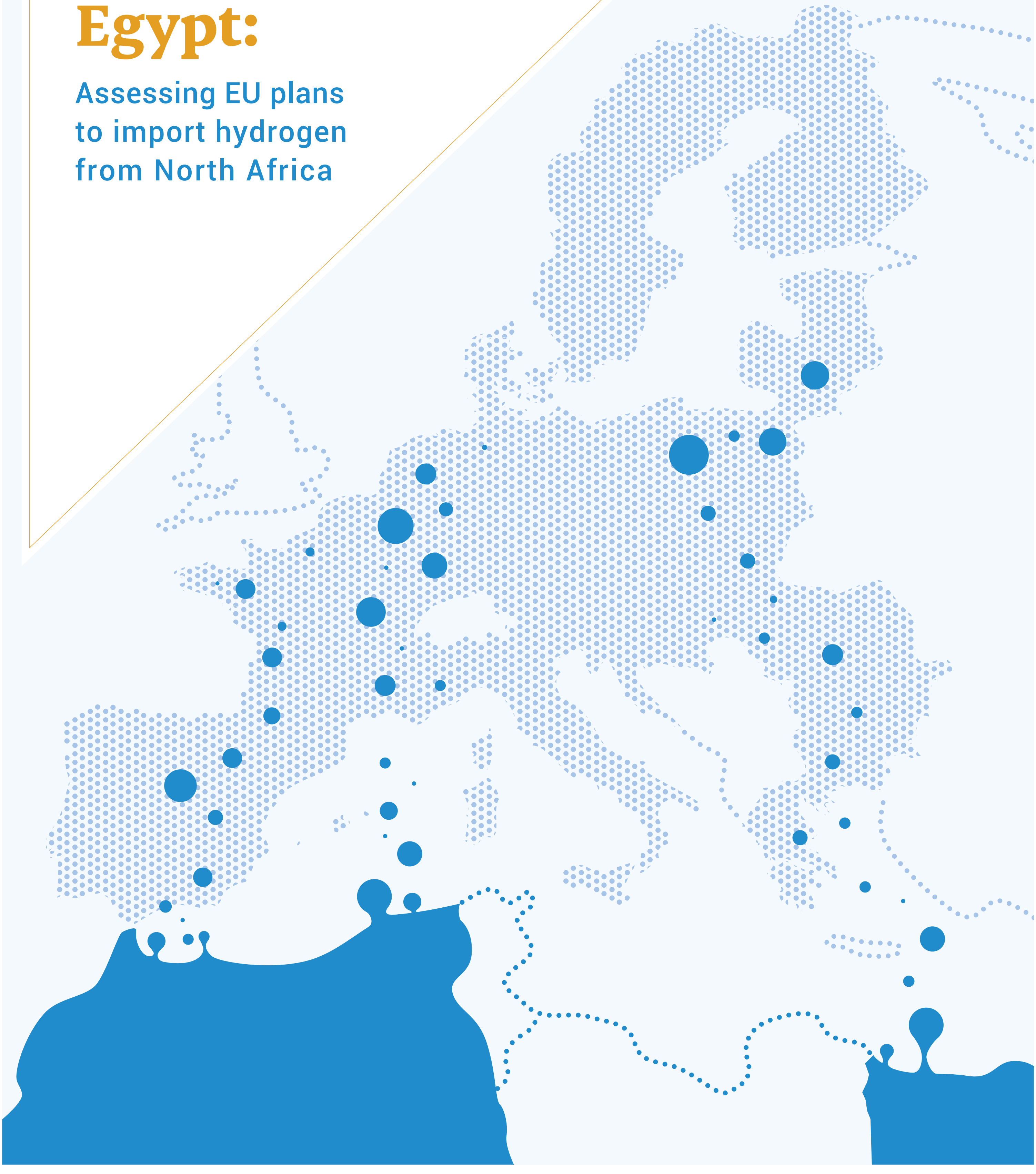
Morocco, Algeria, Egypt:

Assessing EU plans to import hydrogen from North Africa



Corporate Europe Observatory

tni transnationalinstitute

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Executive summary

The European Commission's 2020 hydrogen strategy has a big focus on importing 'green' renewables-based hydrogen from its neighbourhood (North Africa and Ukraine). Since the recent invasion of Ukraine and the subsequent need to reduce dependency on Russian gas, the EU has doubled its import targets to 10 million tonnes per year by 2030, as per the RePowerEU communiqué.

This report examines three North African countries that in recent years are increasingly focused on hydrogen, based in significant part on the interest of the EU and its corporations. Morocco, Algeria and Egypt are all planning to manufacture green hydrogen and hydrogen-based products, and ship them to the EU via boats and pipelines, to help meet this projected demand. But how feasible are such a plan, how much would they cost, and would they be the best use of renewables in those countries?

There are big question marks over whether green hydrogen can ever be exported at sufficiently attractive prices, given the high production and transportation costs:

Using intermittent renewables to power electrolysers will lead to higher costs, but connecting to the grid to mitigate against this could further increase costs, as well as the CO2e footprint. It would also undermine the EU's criteria for green hydrogen.

Shipping green hydrogen by sea takes three times the energy to liquify it as natural gas requires, while the same volume of tanker would only carry 27% of the energy. Also, 0.2% of the hydrogen would boil off every day while being shipped.

Transporting hydrogen via pipeline damages the pipes themselves, and the electronic equipment within them. The density of hydrogen would require tripling the energy used, and thus also the cost of pumping it through the pipelines. There will also be high fugitive emissions.

Green hydrogen could cost as much as 11 times more than natural gas per unit of energy at prices before the winter energy crisis and the invasion of Ukraine, even before storage and transportation. Hydrogen is expensive to distribute via shipping and pipeline, which is why today the large majority of it is manufactured at the point of consumption. Realistically, is Europe going to be willing to pay that very significant price difference?

North African governments and firms should therefore be wary of promises of large export markets for expensive to manufacture and ship green hydrogen, and the synthetic fuels made from it.

In oil and gas producing Algeria and Egypt, the hydrogen projects being explored are not just based on renewable electricity ('green'), but also on gas with Carbon Capture Storage ('blue'). Blue hydrogen is still double the price of unabated ('grey') hydrogen, and has the significant problem of high CO2e emissions, especially if the captured CO2 is used for enhanced oil recovery.

As all three countries examined have significant fertiliser industries, and either produce or import large quantities of grey ammonia, greening this domestic use could have a significant short-term climate impact before transitioning to agricultural practices that are not so fertiliser intensive.

The renewable electricity generated by these countries could also be better used to displace domestic fossil fuel power generation and meet local energy needs, while interconnectors with neighbouring countries - and eventually the EU - could help balance grids.

It makes little sense for Morocco, Algeria or Egypt to use their renewable electricity to make hydrogen and products from hydrogen, then ship them to Europe at significant loss of energy, so that the EU can achieve climate emissions reductions. And would European consumers be prepared to foot the very significant bill? The EU may need to re-examine its hydrogen strategy, in particular its green import targets, and reassess the feasibility and cost of achieving them.

Morocco

- Morocco aims to replace ammonia imports with local green production for its national fertiliser industry.
- Beyond eliminating high ammonia emissions, other touted uses of green hydrogen don't hold up to scrutiny.

Algeria

- Algeria plans to gradually switch its EU exports from natural gas to green and blue hydrogen, with interest from European partners.
- Eni's green hydrogen solar project is predicted to cost 11 times more per unit of energy than natural gas, even before distribution.
- Eni is also looking at blue hydrogen, which will cost more than double grey (unabated), and will be five times the cost of natural gas per unit of energy, with significant methane emissions.

Egypt

- Green hydrogen is seen as a key economic development pathway. The EBRD is helping, while Egypt is already providing fiscal support measures.
- Maersk involved in a project developing hydrogen-based shipping fuels to replace polluting bunker fuel but they face challenges:
    - Green methanol is toxic, has half the energy density of bunker fuel and could cost around five times as much,
    - Green ammonia is also toxic, with spills on a ship potentially life threatening, and will cost almost four times as much as marine fuel.
- Numerous European companies involved in green and blue hydrogen export projects around Suez Canal Economic Zone.

Introduction: EU plans to import green hydrogen

In 2020 the European Commission released its hydrogen strategy,[1] promoting 'low-carbon' hydrogen as an important tool in decarbonising Europe's economy, including a big focus on 'green' hydrogen produced using renewable electricity. The EU is targeting 40 GW of new electrolyser capacity by 2030 to manufacture this green hydrogen.

However, the EU and its member states (particularly Germany) are clear that if the EU wants to create a 'hydrogen economy', one that far exceeds today's limited usage, it will not be able to produce enough green hydrogen domestically, and thus will have to import it. Therefore the strategy also targets the installation of 40GW of capacity in the EU neighbourhood, specifically the Ukraine and North Africa, predicted to produce 5.6 million tonnes of hydrogen per year by 2030.[2]

The EU ensured that green hydrogen was at the centre of the recent European Union-African Union Summit in Brussels,[3] and integrated it into the Africa-EU Energy Partnership.[4]

But since the invasion of Ukraine and the EU's subsequent attempts to diversify its energy supply away from Russian gas, green hydrogen has been given an even bigger job to do.[5] The Commission's RePowerEU communiqué, responding to the invasion, has doubled the import targets for green hydrogen to 10 million tonnes per year by 2030.[6] Realistically, the invasion also means Ukraine is far less likely to be able to export green hydrogen to the EU, which places an even greater expectation on North Africa to produce it.

Morocco, Algeria and Egypt all have plans to manufacture green hydrogen and synthetic derivatives such as ammonia and methanol and ship it to the EU via boats and pipelines to meet this projected demand. But how feasible are these plans, how much will they cost, and would this be the best use of renewables in those countries? Each country will be assessed in this study.

Current hydrogen use in the EU - a downward trend

As of 2021, the EU uses about 9.7 million tonnes of hydrogen a year in industrial processes - mostly in oil refineries and manufacturing fertilisers. The hydrogen is derived predominantly from unabated natural gas (known as 'grey hydrogen'), resulting in 70-100 million tonnes of CO2 emissions. This makes up 3% to 4% of the EU's annual emissions, even before upstream methane leaks are taken into account. The EU strategy is not focused on 'greening' current use, but if the EU is to achieve its climate targets then such carbon-intensive activities will have to significantly reduce, in turn greatly reducing EU demand for hydrogen.[7]

1 EU Hydrogen Strategy, 2020.

2 EU Hydrogen Strategy, 2020.

3 A hydrogen strategy for a balanced EU-Africa partnership, Euractiv, 2022.

4 Green Hydrogen: Bridging The Energy Transition In Africa And Europe, AEEP, 2020.

5 RePowerEU, 2022.

6 RePowerEU, 2022.

7 Shrinking Hydrogen Demand & Hydrogen Decarbonization Will Have Major Climate Benefits, Barnard, 2021.

Green hydrogen: expensive to produce, energy inefficient

Summary

Big question marks over whether green hydrogen can ever be exported at attractive prices due to high production and additional costs.

Reductions in electrolyser costs will not reduce capital costs as much as assumed.

To be cost-competitive green hydrogen needs cheap and constant electricity, which is costly with site-specific renewables.

Plugging electrolysers into the grid increases cost and CO2e footprint significantly, and undermines EU criteria.

As a storage medium for electricity, green hydrogen would provide only 37% of the energy used to make it, wasting more than 60% of the original electricity.

Green hydrogen is made through electrolysis, based on renewable electricity, and the EU and industry predict production costs rapidly falling as this technology achieves scale.

This assumption underpins their plans to create an European and global green hydrogen market that is competitive with both grey hydrogen or natural gas. In 2020, grey hydrogen, which is made from natural gas, could be produced in Europe for around €2/kg, while green hydrogen costs between €2.5-5.5/kg.[8]

However, it is actually highly questionable whether green hydrogen can ever be exported at attractive prices.

The colours of hydrogen:

Green: hydrogen produced by electrolysis of water using electricity from renewable sources like wind or solar.

Blue: hydrogen produced from fossil fuels where CO2 is captured and either stored or repurposed.

Grey: hydrogen extracted from natural gas using steam-methane reforming. This is the most common form of hydrogen production in the world today.

Yellow: hydrogen produced by electrolysis using grid electricity from various sources (i.e., renewables and fossil fuels).

Turquoise: hydrogen produced by thermal splitting of methane (methane pyrolysis). Instead of CO2, solid carbon is produced.

Purple/pink: hydrogen produced by electrolysis using nuclear power.

Brown/black: hydrogen extracted from coal using gasification.

Colours of hydrogen chart courtesy the Applied Economics Institute[9]

Cost of components unlikely to decrease

The standard generation process for green hydrogen uses a proton exchange membrane (PEM) electrolysis unit. But as the International Renewable Energy Agency (IRENA) showed in its report on scaling,[10] many additional components surround the electrolyser, and these very standard technologies have already achieved high optimisation due to large scale manufacturing and deployment.

As Paul Martin of the Hydrogen Science Coalition[11] points out, while the cost of electrolysers might decrease, the surrounding components are less likely to decrease in cost.[12]

The capital cost of the hydrogen manufacturing plant makes up a significant part of the total cost of hydrogen production, so reductions in the cost of the electrolyser won't reduce overall capital costs as much as many claim.

8 EU Hydrogen Strategy, 2020.

9 https://aeclinic.org/aec-blog/2021/6/24/the-colours-of-hydrogen.

10 Green Hydrogen Cost Reduction, IRENA, 2020.

11 Hydrogen Science Coalition.

12 Paul Martin Talks H2 Science Coalition & More Problems With Hydrogen, CleanTechnica, 2022.

Wright's Law: economies of scale already operative

Vertical scaling refers to making physical plants bigger to gain economies due to basic laws of physics. Taller wind turbines get more consistent and stronger wind further from the ground, and longer wind turbine blades capture much more wind.

Scaling by numbers or horizontal scaling involves manufacturing many more units of something. The efficiency curve, also known as Wright's Law, observes that after the first few dozen of a new product are manufactured, statistically every doubling of units manufactured leads to a reduction of unit cost by 20% to 28%. This applies to new elements, but common components like basic electrical pumps and piping have already reached the end of efficiency gains.

Thus, while electrolysis plants may improve efficiency through vertical scaling, as only the electrolyser component is novel, it alone will decrease in price.

Cheap electricity and constant supply unlikely with renewable energy sources

For green hydrogen to be cost-competitive with grey hydrogen (which cost €2/kg to manufacture before gas prices spiked),[13] Lazard's 2021 levelized cost of hydrogen analysis (see table below),[14] shows that electricity used to create it has to be extremely cheap and the system has to run continuously. Otherwise green hydrogen will be prohibitively expensive.

PEM (100 MW)

Energy Cost ($/MWh)	Electrolyzer Utilization				
$/kg	100%	90%	80%	70%	60%
$10	$1.26	$1.32	$1.37	$1.50	$1.65
$20	$1.57	$1.62	$1.68	$1.81	$1.96
$30	$1.88	$1.93	$1.99	$2.11	$2.27
$40	$2.19	$2.24	$2.30	$2.42	$2.58
$50	$2.49	$2.55	$2.60	$2.73	$2.88

Price sensitivity of hydrogen manufacturing to utilization and cost of electricity, Lazard, Levelized Cost of Hydrogen, 2021[15]

13 EU Hydrogen Strategy, 2020.

14 Levelized Cost of Hydrogen, Lazard, 2021.

15 Lazard LCOEs are unsubidised global averages, and the best available without specific project details https://www.lazard.com/media/451779/lazards-levelized-cost-of-hydrogen-analysis-vf.pdf.

Wind and solar farms in a limited geographical region are intermittent by their nature, thus raising costs of hydrogen production:

- Wind energy: areas with good onshore wind energy resources which are inexpensive to build see capacity factors (the percentage of potential generation for a year that is actually generated) in the range of 37%, and wholesale cost of electricity prior to transmission in the $20 per MWh range. Offshore is better, regularly seeing 45% to 50% capacity factors, but at costs above $50 per MWh.

- Solar energy: photovoltaic (PV) solar plants in good solar areas see annual capacity factors of 20% to 25%, generating electricity for potentially a dozen hours a day near the equator (although weaker in the morning and evening). Average industry wholesale costs are in the $30 per MWh range, excluding transmission.

Attempts to lower the 'Energy Cost' ($/MWh) by only running the electrolyser when electricity is very cheap also leads to low utilisation rates and high costs. Green hydrogen was initially marketed this way - produced from "excess" renewable electricity when there was too much wind or sun for the grid.

Ensuring high electrolyser utilisation rates by connecting the system to the grid will mean a high energy cost from retail electricity prices likely to be well over $50 per MWh. In Morocco, Algeria and Egypt, the grids are predominantly run on fossil fuels, meaning the CO2e footprint of the hydrogen goes up significantly. This also undermines the EU's strict criteria for green hydrogen, which state that green or renewable hydrogen must come from renewable sources other than biomass.[16]

Due to the dependence on wind and solar for green hydrogen, it is reasonable to assume that the likely best case scenario for hydrogen manufacturing cost is prices in excess of $2/kg (see box). And as Lazard points out, other factors could also increase costs, including development costs of the electrolyser and associated renewable energy generation facility, conversion, storage or transportation costs and costs to upgrade existing infrastructure, amongst others.[17] Therefore the hydrogen produced may involve a lot of additional costs.

16 New Definitions for Blue and Green Hydrogen, Inside Energy & Environment, 2022. https://www.insideenergyandenvironment.com/2022/01/new-definitions-for-blue-and-green-hydrogen-the-european-commissions-package-on-hydrogen-and-decarbonized-gas-markets/.

17 Levelized Cost of Hydrogen, Lazard, 2021. https://www.lazard.com/media/451779/lazards-levelized-cost-of-hydrogen-analysis-vf.pdf

Energy inefficiency of manufacturing hydrogen

Manufacturing hydrogen is relatively energy inefficient, and using it as a source of energy is inefficient as well. Best in class PEM electrolysers are 70% efficient at turning electricity into equivalent heat energy.[18] Turning it back into electricity is at best 60% efficient in modern fuel cells. There are storage and distribution efficiency losses as well. Therefore if green hydrogen were used as a storage medium for electricity, it would only provide 37% of the energy originally used to make it in the best case scenario, meaning close to 60% of the renewable energy would be wasted.

Using hydrogen as a source of heat is somewhat more efficient. The manufacturing inefficiencies apply, but when burnt it releases 100% of the heat energy. However, some of it is lost to water vapour losses, and distribution inefficiencies also occur.

How much green hydrogen could be produced by a GW of solar?

It takes about 50 MWh for process heat to electrolyse a metric tonne of hydrogen. The other components in the process also consume electricity, so just manufacturing the tonne of hydrogen consumes approximately 60 MWh. A GW of solar will produce about 2,190 GWh of electricity in a year, assuming a 25% capacity factor. That in turn would manufacture about 36,500 metric tonnes of hydrogen.

The energy density by mass of hydrogen is quite a bit higher than methane, the primary component of natural gas. Hydrogen's energy density is 2.5 times that of natural gas'.[19] Thus the hydrogen is the energy equivalent — at the point of manufacturing — of about 93,000 metric tonnes of natural gas, or about 110 million cubic metres of natural gas.

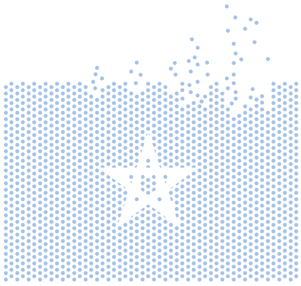
While that may sound like a lot, in 2018 Algeria exported approximately 52 billion cubic metres of natural gas, mostly to Europe.[20] A GW of solar electrolysis would thus create 0.2% of Algeria's 2018 energy exports, meaning it would need 500 GW of solar (plus electrolysers) to produce enough hydrogen to replace gas exports. That is more than a thousand times what currently exists, with major implications for land and resource use.[21]

18 Using the lower heat value (LHV) efficiency that determines usable energy and excludes the vaporisation of excess water.

19 Energy Density of some Combustibles (in MJ/kg), Transport Geography.

20 Algeria Natural Gas: Exports, 1960-2020, CEIC Data.

21 Energy Profile – Algeria, IRENA, 2021



Morocco's Green Hydrogen Vision

Morocco aims to replace ammonia imports with local green production for its national fertiliser industry: big domestic use and a significant export product

Beyond potentially eliminating high ammonia emissions, other touted uses of green hydrogen don't hold up to scrutiny

Many potential green hydrogen projects with Germany, but low electrolyser utilisation rates mean likely reliance on grid electricity

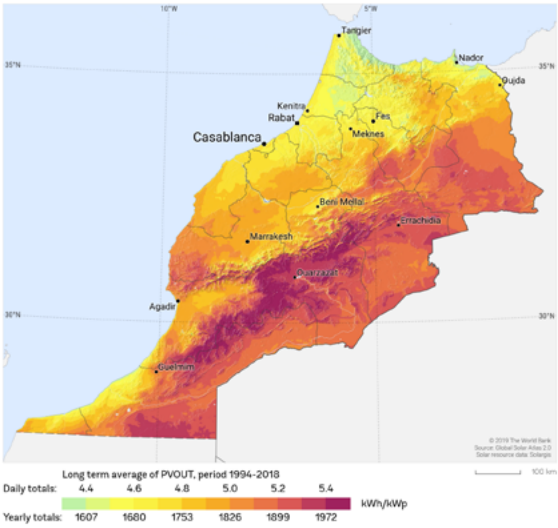
Green ammonia project with Dutch commodity trader Vitol based on unproven technology, looking to export as far as the US

Plans to ship green hydrogen face multiple challenges and high costs

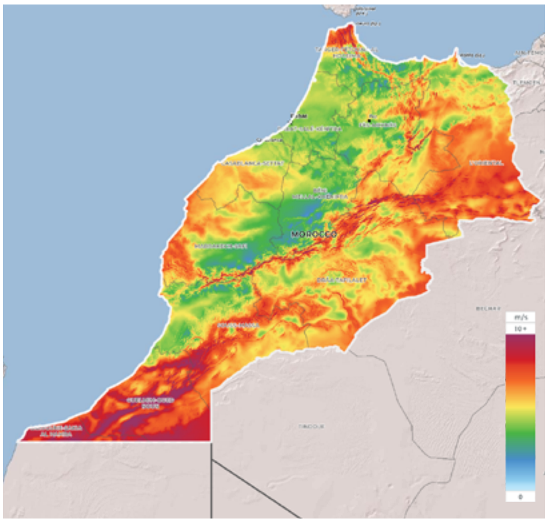
Renewables could instead replace 27 TWh of coal and meet local energy needs; interconnectors with North Africa and the Middle East, and eventually the EU, could help balance the grid

Morocco, which has an abundance of wind and solar resources, has recently developed a Green Hydrogen Roadmap,[22] as well as other policies and international collaborations on hydrogen.[23]

SOLAR RESOURCES MAP
PHOTOVOLTAIC POWER POTENTIAL



GLOBAL WIND ATLAS
MEAN WIND SPEED AT 100m



Morocco has abundant solar and offshore wind resources[24]

Green Hydrogen Roadmap

Despite being one of the world's top five fertiliser exporters and possessing over 70% of the world's phosphate reserves,[25] Morocco still imports 1.8 million tonnes of grey ammonia annually to provide nitrogen for its fertilisers, primarily from Russia.[26] Grey ammonia is manufactured using hydrogen from natural gas - this not only exposes Morocco to global markets and price spikes, but also results in high emissions. Hence the country's objective in the Green Hydrogen Roadmap that, "The establishment of a national industry based on hydrogen would firstly replace ammonia imports with a local production of this important raw material for the fertiliser".[27]

Nitrogen fertilisers are a major climate problem, with every tonne used corresponding to up to 12 tonnes of CO2e.[28] Morocco's agricultural sector provides 15% of the country's GDP. It relies heavily on ammonia-based fertiliser, so reducing it in the short term coudl have significant climate impact before transitioning away from fertiliser use entirely.

22 Green Hydrogen Roadmap: Energy Transition Vector and Sustainable Growth plan, Kingdom of Morocco, 2021.

23 Morocco, Germany to jointly work on green hydrogen production, Renewables Now, 2020; and in the EU-Morocco "Green Partnership" announced before COP26, EU and Morocco form a Green Partnership on energy, climate and the environment ahead of COP 26, European Commission, 2021.

24 Global Solar Atlas, Global Wind Atlas.

25 Leading fertilizer exporting countries worldwide in 2020, based on value, Statista, 2021.

26 Morocco's OCP aims to boost fertiliser output despite lack of Russian ammonia, Reuters, 2022; Morocco Ammonia; anhydrous imports by country in 2019, World Integrated Trade Solution, 2019.

27 Green Hydrogen Roadmap: Energy Transition Vector and Sustainable Growth plan, Kingdom of Morocco, 2021.

28 Three tonnes come from upstream methane emissions through leakage, three from manufacturing hydrogen from natural gas (see box on blue hydrogen), and up to six after being spread on fields as it turns into nitrous oxide, with a global warming potential of 265.

The Roadmap, however, rapidly diverges into areas where hydrogen is touted as an energy solution, but these proposals don't hold up to scrutiny:

- Blending with methane in natural gas pipelines: While at present Morocco is not a natural gas exporter, it has rich reserves that European firms are working to exploit and send through the Maghreb-Europe Pipeline.[29] Morocco is considering blending hydrogen with natural gas in the pipeline, however this makes neither energetic nor economic sense, as the chapter on Algeria shows.

- Vehicle fuel: this continues to be promoted, even though battery electrification is likely to dominate all but the most extreme modes of transportation, deep-water shipping[30] and long-haul aviation in the future.[31]

- For electricity: The conversion losses from turning electricity into hydrogen and then back into electricity via fuel cells mean you are left with about 37% of the original energy. Using hydrogen for electricity instead of natural gas means wasting two-thirds of the renewable electricity instead of just using the electricity directly.

- Crude oil refining: The use of hydrogen to refine crude oil is also likely to diminish rapidly as peak oil demand is reached later this decade.[32]

Thus while green hydrogen manufactured in Morocco could help eliminate high-emissions ammonia inputs, it does not offer much viable potential for other envisaged uses.

German green hydrogen partnership

Multiple green hydrogen projects in Morocco involve German governmental or technical institutes, including the "Power-to-X" scheme. Under the cooperation pact between both governments the Moroccan Sustainable Energy Agency (MASEN) will build a 100 MW renewable facility to manufacture green hydrogen.[33]

However, even with a wind and solar farm directly connected to a hydrogen manufacturing plant, it will still have limited electrolyser utilisation rates (20% to 25%) and high energy costs (see 'Green hydrogen' section). As a result, to bring down hydrogen production costs electricity would likely have to be taken from the grid, at a current cost of $0.108 USD per kWh.[34] It would also create significant CO2 issues, given that 81% of Morocco's electricity generation in 2019 was non-renewable.[35]

29 U.K. firms spearhead Morocco's natural gas ambitions - MarketWatch 2022.

30 Global Shipping Less Of CO2e Problem Today Than Aviation, More By End Of Century, Barnard, CleanTechnica, 2022.

31 How Aviation Will Decarbonize Decade By Decade Until 2100, Barnard, CleanTechnica, 2021.

32 Shrinking Hydrogen Demand & Hydrogen Decarbonization Will Have Major Climate Benefits, Barnard, 2021.

33 Morocco, Germany to jointly work on green hydrogen production, Renewables Now, 2020.

34 Morocco electricity prices.

35 Energy Profile - Morocco, IRENA.

Green ammonia from unproven technology

A second collaboration involves Irish Fusion Fuel, Greek Consolidated Contractors Company, and Dutch energy and commodities trader Vitol. The project aims to manufacture 31,000 tonnes of hydrogen annually, in order to create 183,000 tonnes of green ammonia for fertiliser production.[36] However, the technology involved is still unproven[37] and Fusion Fuel's claims regarding solar panel efficiencies have not been independently verified.[38] The company also indicates the system can be plugged into the grid to deliver hydrogen overnight, which would mean relying on fossil fuel-generated electricity rather than renewable energy sources (as specified by the EU). This would therefore not be classified as 'green' hydrogen.

Vitol has indicated that it will look at all markets for ammonia, including shipping to the USA, although the cost may prove prohibitive. As Morocco already imports ammonia, reversing that trend and shipping surplus green ammonia to Europe could be a more viable alternative. However, making significant bets on unproven hydrogen technologies is a gamble, when there are already proven technologies and vendors.

Shipping hydrogen to the EU: expensive and inefficient

More problematically, Morocco is considering shipping green hydrogen exports in conjunction with IRENA.[39] While short-sea hydrogen shipping isn't quite as challenging as deep-sea shipping due to the shorter routes, nevertheless the technical and economic challenges persist (see box 'the challenges of shipping hydrogen').

The challenges of shipping hydrogen[40]

- Shipping hydrogen requires liquifying it by chilling it to -249° Celsius. It takes three times the energy to liquify hydrogen as it does to liquify natural gas (LNG).
- As liquid hydrogen is less energy dense than LNG, a ship with the same volume could only carry 27% of the energy in hydrogen that it could carry in natural gas.[41]
- Due to low boiling temperatures, at least 0.2% of the hydrogen will boil off every day the ship is in port or in transit. Moreover hydrogen can't be re-liquified as LNG would, due to the much greater energy and technical requirements.[42] A short-sea shipping journey of 15 days from Morocco to Rotterdam could thus lead to around 3% of the hydrogen being lost.

36 Announcement of Fusion Fuels, CCC, Vitol project.

37 Fusion Fuel intends to manufacture hydrogen using only solar energy and its proprietary micro-proton exchange membrane electrolysis unit embedded directly in the solar collectors. The test site in Évora, Portugal, was supposed to have been in production in mid-2021, but there is no indication that it is working at this point. Fusion Fuels projects page.

38 Fusion Fuels claim efficiencies of 40% in converting solar energy to electricity, something at the outer limits of solar panel performance achievable in a minute percentage of circumstances, plus use of the 60% of waste thermal solar heat for efficient manufacturing. Commercial solar panel efficiency is typically in the range of 15%-20%. They indicate that they can be plugged into the grid to deliver hydrogen overnight, despite losing the 60% thermal heat component. Fusion Fuel technology page.

39 Morocco eyes green hydrogen exports with IRENA renewables collaboration, S&P Global, 2021.

40 Shipping Liquid Hydrogen Would Be At Least 5 Times As Expensive As LNG Per Unit Of Energy, Barnard, CleanTechnica, 2021.

41 Comparison of Alternative Marine Fuels - SEA\LNG Ltd, 2019.

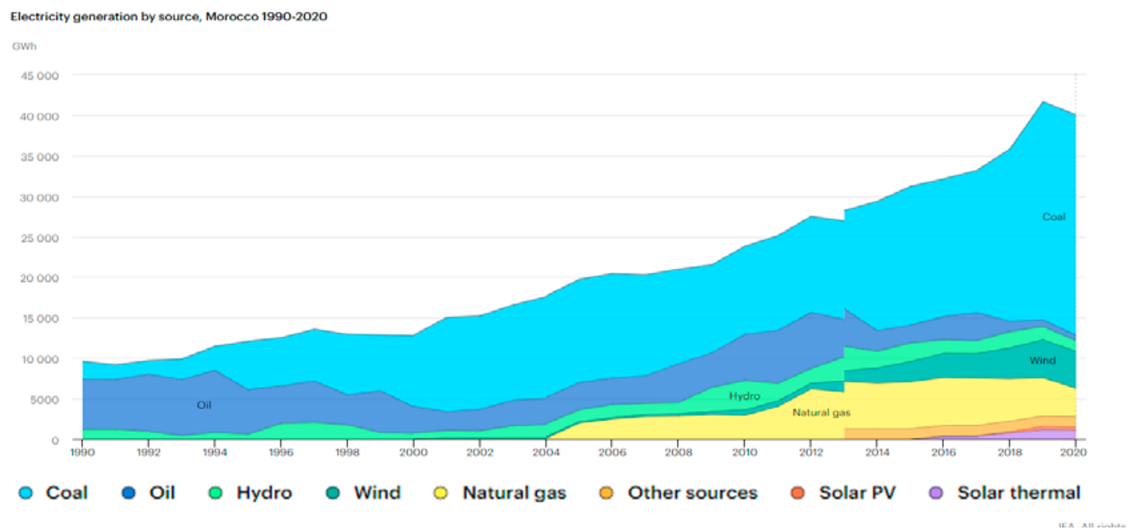
42 While boiled-off LNG can be re-liquified, this is not possible for hydrogen due to the much greater requirements of getting it to -249° Celsius. Global Shipping Less Of CO2e Problem Today Than Aviation, More By End Of Century, Barnard, CleanTechnica, 2022.

The combination of low utilisation factors or high electricity costs for electrolysers in Morocco combined with the high cost per unit of energy delivered to the EU makes shipping deeply uneconomical. Morocco and IRENA should thus be cautious of shipping hydrogen as a chemical for use in industry in the EU, and even more so as an energy medium.

What could Morocco do with its renewable electricity instead?

The most obvious thing for Morocco to do with renewable electricity is to use it to replace the over 27 TWh of electricity that the country generates from coal annually. Coal generation emits a metric megatonne of CO_2 per TWh of generation - so 27 MT of CO_2 could be directly avoided annually if coal generation were replaced with renewables. Morocco is aiming to generate 52% of its electricity from renewables by 2030.[43]

Electricity generation by source for Morocco



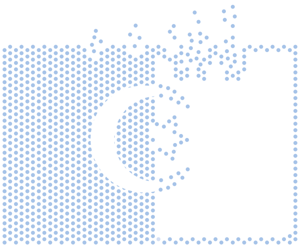
courtesy IEA[44]

If Morocco decides to become an energy supplier to the EU, it could use the existing 1.5 GW capacity undersea transmission connection linking it to Spain. Expanding the Euro-Mediterranean electricity network, MEDGRID, with high voltage, direct current (HVDC) cables, with losses of 3.5% per 1,000 km, would deliver over 95% of the renewable electricity directly to Europe's grid at a fraction of the cost of turning it into hydrogen.

It makes little sense for Morocco to use its renewable electricity to make hydrogen and hydrogen products, and then ship them to Europe at significant loss of energy, so that the EU can achieve higher climate emissions reductions.

43 Morocco, Climate Action Tracker, 2021

44 IEA Morocco Energy Overview.



Algeria's Hydrogen Pipeline Fantasy

Algeria plans to gradually switch EU exports from natural gas to green and blue hydrogen via its pipelines and LNG terminals.

Eni's green hydrogen from solar project likely to cost in the range of USD$4.40/kg, 11 times more per unit of energy than natural gas.

Blue hydrogen (with Carbon Capture and Storage) would cost more than double grey hydrogen, and five times the cost of natural gas per unit, with significant methane emissions.

As an oil producer, Algeria is likely to use captured CO2 for enhanced oil recovery.

Transporting hydrogen via pipeline damages equipment, triples transport costs and leads to high fugitive emissions.

It will cost additional billions to transport Algeria's green and blue hydrogen - is Europe willing to pay 5-11 times what it currently pays for energy?

Algeria could instead reach its goal of 27% of electricity from renewables by 2030 at a cost of USD$7bn, partially displacing natural gas.

Abundant wind and solar resources in Algeria[45]

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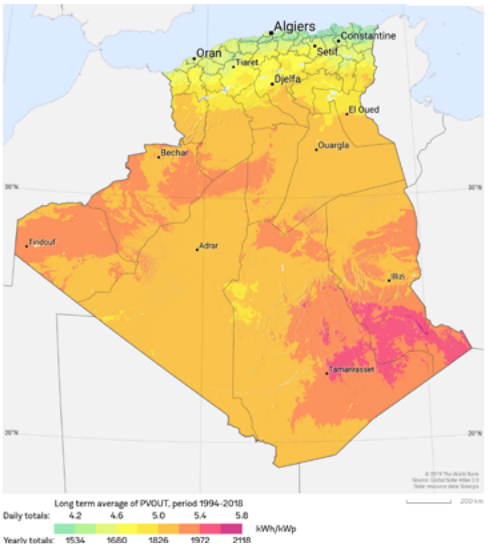

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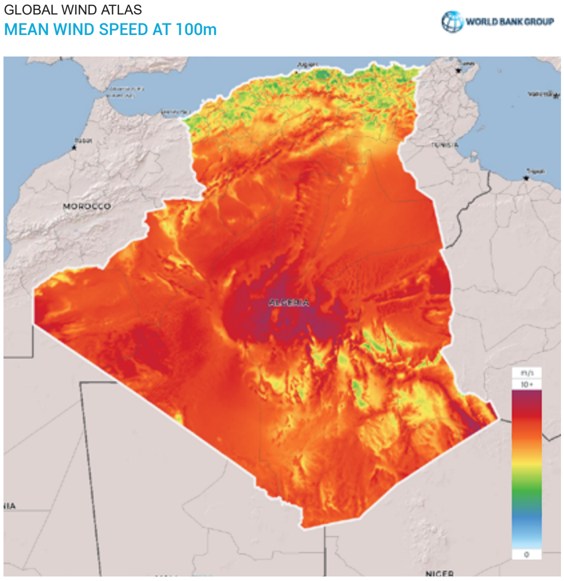


Despite its abundant wind and solar resources, Algeria has done little to exploit them. Renewables represent less than 1% of its electricity supply,[46] and the country is lagging on electrification of heating, transportation and industry as well. This is in part because Algeria is a long-time oil and gas producer, and a trusted provider of natural gas through pipelines and LNG shipping to the EU. Its national oil firm, Sonatrach, has strong relationships with fossil fuel companies in Europe.

Substituting natural gas with hydrogen

Algeria intends to first add to, and then replace, the natural gas flowing to Europe through its pipelines and in its LNG ships with green and blue hydrogen.[47] Algeria's domestic energy transition plan also calls for 25 GW of power generation from green and blue hydrogen by 2050.[48]

Italian multinational Eni's hydrogen plans

Italian multinational oil and gas company Eni has extensive holdings in Algeria and has already signed several memorandums of understanding with Sonatrach on hydrogen manufacturing.[49] It intends to build a GW of solar energy for green hydrogen production. However, relying on solar alone would restrict electrolyser utilisation rates to 20-25%, as the plant will sit idle at night and tail off in the mornings and evenings. This suggests that the pure solar planned for Algeria would have a hydrogen cost in the range of USD$4.40/kg or USD $4,000 per tonne prior to

45 Global Solar Atlas.
46 Algeria - Key energy statistics, 2019 - IEA, 2019.
47 Énergie: L'Algérie prend option pour l'hydrogène vert, 24H Algeria, 2021
48 Algeria's Energy Transition Plan, International Trade Administration, 2021.
49 Algeria's Sonatrach and Eni to explore hydrogen production, H2 Bulletin, 2021.

any storage, distribution or leakage costs. This would be about 11 times more expensive per unit of energy than natural gas prior to the massive price increases from winter shortages and the invasion of the Ukraine, and still three times more expensive than today's highest prices per unit of energy.[50]

Moreover a GW of solar would only supply enough hydrogen to cover 0.2% of Algeria's 2018 natural gas exports. Switching all 52 bcm to green hydrogen would therefore require 500 GW of solar energy, which is more than a thousand times Algeria's current installed solar capacity.[51]

Eni is also considering blue hydrogen in Algeria, made from natural gas using steam methane reformation (SMR) with carbon capture and storage (CCS).[52] The methane emissions from such production are a big climate problem, while captured CO2 is widely used for enhanced oil recovery (EOR), also increasing emissions (see box, 'costs and climate impacts of blue hydrogen'). Basic cost calculations show blue hydrogen costing less than half the price of Eni's solar-generated green hydrogen, but this would still be more than double the price of grey hydrogen, and five times more expensive than natural gas per unit of energy at pre-spike prices.

As an oil-producing country, Algeria is likely to be interested in the short to medium-term in using captured CO2 for enhanced oil recovery, with a preference for expensive blue hydrogen over even more expensive green hydrogen, despite the climate impact.

Costs and climate impacts of blue hydrogen

Blue hydrogen costs

Capture, storage, distribution and sequestration of CO2 costs from USD $100 to $140 per metric tonne[53] even after decades of optimisation, meaning we will not see massive cost reductions in future.[54] Thus fossil hydrogen with CCS ('blue hydrogen') is still likely to be cheaper than electrolysers running at 25% efficiency, but much more expensive than the grey hydrogen currently used.

While hydrogen made from natural gas using steam methane reformation (SMR) might have a manufacturing cost of $800 per tonne, capturing and sequestering the carbon would add a cost in the range of $800 to $1,400, bringing the cost to a median of $1,900 per tonne. This is less than half the cost of Eni's green hydrogen (see above), but still five times more expensive than natural gas per unit of energy pre natural gas price spikes. Even grey hydrogen (without CCS) is still multiple times more expensive per unit of energy than the natural gas it is made from.

Blue hydrogen emissions

Methane from fossil fuel sources has a global warming potential 82.5 times that of carbon dioxide over 20 years according to the latest IPCC report.[55] Outside of very careful sealing and maintenance of all methane extraction, processing and distribution infrastructure (often thousands of kilometres of pipes running through rugged terrain), there is no methane capture and sequestration solution, meaning fugitive emissions in the upstream phase.

50 European Union Natural Gas Import Price is at a current level of $32.20, down from $42.39 last month and up from $7.147 one year ago. European Natural Gas Import price.

51 Energy Profile – Algeria, IRENA, 2021

52 Algeria's Sonatrach and Eni to explore hydrogen production, H2 Bulletin, 2021

53 Carbon capture is expensive because physics, Barnard, The Future is Electric, 2019.

54 The world has been capturing CO2 in industrial processes for 150 years and using it for enhanced oil recovery (EOR) for 50.

55 IPCC Sixth Assessment Report Global Warming Potentials, ERCE, 2021.

According to Howarth and Jacobson, who use a baseline of 3.5% of upstream methane emissions, CO_2e emissions from a tonne of grey hydrogen are in the range of 16-20 tons of CO2.[56] Assuming an 85% efficient CO2 capture, as Howarth and Jacobson do, blue hydrogen emissions are in the range of 9-12 tons of CO2e per tonne.[57] A European life cycle assessment has a lower figure for best case upstream emissions (1.5% is often quoted), so emissions could be lower but still significant.

Waste CO2 and storage

When hydrogen is made from natural gas using steam reformation, 8-10 times the mass of CO2 is emitted as the created hydrogen. Theoretically, the CO2 captured while making blue hydrogen is injected underground in repositories for sequestration. However, as carbon dioxide is almost three times heavier than methane, 2.75 times as much CO2 would have to be pumped underground as was extracted as natural gas in the first place. The process creates vastly more waste CO2 than either the natural gas or the valuable hydrogen.

Enhanced Oil Recovery

This author has assessed every major carbon capture sequestration installation globally,[58] and the vast majority of them are used for enhanced oil recovery (EOR), injecting CO2 into tapped out oil wells to pump out previously unextractable crude oil. Every tonne of CO2 injected for EOR returns 0.25 to 1.0 tonnes of crude oil. This results in 2-3 tonnes of new CO2 when the crude oil is turned into fuel and burned.

Shipping hydrogen: costly conversion required

Algeria already has LNG export shipping facilities which could be converted, at considerable expense, to manage hydrogen. As mentioned in the section on shipping, liquifying hydrogen takes three times the energy as natural gas, the same volume would only contain 27% of the energy, and at least 0.2% of the hydrogen would be lost daily due to boil off.

Algeria has natural gas pipelines, and proposes to first blend hydrogen with natural gas, and then move to 100% hydrogen.

Blending in Pipelines: energy inefficient

Algeria initially proposes blending up to 20% of hydrogen with natural gas in its existing pipelines.[59] However, given the lower energy density by volume of natural gas, a cubic metre of 20% blended natural gas and hydrogen only has 86% the energy of a cubic metre of natural gas. Thus you would have to burn 14% more of the blend to get the same energy. This means that at best only 6% less CO2 is emitted when the mixture is burned to achieve the same energy. Further, the mixture is more diffuse, and hence requires more energy to compress and pipe than natural gas.[60]

Such a mixture will be significantly more expensive than natural gas alone. Further, at

56 Even at 1.5% upstream methane emissions, another commonly cited number, CO2e emissions from a tonne of grey hydrogen would still be in the range of 13-15 tonnes.

57 How green is blue hydrogen?, Howarth and Jacobson, 2021.

58 Carbon Capture's Global Investment Would Have Been Better Spent On Wind & Solar, Barnard, CleanTechnica, 2019.

59 Does Algeria export hydrogen in gas pipelines? Benatou Ziyan speaks to "Energy" - Attaqa, 2022 - Translated via Google Translate.

60 Is Hydrogen The Best Option To Replace Natural Gas In The Home? Looking At The Numbers, Paul Martin, CleanTechnica, 2021.

20% per volume, there is a likelihood that the challenges brought by hydrogen necessitate upgrades along the supply chain (see below). More energy to move a much more expensive gas that only results in 6% greenhouse gas emissions reductions doesn't seem like a worthwhile climate solution.

Hydrogen in Pipelines: problems ahead

There are multiple problems with reusing existing natural gas transmission pipelines to carry hydrogen.[61] The first is metallurgical. Long-distance pipelines for natural gas are assembled on site from sections of spiral coiled steel and welded. As pressure changes in the pipes (something which occurs multiple times per day with pumping regimens) microfractures occur, especially in the welded areas. Hydrogen molecules, being the smallest in the universe, slip into the fractures and can substantially shorten the service life of pipelines designed for natural gas. This can also lead to significant losses, as hydrogen will leak much more readily. The standard 3.5% upstream methane leakage is likely to be much higher with hydrogen, which is more expensive than methane. Hydrogen also has a global warming potential 7.9 times that of CO2 over 100 years.[62]

The second problem is the energy required to push hydrogen through the pipe. Hydrogen, being much more diffuse than natural gas, requires three times the energy to move an equivalent volume the same distance, also tripling the costs. Hypothetically, if Algeria were to export 52 billion cubic metres of hydrogen rather than natural gas using the Maghreb-Europe pipeline, the energy transport costs are estimated to increase from USD $1.8 billion[63] per year to $5.5 billion. This would be added to the price of delivered energy.

In addition to making major gas pipelines fit for hydrogen with sealants so that it doesn't leak badly, any compressors would have to be replaced at significant expense as they were not built for the energy needs of compressing hydrogen.[64] Hydrogen also interacts with electronic components differently than natural gas, so it is quite possible that sensors in the compressor stations and in the pipeline itself would also have to be replaced.

Algeria has a choice between producing blue hydrogen that costs five times what natural gas does per unit of energy and comes with a very large carbon burden, or green hydrogen that costs 11 times what natural gas does without a carbon burden. In both cases it will also cost billions more to export the hydrogen. Realistically, is Europe willing to pay 5-11 times what it was paying for natural gas in mid-2021?

61 Paul Martin Talks H2 Science Coalition & More Problems With Hydrogen, CleanTechnica, 2022; Is Hydrogen The Best Option To Replace Natural Gas In The Home? Looking At The Numbers, Martin, CleanTechnica, 2020.

62 Atmospheric implications of increased Hydrogen use, Warwick et al, BEIS, 2022.

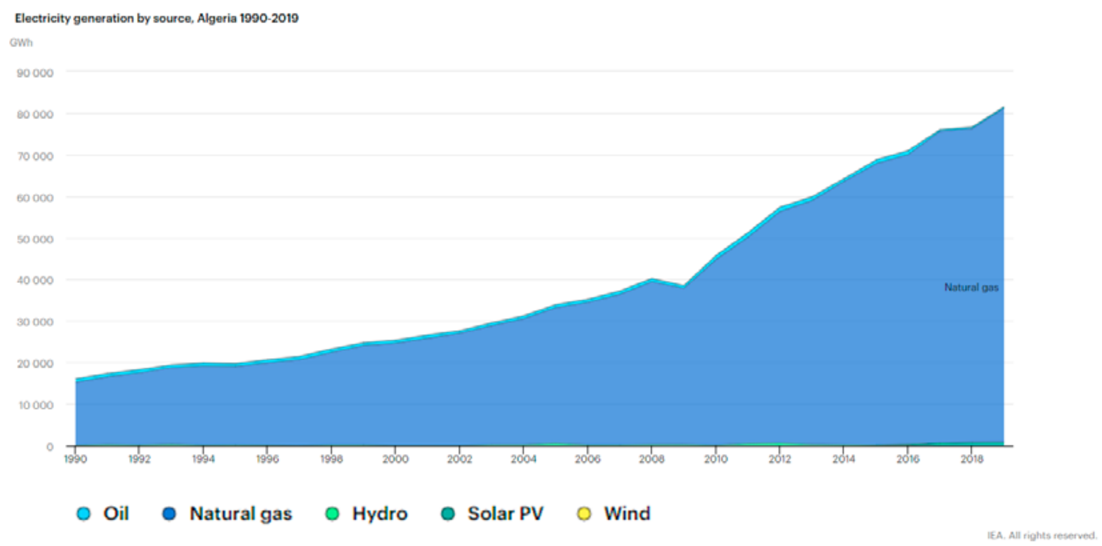
63 Estimating the Cost of Pipeline Transportation in Canada, Karangwa, Transport Canada.

64 Compressor stations fill large buildings with compressors, cooling equipment, scrubbers and filters and are typically placed every 70 to 110 kilometres. Understanding Natural Gas Compressor Stations, Penn State, 2015.

What could Algeria do with its renewable electricity instead?

Algeria is a country whose economy is heavily dependent on oil and gas exports, with an oil rent of 14.39%.[65] But as the costs of both shipping and pipelines show, hydrogen is expensive to distribute, which is a significant factor in why the large majority of it is manufactured at the point of consumption today. Replacing natural gas exports with hydrogen appears unlikely, but Algeria does have value propositions for both green energy and green hydrogen.

Electricity generation by energy source



Courtesy of IEA[66]

Build renewable to deliver on commitments

Algeria's Intended Nationally Determined Contribution (INDC) submitted to the United Nations commits to 27% of its electricity generation from renewables by 2030.[67] However, it is almost exclusively dominated by natural gas currently (see graph). The 80 TWh of natural gas generation represents roughly 40 megatonnes of CO2, plus more from upstream methane leakage.

Assuming an equal mix of wind and solar, reaching 27% renewables would require about 6 GW of solar capacity and 3.5 GW of wind energy capacity being developed in eight years, which would cost around USD$8 billion including transmission and storage.[68]

Natural gas prices have shot up following Russia's invasion of Ukraine, meaning so have Algeria's profits. That means Algeria and Sonatrach have billions in hand to pay for the wind and solar deployment and related infrastructure. But they also have other priorities for expenditure that will compete with renewables.

65 Algeria - Oil Rents (% of GDP), Trading Economics, 2019.

66 Algeria Energy Supply, IEA.

67 Intended Nationally Determined Contribution-INDC-Algeria, The People's Democratic Republic of Algeria, 2015.

68 With the plummeting price of wind and solar, the industry standard is now around $0.8 billion per GW, including storage and transmission.

Green own hydrogen consumption: fertiliser

Algeria is a major consumer and exporter of both ammonia and urea fertilisers,[69] which are made from hydrogen from natural gas. The country also has plans to further develop its phosphate sector for export.[70] Domestically it used about 15.5 million tonnes of fertiliser per year in 2018.[71] That fertiliser represents in the range of 180 million tonnes of CO2e, including upstream emissions. Replacing grey with locally produced green hydrogen to manufacture ammonia and urea would help Algeria achieve its climate goals, although it may not prove financially viable to export.

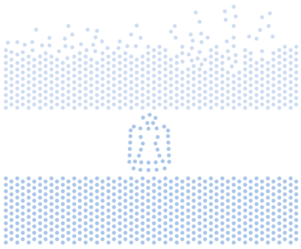
Algeria's 2020 energy transition plan targets 25 GW power generation from blue and green hydrogen by 2050,[72] but as the analysis shows, regardless of how the hydrogen is generated, using it for power generation would cause energy prices to skyrocket, while using blue hydrogen would also generate large carbon emissions.

69 Plants expanding production of fertiliser in Algeria, Oxford Business Group; in 2019 Algeria's fertiliser exports reached USD $851 million Total value of fertilizer exported from Algeria from 2012 to 2019.

70 Algeria invests $7 billion to produce fertilizer from phosphate, Econostrum, 2022.

71 Algeria - fertiliser consumption per unit of arable land, Knoema.

72 Algeria's Energy Transition Plan, International Trade Administration, 2021.



Egypt's Green Ammonia-Fuelled Shipping Dreams

Green hydrogen seen as a key economic development pathway, with Egypt already providing fiscal support measures and producing a strategy with the European Bank of Reconstruction and Development

Project with Maersk for hydrogen-based shipping fuels, green methanol and green ammonia to replace polluting bunker fuels

Green methanol is toxic, half the energy density and could cost five times as much to travel a similar distance

Green ammonia is also toxic, with spills on a ship potentially life threatening, and will cost more than double grey ammonia and almost four times as much as marine fuel

Multiple green and blue ammonia and hydrogen export projects, around the Suez Canal Economic Zone, involving Equinor, Toyota, Siemens, DEME, Eni

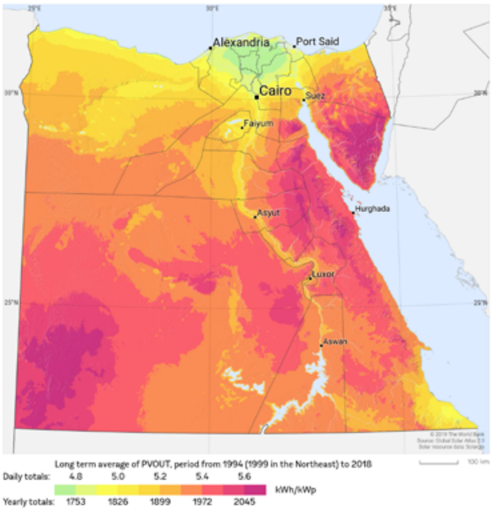
Eni exploring blue hydrogen, likely using CO2 for enhanced oil recovery

Egypt could alternatively use renewables to meet its climate target of 42% renewables by 2035, and replace oil and gas generation

Egypt also has abundant wind and solar resources, as well as the Aswan Dam, which supplies a surprisingly small percentage of its electricity today - about 7.5%.

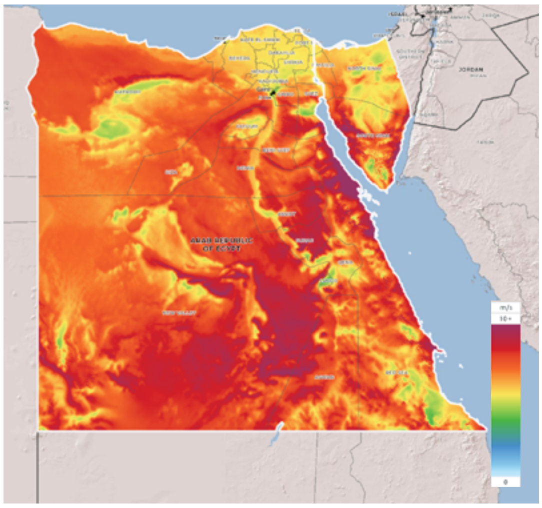
Wind and solar resources in Egypt are exceptional[73]

SOLAR RESOURCES MAP
PHOTOVOLTAIC POWER POTENTIAL



GLOBAL WIND ATLAS
MEAN WIND SPEED AT 100m

WORLD BANK GROUP



Egypt is not as reliant on oil and gas as Algeria, but direct revenues still represent 4% of GDP.[74] The country has been growing its natural gas exports, including LNG, with new offshore discoveries in the Mediterranean likely to add to this. However, the country does aim to generate 42% of its energy from renewables by 2035.[75]

Egypt's hydrogen plans: EBRD involved

The country currently produces 1.85 million tonnes of grey hydrogen per year,[76] and its green hydrogen plans are well underway. The government considers hydrogen a key economic development pathway and is providing a wide range of fiscal support for green hydrogen and ammonia projects.[77] A strategy, drawn up with the European Bank of Reconstruction and Development (EBRD) is expected by mid 2022 (see box 'Europe's development bank pushing hydrogen for energy'), and many projects involve EU companies. However, once again, many initiatives are also highly questionable from a cost-effectiveness or energy efficiency perspective.

73 Global Solar Atlas.

74 Oil rents (% of GDP) - Egypt, Arab Rep. - World Bank.

75 https://www.arabnews.com/node/1952441/business-economy.

76 Egypt aims to boost renewable energies to over 42% by 2035: Electricity minister, Arab News, 2021.

77 Investment Law No. 72 of 2017 provides a wide range of fiscal support: article 20 of the Investment Law enables projects deemed strategic by Cabinet to be granted a licence to operate and land in a single, rapid process; article 11 provides tax breaks from 30% to 50%; other provisions include state-funded grid connections and other benefits, see Egypt: Green hydrogen and green ammonia projects to benefit from state support. Baker McKenzie, 2022.

Europe's development bank pushing hydrogen for energy

In early 2022, Egypt's Ministry of Electricity and Renewable Energy and Ministry of Petroleum and Mineral Resources reached an agreement with the EBRD to develop a hydrogen strategy, expected by mid-2022.[78] Given the EBRD's positive view of hydrogen as an energy carrier (substituting natural gas), rather than as a chemical feedstock, it is reasonable to assume the resulting strategy will take a similar approach.[79]

Hydrogen vs electricity for industry

An EBRD spokesperson is on record as saying electricity does not work for high heat applications.[80] However, common electric steel mini-mills using electric arc furnaces reach 1,500° to 3,000° Celsius. Aluminium smelting also uses electricity at very high heat.

It is not currently possible to refuel most existing industrial infrastructure built for high-quality heat from natural gas with electricity. However, as industrial facilities are scrapped and replaced, using electricity as a source of high-quality heat is almost always viable, with very few industrial processes where there is no alternative to fuel.

Hydrogen is not currently used as an energy carrier, and electricity is significantly more fit for purpose, both more efficient and much cheaper. The EBRD would be better off focusing on displacing chemical feedstocks using grey hydrogen, helping countries retire legacy industrial infrastructure, and developing electrically powered industrial processes rather than pushing hydrogen as an energy source.

Hydrogen for shipping fuels: Maersk

Projects have been announced in Egypt with European firms focused on manufacturing shipping fuels. At present, multiple hydrogen-based technologies are being evaluated as replacements for highly polluting bunker fuel.[81] Danish shipping magnate Maersk is investing in early efforts around green methanol, although results are underwhelming at this point.[82] Others are considering green ammonia as a fuel, something which is likely to present more economic and technical challenges than green methanol.[83]

Green Methanol: toxic, expensive, inefficient

Methanol, a globally-produced alcohol, is toxic. It can cause significant health problems if ingested, if it gets on skin, is vaporised and inhaled, or if it gets in a person's eyes.

Green methanol is made by combining green hydrogen with captured CO2. Producing it is not only expensive, but its energy density is about half that of diesel or bunker fuel, meaning it would cost far more than today's shipping fuels. One tonne of green methanol could cost as much as USD $1,250,[84] but the equivalent fuel cost, given its energy density, would be closer to USD $2,500 for the same distance travelled. That is around five times the cost of

78 EBRD assesses low-carbon hydrogen in Egypt, EBRD, 2022.

79 See the EBRD article 'How green hydrogen could power tomorrow's industry', EBRD, 2021, as well as its approach to green hydrogen in Ukraine, see 'EBRD and Ukraine boost low-carbon hydrogen development', EBRD, 2021.

80 How green hydrogen could power tomorrow's industry, EBRD, 2021.

81 Bunker fuel is one of the waste by-products of refining crude oil, similar to asphalt, and is highly polluting. See 'At Last, the Shipping Industry Begins Cleaning Up Its Dirty Fuels', Maria Gallucci, Yale Environment 260, 2018.

82 Maersk Delivers $150 Million PR Win For Shipping Industry With Methanol Ships Purchase, Barnard, CleanTechnica, 2021.

83 Smells like sustainability: Harnessing ammonia as ship fuel, DNV, 2022.

84 Chevron's Fig Leaf: A Case Study of Carbon Engineering's Direct Air Capture Plan, Barnard, CleanTechnica Report, 2018.

conventional shipping fuel - although prices have risen since the invasion of Ukraine.[85]

Maersk has already reached a joint agreement with several Egyptian ministries and agencies for the development of a green hydrogen marine fuel facility in the Ain Sokhna economic zone near the Suez Canal.[86] Given the company's focus on methanol, it is likely that they will manufacture that fuel, but who will be willing to pay for it?

Green Ammonia: toxic, costly, untested as a marine fuel

Ammonia is also toxic and will kill a person who breathes it in concentrations as low as 0.5% of the atmosphere. If it comes in contact with water, it reacts quickly and turns into ammonium hydroxide, a caustic substance which can seriously damage lungs, before dissociating into ammonium and hydroxide, which are less harmful but still not safe for humans.[87] Shipping is by definition exposed to water, meaning ammonia spills on a ship could be life threatening.

As a fuel, ammonia takes three times the energy to ignite as diesel, which makes dual-fuel engines (running on diesel and ammonia) problematic. Burning anything in oxygen creates nitrous oxides, including a variant with 265 times the global warming potential of CO2.

Green ammonia will be made with green hydrogen, and therefore much more expensive. According to global commodity market specialists Argus, green ammonia will cost more than double the price of grey ammonia and almost four times as much as marine fuel - although this was before the current price spikes.[88] The first dual-fuel ammonia marine engine is only expected to be tested in 2024 – it is thus hardly a given that ammonia can become a marine fuel.

Egypt's official statements indicate that the country intends to manufacture both green methanol and ammonia, but whether these will be the shipping fuels of the future for the journeys that can't be electrified is clearly far from certain.

Exporting green and blue hydrogen and ammonia: EU and Asia

Ammonia isn't just being considered as shipping fuel, it is also being considered for export, especially to Asia. Ammonia is a key chemical feedstock for the manufacturing of fertilisers, and is also used directly as a fertiliser itself. Globally, its manufacture accounts for 37% of pure hydrogen demand.[89]

Like Algeria, Egypt is a big ammonia producer, including for export.[90] However, projections made by this author see hydrogen and ammonia increasingly being manufactured domestically in countries from decarbonised grid electricity, in part due to the high shipping costs.[91] Nevertheless Egypt has embarked on multiple green ammonia export projects, as well as blue ammonia and the export of green and blue hydrogen.

85 Rough average taken over the past 18 months for VLSFO, MGO and IFO380 fuels, Global Average Bunker Price, Ship & Bunker, 2022.

86 Egypt, Maersk sign MoU to build green hydrogen plant in Ain Sokhna, Egypt Today, 2022; Maersk explores new ways to accelerate green fuel production, Maersk, 2022.

87 Sharing chemistry with the community: The solubility and alkalinity of ammonia, University of Waterloo Chem13 News Magazine, 2015.

88 'Green' ammonia prices double that of regular supplies, Argus, 2021.

89 Green hydrogen's rise will coincide with falling demand, Barnard, Illuminem, 202.

90 Egypt 6th Producer, 5th Largest Exporter of Urea Worldwide, All Africa, 2021; Egypt, Arab Rep. Ammonia; anhydrous exports by country in 2019, World Integrated Trade Solution, 2019.

91 Global Shipping Less Of CO2e Problem Today Than Aviation, More By End Of Century, Barnard, CleanTechnica, 2022.

Green and blue hydrogen and ammonia export projects in Egypt

Who is involved	Details
equinor Norwegian Statec (part-owned by Equinor), Suez Canal Economic Zone, Egypt's Sovereign Fund, Ministry of Electricity and Renewable Energy[92]	- Signed Memorandum of Understanding - USD $5 billion deal to build green ammonia plant near the Suez Canal - Will start producing 1 million tonnes per year by 2025, increasing to 3 million tonnes - Mainly for export to European and Asian markets
TOYOTA TSUSHO Japan's Toyota Tshusho, Egypt's state-owned Egas, Egyptian Petrochemical Holding[93]	- Agreed to begin exploring opportunities - Manufacturing ammonia from blue hydrogen (using CCUS technology) - Exporting blue ammonia to Japan
SIEMENS Germany's Siemens, Egyptian Electricity Holding Company[94]	- Signed Memorandum of Understanding - Developing hydrogen industry with "export potential"
DEME Belgium's DEME, Egyptian Electricity Holding Company[95]	- Agreement to undertake studies into implementation of green hydrogen trial project - In line with EU and Belgian emissions reduction plans - Potentially for export to Belgium
eni Italy's Eni, Egyptian Natural Gas Holding Company[96]	- Signed agreement to assess technical and commercial feasibility of hydrogen production - Will conduct study to explore green and blue hydrogen potential (storing CO2 in "depleted" gas fields) - Explore local market and export opportunities

All of these export projects may struggle to find an export market: green ammonia is double the price of grey ammonia; exporting green hydrogen in liquid form via ships or in gaseous form via pipelines is very expensive for the units of energy delivered; blue hydrogen, and therefore blue ammonia, is not compatible with the emissions reductions laid out in the Paris Agreement.

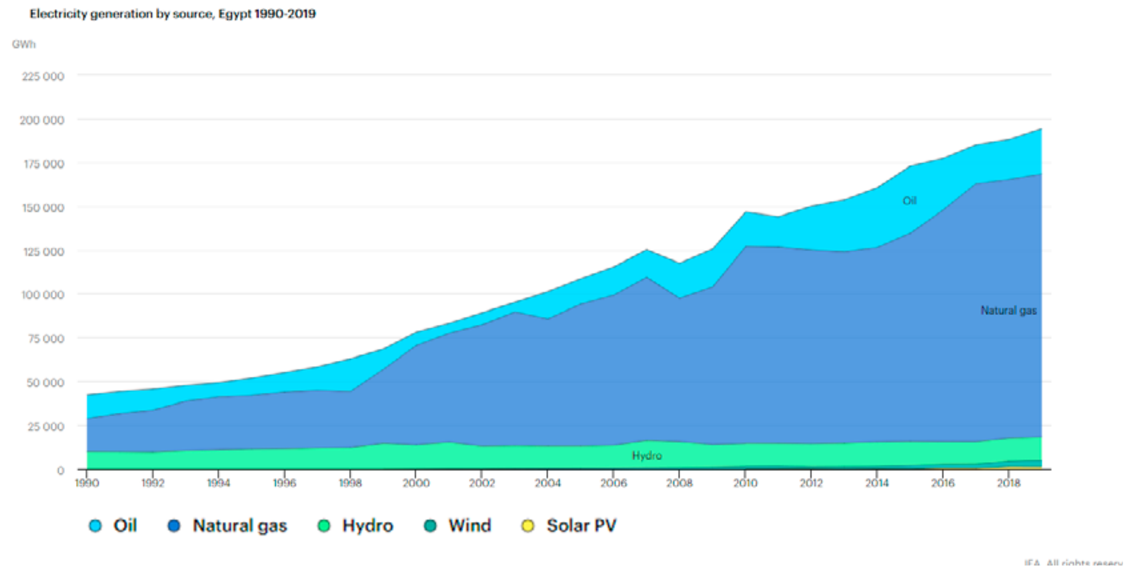
Most captured CO2 is used for enhanced oil and natural gas recovery, and as Egypt is an oil and gas producer, it is likely to use CO2 for that purpose. Eni's project already mentions storing CO2 in "depleted" gas fields. If this occurs it will only increase fossil fuel production.

Using blue hydrogen for ammonia will keep emissions high, which may also limit Egypt's ability to export it, as climate-related trade measures such as the EU's proposed carbon border adjustment mechanism will penalise high-carbon imports.[97]

92 Egypt, Norway's Scatec Sign MOU on Green Ammonia Project, Asharq Al-Awsat, 2022.
93 Egypt, Japan's Toyota Tshusho exploring blue hydrogen, Argus, 2021.
94 Siemens, Egypt agree to develop hydrogen projects, 200 MW electrolyzer facility, S&P Global Commodity Insights, 2021.
95 Agreement with Belgian DEME for Studies of Green Hydrogen Production, Egypt Oil & Gas, 2021.
96 Eni signs an agreement to produce hydrogen in Egypt, Eni, 2021.
97 Carbon Border Adjustment Mechanism: Questions and Answers, European Commission, 2021.

What could Egypt do with its renewable electricity instead?

Egypt's electricity generation by energy source



courtesy IEA[98]

Green electricity towards renewable transition

Emissions from electrical generation in Egypt have increased substantially since 1990 as gas and oil use have increased, with the Aswan Dam now only contributing a fraction.

Building enough renewable capacity to replace electricity generation from oil and gas appears a better use of resources than significantly reducing the energy and value of generated renewable electricity by turning it into hydrogen and other fuels for export. Egypt's current electricity demand is twice Algeria's, about 160 TWh per year, but its renewables targets are also more ambitious, aiming to reach 42% by 2035.[99] This would require investment in the ballpark of $24 billion to deliver roughly 19 GW of solar, 10 GW of wind energy, transmission and storage capacity over 13 years.[100] While Egypt's oil and gas windfall of 2021 and 2022 haven't been as large as Algeria's, its economy is 2.5 times bigger, so just under $2 billion per year until 2035 is not an unmanageable figure.

Similarly, developing increased connections through northern and eastern Africa as well as the Middle East to share electricity and storage would be much more effective than attempting to create an export market for very expensive chemicals that will likely be manufactured domestically in most countries. It would also be beneficial from an economic and climate perspective.

98 Electricity generation by source, Egypt 1990-2019, IEA

99 Siemens, Egypt agree to develop hydrogen projects, 200 MW electrolyzer facility, S&P Global, 2021.

100 With the plummeting price of wind and solar, the industry standard is now around $0.8 billion per GW, including storage and transmission.

Greening domestic fertiliser use and manufacture

All of Egypt's nitrogen-based fertiliser manufacturing is from grey hydrogen, with 16-20 tonnes of CO2e produced for every tonne of hydrogen (see box 'costs and climate impacts of blue hydrogen'). Egypt's annual consumption of fertiliser in the rich Nile Valley and delta was in the range of 1.7 million tonnes in 2018.[101] Given the CO2 and CO2e emissions before use of nitrogen-based fertilisers (see Morocco chapter), that represents in the range of 20 million tonnes of CO2e annually, a significant portion of Egypt's overall emissions.

Egypt would thus be better off greening its local fertiliser manufacturing and meeting domestic demand, before it declines due to changing agricultural practices that are not so fertiliser intensive. This is important as even green ammonia-based fertiliser is still a significant climate problem, releasing six tonnes of CO2 for every tonne spread on farmland.

If Europe's development bank is interested in assisting northern Africa, it should focus on areas like the above, rather than directing these countries towards expensive, untested and potentially economically unviable hydrogen export.

101 Egypt - fertiliser consumption per unit of arable land, Knoema.

Conclusion

The European Commission is looking to import large quantities of green hydrogen from North Africa. However, this study demonstrates that for the case of Morocco, Algeria and Egypt, big question marks remain over whether green hydrogen will ever be exported at attractive prices due to high production and transport costs.

The intermittency of site-specific renewables farms as well as lower-than-expected cost savings will keep prices high (up to 11 times more than using natural gas), while connecting to the grid could also raise costs while undermining the 'green' credentials of renewable hydrogen. The high predicted additional costs of shipping or piping hydrogen is a big reason why the large majority of it is manufactured at the point of consumption today.

If Europe is not prepared to pay the difference between green hydrogen and natural gas, North African governments should be wary of promises of large export markets.

In oil and gas producing Algeria and Egypt, the hydrogen projects being explored are not just based on renewable electricity ('green') but also from gas with CCS ('blue'). Blue hydrogen is still double the price of unabated ('grey') hydrogen, and has the big problem of high CO2e emissions, especially if the captured CO2 is used for enhanced oil recovery.

As all three countries examined have significant fertiliser industries, and either produce or import large quantities of grey ammonia, greening this could be a short-term domestic move.

Other domestic uses that envisage hydrogen as an energy carrier don't hold up to scrutiny. Today hydrogen is not used as an energy carrier and electricity is more fit for purpose, more efficient and much cheaper. As a storage medium for electricity, green hydrogen would provide only 37% of the energy used to make it, wasting more than 60% of the original renewable electricity.

The renewable electricity generated by these countries would be better used to displace domestic fossil fuel power generation and meet local energy needs, while interconnectors with neighbouring countries - and eventually the EU - could help balance grids.

European companies and government institutions would be better off focusing on displacing chemical feedstocks using grey hydrogen, helping countries to retire legacy industrial infrastructure that use natural gas or coal, and developing electrically powered industrial processes within the EU.

It makes little sense for Morocco, Algeria or Egypt to use their renewable electricity to make hydrogen and products from hydrogen, then ship them to Europe at significant loss of energy, so that the EU can achieve lower climate emissions reductions. And would European consumers be prepared to foot the very significant bill? The EU may want to re-examine its hydrogen strategy, in particular its green import targets, and reassess the feasibility and cost of achieving them.

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