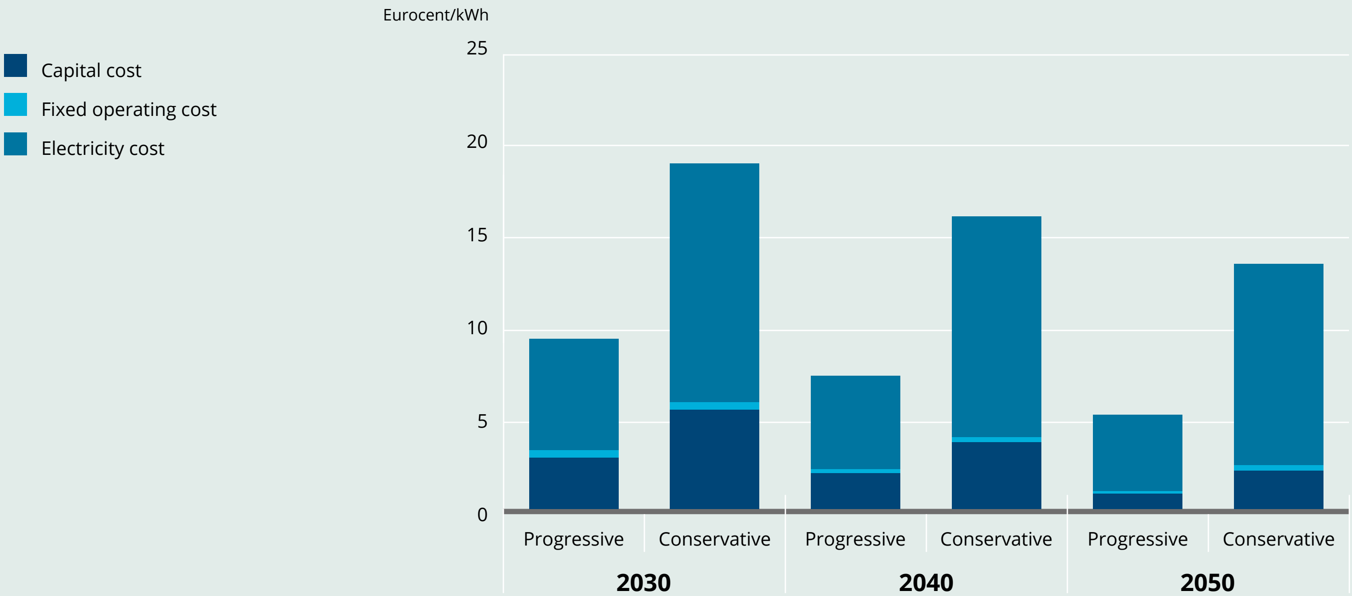
Technical and economic parameters for cost calculation of green hydrogen in Tunisia

	2030		2040		2050	
	Progressive	Conservative	Progressive	Conservative	Progressive	Conservative
Investment cost (in EUR/kW)	670	1100	485	800	300	500
Technical lifespan (in years)	23		25		27	
Efficiency (in %)	62		65		68	
Fixed operating cost (in % of investment cost)	1.70		1.70		1.70	
Full-load hours (in h/a)	5400		5400		5400	
Electricity-generation cost (in EUR/MWh)	31	68	26.5	64.5	22	61
WACC	14.9 %	16 %	13.1 %	16 %	11.41 %	16 %

Source: Wuppertal Institute for Climate, Environment and Energy 2021

The analysis takes into account seven different cost factors: specific investment, technical lifespan, degree of efficiency, fixed operating costs, electricity-generation costs from renewable energy sources, full-load hours of plants and interest rate. The assumed costs have been calculated for two scenarios in order to outline possible future cost development paths for PtX in Tunisia. In the progressive scenario, the cost of early investments drops more rapidly over time, while the conservative scenario assumes a slower decline in price. The table summarises the different technical and economic assumptions between the progressive and the conservative scenario.

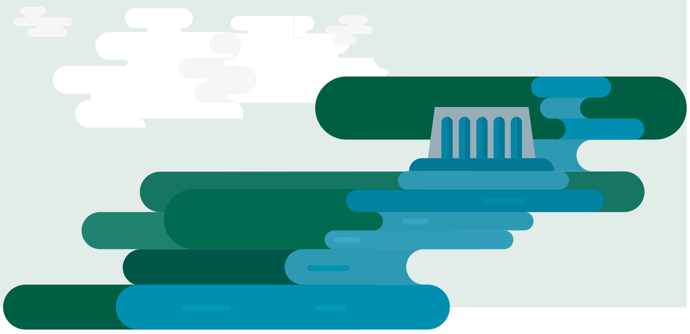
Technical and economic parameters for cost calculation of green hydrogen in Tunisia



The figure shows green hydrogen production costs in 2030, 2040 and 2050. The estimated production cost for green hydrogen in Tunisia is between 9.50 eurocents/kWh and 19.24 eurocents/kWh in 2030. In 2050, the lowest estimated production cost in the progressive scenario amounts to 5.41 eurocents/kWh (without transport) and 13.60 eurocents/kWh in the conservative scenario.
The greatest cost factor for green hydrogen is the cost of electricity from renewable energy. However, this cost is likely to decline substantially over time.

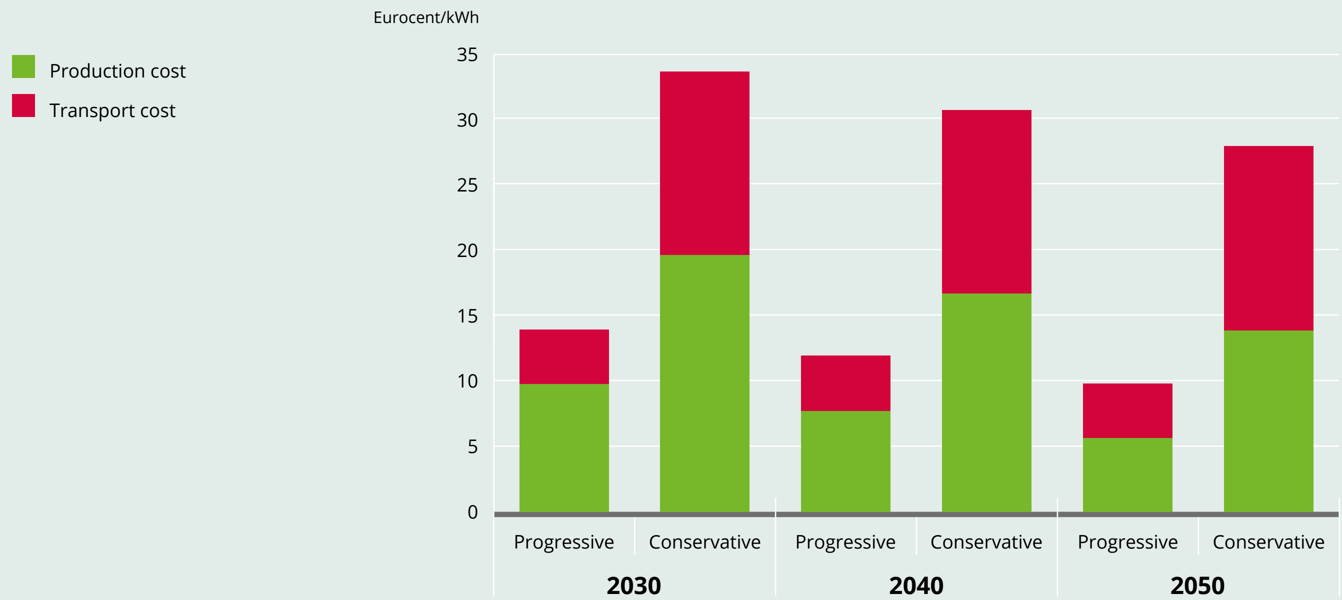
Water supply

Tunisia's overall water resources are estimated at 4,874 billion m3/year. Tunisia is one of the water-poorest countries in the Mediterranean region and suffers from water scarcity.
Desalination technologies are already commercially available, but their operation is largely based on fossil fuels. The production of green hydrogen would therefore require a changeover to renewable energies.
Although sea water desalination involves costs, these costs account for only a negligible part of the cost of producing green hydrogen. Sea water desalination is estimated to account for well below 1% of the overall PtX cost.



Hydrogen transport

Existing infrastructure



The figure shows an additional factor that plays a major role in green hydrogen production: transport cost. The distance between Tunisia and Germany is around 4,115 km. The cost of transport to Germany will be between 15.05 eurocents/kWh and 33.01 eurocents/kWh in 2030 and between 9.86 eurocents/kWh and 27.47 eurocents/kWh in 2050. Compared with other countries such as Morocco, the transport cost from Tunisia to Germany is substantially higher owing to the greater distance.

In addition to exporting green hydrogen, it can also be used as feedstock for conversion to PtL fuels for the country's own transport sector or for export.

It is most likely more economically viable to export PtX products such as ammonia, methanol and kerosene from Tunisia to Germany than green hydrogen. From a cost perspective, green hydrogen produced in Tunisia should rather be processed into PtX products and then exported or used directly in Tunisia.

Natural gas pipelines

Country		Hub 1	Hub 2	Number of circuits	Voltage (kW)	Length (km)	Imax (A)	Commis-sioning year
Tunisia	**Algeria**	Tajerouine	El Aouinet	1	90	60	450	1952
		Fernana	El Kala	1	90	35	525	1955
		Tajerouine	El Aouinet	1	220	59	620	1980
		Metlaoui	Jebel Onk	1	150	62	620	1984
		Jendouba	Chefia	1	400	160	1540	2014
Tunisia	**Algeria**	Tataouine	Rowies	1	220	160	620	2001
		Médenin	Abou Kamash	2	220	110	620	2011

Source: STEG 2021

The Tunisian transit pipelines are part of the Transmed system, which transports natural gas from Hassi R-Mel, Algeria, to Sicily and to the Italian market. The Algerian section is operated by the state-owned company Sonatrach. The Société Tunisienne du Gazoduc Trans-Tunisien (Sotugat) owns the Tunisian section (two 48-inch pipelines). Sotugat is controlled, operated, and maintained by subsidiaries of Eni TPPC (Trans Tunisian Pipeline Company) and Sergaz. The underwater section between Tunisia and Sicily consists of three 20-inch pipelines and two 26-inch pipelines. It is owned by the Transmediterranean Pipeline Company Limited (TMPC) and operated by Transmed Sp.A. – a joint venture between Eni and Sonatrach.

Port infrastructure

Port	Depth (in feet)	Dock length (in metres)
SKHIRA		60-300
Compression station 1 (PP) **Compression station 2 (crude and PP)** **Compression station 1 (PC)**	37 47-50 (high tide) 24-27 (low tide)	100-300
BIZERTE		
Dock A **Dock B**	35 26	250 150
RADES	31	170
GABES	10.5	120
ZARZIS	28	175

Source: Wuppertal Institute for Climate, Environment and Energy 2021

Tunisia has five ports of discharge for petroleum end products:

- **Skhira:** petrol, gas oil and fuel
- **Bizerte:** liquefied gas, petrol, gas oil and fuel
- **Radès:** liquefied gas, gas oil, fuel and aircraft fuel
- **Gabès:** liquefied gas
- **Zarzis:** petrol, gas oil and aircraft fuel

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The German-Brazilian Chamber of Commerce and Industry in Rio de Janeiro and São Paulo offer a green hydrogen competence centre via the German-Brazilian Green Hydrogen Alliance and serve as points of contact for interested companies.

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