MAPPING MENA'S RENEWABLE ENERGY SUPPLY CHAINS

THE EMERGENCE OF GREEN ENERGY ECOSYSTEMS IN THE MIDDLE EAST AND NORTH AFRICA

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DISCLAIMER

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Cover photo: Aluminium from Dubai produced using solar energy at the opening of a new electric car motor housing production line at the BMW Landshut factory in Ergolding, Germany. Photo by Leonhard Simon/Getty Images.

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Photo above: A view of solar panels used to power irrigation pumps along the Afir agricultural canal near the city of Kafr el-Dawwar in Egypt's northern province of Beheira, Oct. 12, 2022. Photo by KHALED DESOUKI/AFP via Getty Images.

Introduction

The Middle East and North Africa has the potential to become the world's largest renewable energy-producing region. Solar energy is MENA's most abundant renewable energy resource. The Sahara Desert, which covers the majority of North Africa, receives the world's highest levels of solar irradiation and comprises a territory just slightly smaller than the total area of the United States. The amount of solar energy striking the Sahara Desert is so enormous that, were it all capable of being harnessed for power generation, it would be 7,000 times greater than Europe's total electricity demand at any given moment.[1] Similarly high levels of solar irradiation are also present in the adjacent regions of the Negev Desert, the Jordanian desert, and large swathes of the Arabian Peninsula. MENA's massive solar energy resources are augmented by ample wind power resources, inland, nearshore, and offshore.

Compared to the immense scale of the resources, renewable energy is virtually untapped in the MENA region. While the Sahara Desert's solar resources alone theoretically could support an installed power generation capacity of over 1,000,000 gigawatts (GW), the combined installed solar power capacity across the MENA region in 2022 was 16 GW.[2] For perspective, the entire MENA region's installed solar capacity is roughly the same as that of France in 2022,[3] a country that relies primarily on nuclear power for its electricity supply, and four times less than Germany's 67 GW,[4] which has shut down its nuclear power plants. The predominance of oil and natural gas production across MENA does not by itself explain the region's lack of renewable energy power generation capacity. The United States, the world's leading oil and natural gas producer, boasted 113 GW of installed solar capacity in 2022,[5] over five times more than the entire MENA region.[6] The statistics for MENA's wind power capacity are in line with those for solar power.

The comparative paucity of MENA's renewable energy infrastructure reflects a relatively recent enthusiasm for renewable energy across the region as a whole, with the notable exception of some of the trailblazing nations that form the core focus of this study. From 2012 to 2021, the growth rate in MENA for total installed renewable power generation capacity was 76%, far below the 112% global growth rate for renewable energy.[7] During the previous decade, the drive to develop utility-scale renewable energy systems gained political momentum, as several key MENA nations adopted "Vision 2030 plans" with ambitious infrastructure construction initiatives that include massive build-outs of renewable energy infrastructure. As part of these plans and their associated national energy strategies, several MENA countries adopted targets for increasing the role of renewable energy in their respective national energy systems, with the 2030 targets for renewable energy's share ranging from 15% to 50% of the power supply mix. To meet these targets, many of the proposed projects across the region are scheduled for completion during the current decade.

In mapping the emerging regional trends in renewable energy development and MENA renewable energy supply chains, this study examines the three MENA sub-regions of

1. https://www.weforum.org/agenda/2020/01/solar-panels-sahara-desert-renewable-energy/

2. https://www.energyinst.org/statistical-review

3. https://www.statista.com/statistics/1073552/capacity-production-energy-solar-la-france/

4. https://www.energyinst.org/statistical-review

5. https://www.energyinst.org/statistical-review

6. For the purposes of this study, the Middle East and North Africa region includes the five countries of North Africa from Morocco to Egypt, Sudan, all of the countries of the Levant excluding Turkey, and all of the countries of the Arabian Peninsula. Iraq is only considered in relation to its interconnection to Jordan and its manufacturing interests in Sudan. Iran is not included as part of this study. The geography of the study follows the parameters of the grant from the International Development Research Centre, with a focus on those nations with utility-scale renewable power infrastructure.

7. https://www.solarbeglobal.com/middle-east-a-trillion-market-for-solar/#:~:text=In%202022%2C%20the%20ME%20region,by%20multiple%20in%20recent%20years

North Africa, the Arabian Peninsula, and the Levant. While assessing the state of renewable energy across most of the MENA region, the study takes as its primary focus two trailblazing nations in each sub-region: Morocco and Egypt in North Africa; the United Arab Emirates and Saudi Arabia in the Arabian Peninsula; and Jordan and Israel in the Levant. In 2022, Morocco ranked as the most attractive renewable energy market for investment, according to the Renewable Energy Country Attractiveness Index published by international accounting firm EY (Ernst & Young), when normalized for GDP.[8] Morocco was also the only MENA country that placed within the top 20 of the RECAI's "raw" score, ranking 19th and followed by Israel (21), Egypt, (29), and Jordan (38).[9] On the Arabian Peninsula, the UAE and Saudi Arabia have positioned themselves at the forefront of rapidly developing renewable energy supply chains.

The most successful MENA nations in developing their renewable energy resources to date are doing so through the establishment of green energy ecosystems, in which the development of utility-scale renewable energy infrastructure is coordinated with that of robust offtake markets and the establishment of commercially viable storage and transportation mechanisms to service them. A critical element for renewable energy development, this study shows that the most robust renewable energy supply chains are emerging from green energy ecosystems. While the importance of electricity interconnection for renewable energy exports will be discussed below, electricity interconnection alone as an offtake mechanism is insufficient to establish robust renewable energy production value chains. These value chains have arisen in the MENA region as a result of the emergence of green energy ecosystems whose offtake markets are anchored in the food-water-energy nexus and the development of green hydrogen production.

Given the challenges across the region in coping with extreme water stress, the MENA countries with the most advanced renewable energy production programs also tend also to be leaders in water desalination. Since agriculture accounts for 80-85% of water consumption across most MENA nations,[10] the establishment of green energy ecosystems has emerged through efforts to use renewable energy to ensure the resilience of agri-food production. Beyond desalination, the rise of green hydrogen as a central component of renewable energy production value chains is also anchored in agri-food production, as the source input for fertilizer manufacturing is green ammonia, a green hydrogen derivative.

The attraction of green ammonia initially stemmed from the fact that ammonia, a nitrogen-hydrogen compound, forms the basic component of most synthetic fertilizers upon which modern agri-food production depends. Fertilizer manufacturing accounts for about 70% of global ammonia consumption.[11] While the nitrogen is sourced from the air, the hydrogen used for ammonia production is primarily so-called gray hydrogen produced from natural gas in a process that releases considerable quantities of carbon dioxide (CO_2), one of the main gasses thought to be responsible for climate change. In contrast to conventional gray hydrogen, green hydrogen is produced by using electricity generated from renewable sources to split water into its hydrogen and oxygen components, creating a versatile, carbon-free (hence, "green") energy carrier.

Fertilizer industries are incentivizing the development of green ammonia production capacity, as fertilizer producers attempt to ensure their resilience and cost-effectiveness by phasing out natural gas-derived ammonia in favor of climate-smart, supply shock-resistant green hydrogen-derived ammonia produced from renewable energy. Each of the six trailblazing MENA nations analyzed in this study — Morocco, Egypt,

8. The normalized score is obtained by taking the RECAI "raw" score and dividing it by the log of GDP. EY, "Renewable Country Energy Attractive Index (RECAI), 60th edition", EY, November 2022, p. 20, https://assets.ey.com/content/dam/ey-sites/ey-com/en_us/topics/energy-resources/ey-recai-60-report-november-2022.pdf

9. https://assets.ey.com/content/dam/ey-sites/ey-com/en_us/topics/energy-resources/ey-recai-60-report-november-2022.pdf

10. https://www.mei.edu/publications/fragile-state-food-security-maghreb-implication-2021-cereal-grains-crisis-tunisia; https://www.mei.edu/publications/russia-ukraine-war-forces-egypt-face-need-feed-itself-infrastructure-international

11. https://iea.blob.core.windows.net/assets/6ee41bb9-8e81-4b64-8701-2acc064ff6e4/AmmoniaTechnologyRoadmap.pdf

the UAE, Saudi Arabia, Jordan, and Israel — is already a significant exporter of fertilizers or fertilizer inputs. With a nearly guaranteed domestic offtake option for fertilizer production, green ammonia has emerged as a preferred end-product of green hydrogen production.

Beyond its use in fertilizer manufacturing, green ammonia is presently the most cost-effective way to store and transport green hydrogen and therefore an important means to transport renewable energy.[12] For reasons explained below, green ammonia will likely become the dominant form of traded green hydrogen as opposed to transporting hydrogen gas itself through pipelines. In the form of green ammonia, which can be easily transported by ship, green hydrogen becomes a versatile energy carrier for renewable energy. Being able to transport renewable energy on demand as green ammonia greatly expands the scope of opportunities for developing a diverse array of renewable energy production value chains beyond the limitation of cross-border electricity interconnections.

By recombining green hydrogen and oxygen back into water in a fuel cell, electric current is generated, providing on-demand, climate-smart power. Thus, green ammonia serves as an alternative technology to utility-scale batteries, which require toxic and difficult to obtain minerals, for storing energy produced from renewable sources and then deploying it on demand. While renewable energy exported via electricity interconnection and stored in utility-scale batteries is the rough analogue to the 20th century natural gas trade via pipelines, green ammonia transported on ships is the renewable energy equivalent of liquified natural gas (LNG), which is quickly becoming the dominant form of traded gas.

Given the current state of battery technology development, green ammonia is on track to play a pivotal role in renewable energy supply chains, expanding as well as diversifying the opportunities for developing renewable energy production value chains anchored in the MENA region. The European Union adopted its Hydrogen Strategy for a Climate-Neutral Europe in 2020, formalizing the effort to develop low-carbon hydrogen value chains.[13] As discussed below, Germany has been a pioneer in green hydrogen value chain development within the MENA region, having committed €9 billion to its green hydrogen strategy.[14] France has also committed €9 billion to developing low-carbon hydrogen value chains,[15] while Spain — which seeks to be a supplier to European markets — has committed €18 billion to its hydrogen strategy, doubling its prior anticipated allocation.[16]

From its foundation in the food-water-energy nexus, green ammonia is emerging as a preferred energy carrier for the greening of industrial manufacturing processes, providing the means by which these processes can be fueled and powered by renewable energy. Beyond fertilizer production, green hydrogen will also increasingly serve as a feedstock fuel in industrial manufacturing, particularly steel production (known as “green steel”) and other metals processing. The worldwide steel sector accounts for about 7% of global CO_2 emissions.[17] In 2023, Europe’s first green steel production plant, the H2 Green Steel plant, began operation in Sweden with commercial sales expected in 2025.[18] This will soon be followed by the EU-funded HYBRIT (Hydrogen Breakthrough Ironmaking Technology) green steel manufacturing facility in Sweden, scheduled

12. Although green hydrogen can be transmitted through natural gas pipelines, trans-Mediterranean pipeline export faces formidable technological and economic challenges that renders its commercial viability questionable.

13. https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

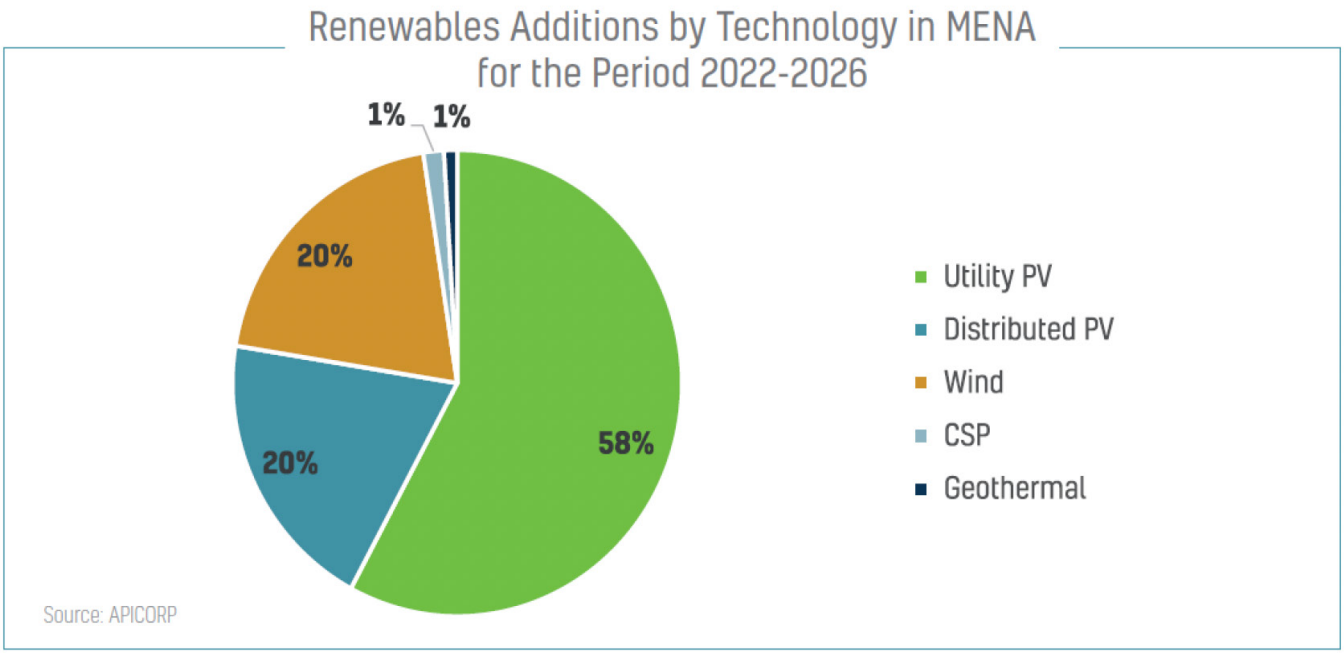
14. https://cleanenergynews.ihsmarkit.com/research-analysis/germany-tops-table-of-states-pouring-finance-into-hydrogen.html

15. https://hydrogentoday.info/en/production-low-carbon-hydrogen-france/#:~:text=France%20has%20set%20itself%20the,revision%20of%20the%20national%20strategy

16. https://www.bloomberg.com/news/features/2023-07-04/green-energy-spain-invests-billions-in-plans-to-export-green-hydrogen

17. https://publications.jrc.ec.europa.eu/repository/handle/JRC127468

18. https://www.mining-technology.com/news/green-steel-hydrogen/?cf-view



to be operational in 2026.[19] Beyond Sweden, major green steel production projects are underway across Europe — including in Spain, France, and Germany[20] — as well as in South Korea[21] and Japan.[22] European and Asian green steel production and other green metals processing will expand the exports markets for MENA-produced green hydrogen, encouraging increased foreign investment in renewable energy infrastructure in the region. Concurrently, increased metals demand will spur the expansion of metals production in the MENA region where the green energy is locally produced.

The transition to renewable energy will require additional production of massive quantities of other key metals such as copper, aluminum, and various rare earths for the construction of solar power and wind power infrastructure, as well as the electric cables that will carry the power over long distances. The Energy Transitions Commission has estimated that the energy transition needed to meet 2050 climate targets could require the production of 6.5 billion tons of end use materials — 95% of which would be steel, copper, and aluminum.[23] The use of green hydrogen means that renewable energy can power the additional, energy-intensive metals processing required for the construction of new renewable energy production infrastructure. In September 2022, the world's first low-carbon copper high-voltage direct current (HVDC) power cables were manufactured in Sweden.[24] HVDC cables are used in undersea electricity interconnectors that provide MENA power producers the means to export their electricity beyond the region. Major undersea interconnection projects are under way in Morocco, Tunisia, Egypt, and Israel, and are likely imminent in the UAE and Saudi Arabia. Similarly, high-voltage alternating current power cables used in transmission lines are composed primarily of aluminum. As discussed below, the UAE has already pioneered the

19. https://climate.ec.europa.eu/news-your-voice/news/hybrit-story-unlocking-secret-green-steel-production-2023-06-20_en

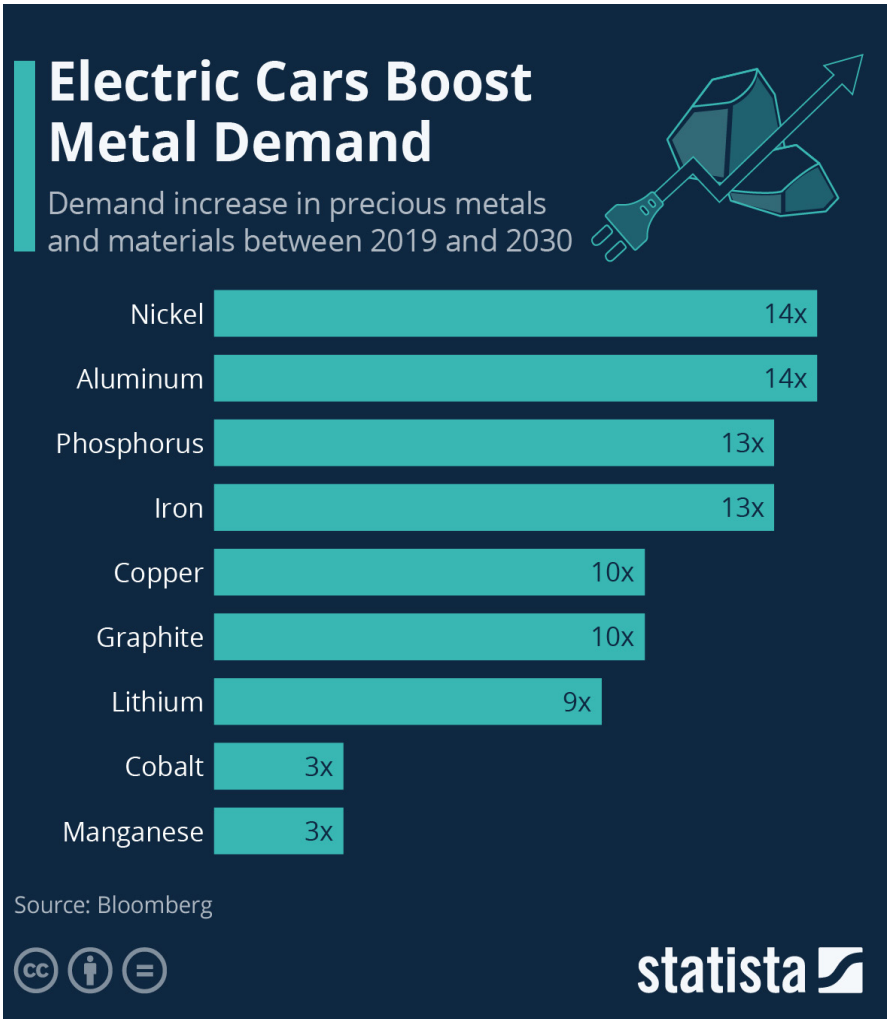
20. https://www.bbc.com/news/business-64538296

21. https://gmk.center/en/news/posco-to-launch-the-production-of-green-steel-by-2030/

22. https://www.japantimes.co.jp/news/2023/03/03/business/nippon-steel-green/

23. https://www.energy-transitions.org/new-report-scale-up-of-critical-materials-and-resources-required-for-energy-transition/#:~:text=Between%202022%E2%80%932050%2C%20the%20energy,cobalt%2C%20graphite%20or%20rare%20earths

24. https://www.nkt.com/news-press-releases/nkt-produces-worlds-first-hvdc-power-cables-using-low-carbon-copper



production of green aluminum from solar power. This green circular economy dynamic is likely to spur more local mining and metals processing in the MENA region where the renewable energy is produced. Four of the six trailblazing nations in this study — Morocco, Egypt, the UAE, and Saudi Arabia — already have significant mining and metal processing sectors. In the case of Morocco and Saudi Arabia in particular, these sectors are in a process of rapid expansion, with Egypt attempting to follow suit. The growth of mining and metals processing in these countries will incentivize further renewable energy power generation development in a mutually reinforcing process.

Green metals production powered by renewable energy also comprises a vital part of the green energy ecosystem through its intimate relationship with green mobility — the transition to the production and widespread use of electric vehicles (EVs) and their charging infrastructure. According to a Bloomberg forecast of EV metals, aluminum and nickel demand will experience a fourteenfold increase by 2030, while phosphorous and iron demand will increase ten times in the same period.[25] A tenfold demand increase is expected for copper and graphite, while lithium demand will increase ninefold.[26] Morocco, which has a well-developed automotive manufacturing sector, has already started large-scale EV production and expects to be producing 250,000 electric cars by 2025.[27] Morocco also has a rapidly developing EV battery production sector and is becoming a global center for EV battery metal recycling. Each of the manufacturing processes associated with green mobility could be powered by renewable energy, creating green circular production.

Green mobility, beyond Morocco, is increasingly becoming an important component of MENA green energy ecosystems. In 2023, both the UAE and Saudi Arabia initiated an EV manufacturing sector. Egypt has also been eyeing the development of EV production. The UAE has opened a recycling facility for end-of-life EV batteries as well. The main customers for the UAE's green aluminum are European automakers. MENA renewable energy will power the metals and materials manufacturing, either locally or outside the region, for the components of climate-smart cars, trucks, busses, and aircraft. With

25. https://www.bloomberg.com/news/articles/2020-12-31/billionaire-friedland-s-spac-readies-funds-for-clean-power-push?srnd=green

26. https://www.bloomberg.com/news/articles/2020-12-31/billionaire-friedland-s-spac-readies-funds-for-clean-power-push?srnd=green

27. https://www.mei.edu/publications/moroccos-green-mobility-revolution-geo-economic-factors-driving-its-rise-electric

their already existing infrastructure for fossil fuels and petrochemical production, some Gulf states are also at the forefront of developing sustainable aviation fuel from green hydrogen.

Although European firms have been leading efforts to partner with MENA nations to develop their green hydrogen potential, Asian markets may rapidly develop if the coal-burning regions of Asia move toward "co-firing," using both ammonia and coal as fuel in hitherto coal-fired power plants.[28] Japan has been pioneering the development of co-firing technology and, in 2023, successfully tested the operation of one its major coal plants using a fuel mix of 20% ammonia and 80% coal.[29] Tokyo aims to achieve 50-50 fuel during the 2030s and then phase out coal entirely in favor of 100% ammonia-fired plants by the 2050s.[30] To meet their own commitments to achieve carbon-neutrality, Japan and other Asian nations using co-firing as an intermediate step will likely seek to import MENA-produced green ammonia, adding a further dimension to MENA renewable energy supply chains and their green energy ecosystems.

In examining the state of renewable energy development across the MENA region and renewable energy supply chains, the formation of green energy ecosystems is the primary indicator for success and growth. Thus, using the state of a MENA nation's green energy ecosystem as an analytical metric provides an insightful means to understand and evaluate the renewable energy power generation mega-project initiatives in that nation. While countries will differ in their pathways to developing a green energy ecosystem, this study suggests that initiatives for renewable energy development succeed when they participate in green energy ecosystems while those that remain primarily on the drawing board are the ones unconnected to such an ecosystem. Green energy ecosystems become a marker for the robustness for renewable energy value chains within MENA and between the MENA region and markets in Europe, Asia, and Sub-Saharan Africa. The green energy ecosystems further constitute an important factor for understanding the prospects of cooperation within the three sub-regions of the Middle East and North Africa. This is a particular concern for the Levant region, where the lack of available land for utility-scale renewable energy will require more regional cooperation. The state of green energy ecosystems will further shape the patterns of cooperation among the MENA sub-regions of North Africa, the Arabian Peninsula, and the Levant.

North Africa

The nations of North Africa are awash in abundant solar energy resources. From Morocco to Egypt, large swathes of the region boast the world's largest photovoltaic (PV) power and concentrated solar power (CSP) potential,[31] as direct normal irradiation (DNI) levels reach or exceed 2,300 kilowatt hours per square meter.[32] By comparison, the most sun-soaked areas of southern Germany — one of MENA's main renewable energy partners — reach only half that DNI level, with most of the country receiving even less solar irradiation.[33] The high DNI region of North Africa includes the Sahara Desert — comprising 9 million square kilometers, over twice the total area of the EU. In addition to receiving the world's highest levels of solar irradiation, the Sahara Desert possesses an abundance of the open land necessary to host the distributed infrastructure required by solar power generation. Even converting only one-thousandth of the solar energy that hits the Sahara into usable power would provide enough electricity to entirely power Europe at any given moment as well as to supply the current power demand of the

28. https://www.ntu.edu.sg/cas/news-events/news/details/can-singapore-unlock-africa-s-green-hydrogen-potential

29. https://asia.nikkei.com/Business/Business-Spotlight/Japan-warms-to-disputed-coal-power-technology-under-West-s-icy-stare

30. https://www.jogmec.go.jp/content/300381295.pdf

31. https://globalsolaratlas.info/download/middle-east-and-north-africa

32. https://globalsolaratlas.info/download/middle-east-and-north-africa

33. https://globalsolaratlas.info/download/germany

entire African continent several times over.[34] In short, North Africa has sufficient solar energy resources to export energy while powering its own industrial and agricultural development. Additionally, North Africa has ample onshore wind power resources, as well as offshore wind resources from Morocco's Atlantic coast to Egypt's Gulf of Suez that complement its solar resources.[35] In regions where there are reliably constant night-time winds, solar and wind power may be combined to provide 24-hour baseload power, as is the goal of the Morocco-to-UK Xlinks interconnector project, discussed below.

The attraction of harnessing North Africa's vast renewable energy resources for electricity exports gave rise to the ambitious Desertec project initiated in Germany in 2009. The forward-looking project sought to create solar and wind power facilities across a 6,500 square mile area of North Africa, along with the requisite trans-Mediterranean electricity interconnection to supply about 15% of Europe's electricity demand. Visionary but poorly conceived, the ill-fated Desertec project collapsed in 2014.[36] Although the private sector played a role through public-private partnerships, Desertec evolved out of a development aid framework and was not sufficiently attuned to North Africa's economic and political needs. Consequently, the project also elicited concerns that it was laying the foundations for green energy neo-colonialism. Desertec's demise dampened enthusiasm for renewable energy transmission via trans-Mediterranean undersea electric cables, casting doubts on its commercial feasibility.

Despite the setback, Morocco and Egypt continued with their plans to construct large, utility-scale solar and wind power facilities. And while both countries are engaged in the construction of undersea electricity interconnectors to Europe, Morocco and Egypt's advances in the construction of renewable energy systems have laid the foundation for these nations to also become North Africa's trailblazers in the development of green hydrogen as an alternative carrier for renewable energy.

The green ammonia production has contributed to the development of a robust green energy ecosystem in Morocco and to a lesser extent in Egypt as well. With no significant reserves of fossil fuels, Morocco's dependence on imported natural gas and coal for industrial and residential power has provided a strong economic motivation to replace their use with renewable energy and green hydrogen. Egypt, by contrast, is Africa's second largest natural gas producer, with an annual output of about 65 billion cubic meters (bcm) prior to the 2023 financial crisis.[37] Contrary to the assumption that investments in natural gas compete with renewable energy investments in a zero-sum game, Egypt has developed its natural gas and renewable energy resources in tandem. Cairo's efforts to develop natural gas self-sufficiency spurred it to concurrently advance the development of renewable energy power generation infrastructure, developing over 2 GW of combined solar and wind capacity. Although Morocco and Egypt stand as exemplars of two different paradigms for the development of green energy in the MENA region — non-hydrocarbon industry-based economies versus heavily hydrocarbon-based economies — these distinct exemplars share a common pathway for the initiation of green energy ecosystems: both countries have highly developed fertilizer

34. EU power demand: https://www.statista.com/statistics/1260536/eu-power-demand/#:~:text=In%202022%2C%20electricity%20demand%20in,comparison%20to%20the%20previous%20year.; Africa power demand: https://www.iea.org/reports/africa-energy-outlook-2019#:~:text=Total%20primary%20energy%20demand%20in%20Africa%20by%20scenario%2C%202018%2D2040&text=Electricity%20demand%20in%20Africa%20today,over%2070%25%20of%20the%20total . EU installed capacity 991.045 GW: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_and_heat_statistics#Installed_electrical_capacity

35. For an example of wind power in the region, see the discussion on Egypt's advances in wind power in: https://www.ispionline.it/en/pubblicazione/egypts-prospects-energy-export-hub-across-three-continents-27408

36. https://www.reuters.com/article/germany-desertec/desertec-shareholders-jump-ship-as-solar-project-folds-idUSL6N0S535V20141014

37. https://www.energyinst.org/statistical-review

manufacturing sectors that have incentivized green hydrogen development.

Morocco: Developing Renewable Energy Supply Chains Through a Green Energy Ecosystem

Morocco has been a pioneer in renewable energy development in the MENA region by establishing a dynamic green energy ecosystem anchored in the food-water-energy nexus. Reflecting a holistic strategic vision, the four key state pillars of Morocco's efforts are managed under the Ministry of Energy Transition and Sustainable Development (formerly the Ministry of Energy, Mines, and the Environment) and include the Morocco Agency for Sustainable Energy (MASEN); the Institute for Research for Solar Energy and New Energies (IRESEN); the National Office of Electricity and Potable Water (ONEE); and the OCP Group (originally, Office Chérifien des Phosphates), the world's largest producer of phosphate products and fourth largest exporter of fertilizer. Morocco possesses over 73% of the world's phosphate rock reserves from which the phosphorus used in these fertilizers is derived.[38] Prior to the 2021 natural gas price shocks, OCP's total revenue in 2020 amounted to $5.94 billion,[39] accounting for about 20% of the kingdom's export revenues.[40] OCP's massive phosphate mining and fertilizer manufacturing sector has transformed Morocco into a gatekeeper of the world's food supply,[41] making the sustainability of the industry through energy transition a matter of national interest for Morocco as well as the nations that depend on its exports.
OCP covers 89% of the energy needs for its phosphate and phosphorus fertilizer production through co-generation (reusing exhaust energy to create cleaner and cheaper power from fossil fuels) and renewable sources and heading toward covering 100% of its energy needs in this manner.[42] To ensure its transition beyond fossil fuels, OCP established OCP Green Energy SA in 2022, as a wholly owned subsidiary to develop its renewable energy generation activities, committing an investment of $13 billion during the 2023-27 period.[43] Dedicated solar plants are being built in the mining towns of Benguerir and Khouribga, home to Morocco's largest phosphate reserves, as well as in other locations.

With the exception of OCP, which was reorganized in 2008, the state institutional framework for Morocco's green energy ecosystem was initiated in 2010 with the creation of MASEN as a private company with public funding to oversee the development of Morocco's massive, muti-phase Noor solar energy power generation project. The president of MASEN previously served as the head of Caisse de Dépot et de Gestion (CDG), which manages long-terms savings and invests in Morocco's infrastructure development.[44] MASEN's board includes the minister of economy and finance, the managing director of ONEE, the administrator of the Ministry of Energy Transition and Sustainable Development, and the administrator of the Ministry of Industry, Trade, Investment, Green, and Digital Economy.[45]

IRESEN was created in 2011as the research arm of Morocco's national energy program across the entire spectrum of the value chains within the green energy ecosystem, including solar energy systems, green hydrogen systems, and electric mobility.[46] IRESEN oversees a network of green energy research and innovation platforms and funds for applied research and collaborative innovation

38. https://www.statista.com/statistics/681747/phosphate-rock-reserves-by-country/

39. https://ocpsiteprodsa.blob.core.windows.net/media/2021-08/OCP-Sustainability_report_2020-GRI_certified.pdf

40. https://www.fitchratings.com/research/corporate-finance/fitch-revises-outlook-on-ocp-to-stable-affirms-at-bb-28-10-2020

41. https://www.mei.edu/publications/moroccos-new-challenges-gatekeeper-worlds-food-supply-geopolitics-economics-and

42. https://www.moroccoworldnews.com/2022/06/349881/ocp-group-green-hydrogen-ammonia-is-the-future-of-energy

43. https://www.ocpgroup.ma/news-article/ocp-group-launches-its-new-green-investment-program-2023-2027

44. https://www.masen.ma/en/governance-organisation

45. https://www.masen.ma/en/governance-organisation

46. https://iresen.org/institut/

Photo above: A Moroccan worker walks in front of a solar array that is part of the Noor 1 solar power project in Ouarzazate on Oct. 19, 2014. Photo by FADEL SENNA/AFP via Getty Images.

projects, helping to propel Morocco toward the forefront of next-generation green energy technology development.[47] IRESEN's board includes members from the Ministry of Energy Transition and Sustainable Development, MASEN, ONEE, and OCP as well as several other key state institutions, including the mining sector's National Office of Hydrocarbons and Mines and Morocco's state-owned mining company Managem.[48] Following IRESEN, ONEE was formed in 2012 through the integration of the National Office of Electricity (created in 1963) and the National Office of Drinking Water (created in 1972), reflecting Morocco's ambition to manage its energy system to provide sufficient water for human consumption as well as its growing industrial and especially agricultural sectors. According to the Ministry of Energy Transition and Sustainable Development, renewable energy accounted for 38% of Morocco's 2022 installed power generation capacity, with the largest proportion being generated by hydroelectric power. [49] In 2022, Morocco's installed capacity from wind power stood at 1.77 GW while solar power stood at 1.43 GW, representing, respectively, 14.38% and 7.82% of the country's total installed capacity of 4.031 GW. Due to the kingdom's progress toward its 2020 energy transition target of having 42% of installed capacity come from renewables, Rabat accelerated its energy transition program by setting a revised 2030 target of renewables accounting for 52% of total installed capacity, with the increase coming mostly from the construction of additional solar and wind power infrastructure. Between 2023 and 2027, Morocco is slated to add approximately 6.5 GW of renewable power generation capacity at a cost of around $5.6 billion.[50]

47. https://iresen.org/institut/

48. https://iresen.org/institut/

49. https://www.mem.gov.ma/en/Pages/secteur.aspx?e=2

50. https://www.moroccoworldnews.com/2023/07/356723/morocco-has-invested-5-6-billion-in-renewable-energy-projects

Morocco's ongoing solar power development program consists of a cluster of "Noor" solar power projects spread across the country.[51] The current flagship projects are Noor I, II, and III with a combined installed capacity of 1.6 GW. Noor I, also known Ouarzazate Solar Power Station, features the world's largest CSP facility with a 580 megawatt (MW) installed capacity developed in four phases with PV infrastructure for a total of 800 MW.[52] Noor II and Noor III, also known as Noor Midelt II and Noor Midelt III, are each in the process of developing a 400 MW installed capacity of PV solar power.[53] MASEN prequalified companies for the Midelt II and III projects in July and August 2023, respectively.[54] Several of the smaller solar projects across the kingdom were or are being developed by ONEE.[55]

Morocco's wind power installed capacity is distributed over nine projects across the country with over two-thirds located in coastal regions.[56] Newer and larger wind power development projects are directly driven by the needs of Morocco's green energy ecosystem and international renewable energy supply chains. For example, Morocco's largest wind power facility is being developed by Total Eren, now a wholly owned subsidiary of French energy giant TotalEnergies,[57] as part of the company's larger $10 billion project to establish green ammonia production in Morocco's Guelmim-Oued Nour region.[58] The 5 GW wind farm will be combined with 5 GW of dedicated solar capacity to power the green ammonia plant, taking advantage of the region's near constant nighttime winds to provide virtually 24-7 renewable power.[59]

Morocco's green energy ecosystem is anchored in the food-water-energy nexus through its agri-food production and fertilizer manufacturing industries. The country's renewable energy program evolved in tandem with the implementation of its 2010-2020 Green Morocco Plan (Plan Maroc Vert, PMV) to expand its high-value agricultural export sector, which has resulted in Morocco's agri-food sector now accounting for 21% of its exports.[60] The PMV's successor plan, the 10-year Green Generation 2020-2030 initiative, is focused on enhancing the resilience and sustainability of the country's agricultural production through the expanded production and use of renewable energy.[61] To ensure sufficient water for agriculture as well as human consumption in the face of increasing water stress due to climate change, Morocco adopted a $40 billion National Water Plan 2020-2050 that includes the construction of more desalination plants.[62] Seawater desalination is highly energy intensive, typically

51. https://www.masen.ma/en/projects

52. https://www.masen.ma/en/projects/noor-midelt-i; https://esfccompany.com/en/articles/solar-energy/noor-ouarzazate-the-world-s-largest-concentrated-solar-power-plant-csp-built-in-morocco/

53. https://www.zawya.com/en/projects/utilities/morocco-set-to-award-new-solar-power-deal-report-cuf64g7u; https://www.reuters.com/business/energy/morocco-tenders-400-mw-solar-plant-atlas-mountains-2023-08-09/

54. https://www.moroccoworldnews.com/2023/08/356979/morocco-launches-tender-for-construction-of-noor-midelt-iii-solar-project

55. https://www.masen.ma/en/projects; http://www.one.org.ma/

56. https://www.masen.ma/en/projects

57. https://www.agenceecofin.com/energies-renouvelables/2607-110644-energies-renouvelables-apres-5-annees-d-alliance-strategique-totalenergies-acquiert-entierement-total-eren

58. https://www.moroccoworldnews.com/2022/02/346892/total-eren-to-launch-green-hydrogen-megaproject-in-morocco; https://gwec.net/wp-content/uploads/2023/10/Status-of-Wind-in-Africa-Report-V4.pdf

59. https://www.moroccoworldnews.com/2022/02/346892/total-eren-to-launch-green-hydrogen-megaproject-in-morocco; https://gwec.net/wp-content/uploads/2023/10/Status-of-Wind-in-Africa-Report-V4.pdf

60. https://www.etf.europa.eu/en/publications-and-resources/publications/future-skills-case-study-agri-food-sector-morocco

61. https://english.aawsat.com/home/article/2132676/moroccos-king-launches-green-generation-2020-2030

62. https://www.maroc.ma/en/news/head-government-2020-2050-national-water-plan-roadmap-face-challenges-next-30-years

requiring 10 times the amount of energy to produce the same volume of water as conventional surface water treatment.[63] Morocco's additional desalination plants will ultimately require new power generation capacity from renewable energy sources or possibly nuclear power.[64]

The creation of fertilizer manufacturing value chains using renewable energy and green hydrogen is essential for the establishment of sustainable and resilient food production value chains worldwide. One of the highest priorities in this domain is transitioning fertilizer production from using ammonia synthesized from natural gas-derived gray hydrogen to ammonia produced from green hydrogen. The majority of green hydrogen's production costs, about 70%, come from the electricity required to split water into its hydrogen and oxygen components and could be powered by Morocco's solar energy and wind energy resources.

Morocco's rise as a global leader in green hydrogen was prompted by its objective of using its derivative green ammonia to supply the kingdom's lucrative fertilizer industry. The country's lack of natural gas places a limiting factor on the resilience of its fertilizer production, which requires ammonia, now produced from natural gas-derived gray hydrogen. Prior to the outbreak of the war in Ukraine in 2022, OCP needed to import 1.5 to 2 million tons of ammonia per year to meet its production.[65] Since the war, OCP is eyeing a 58% increase in its production capacity to fill European and global fertilizer supply shortfalls.[66]

To create sustainable and resilient production for exports, Morocco will ultimately need to replace its imported ammonia made from gray hydrogen with green ammonia produced locally powered by its solar and wind energy resources. Morocco began its development of green hydrogen production in partnership with Germany in 2018 when OCP signed a cooperation agreement with Germany's Fraunhofer Institute to develop a pilot green hydrogen manufacturing project in cooperation with IRESEN.[67] Replicating the institute's pilot plant in Germany, the Moroccan pilot was slated to have an annual production capacity of 1,460 tons of green ammonia.[68] When Berlin announced its German National Hydrogen Strategy in June 2020,[69] Morocco became the first country to sign a green hydrogen agreement with Berlin to create industrial-scale green hydrogen production.[70] Using Morocco's renewable power infrastructure, the project was financed by the German development bank KfW and managed by MASEN.[71] The two projects have been conducted within a development aid framework and faced political setbacks over Berlin's posture concerning Morocco's autonomy plan for the Sahara region until Germany's 2022 political reconciliation with Rabat.[72]

In the wake of these events and in light of the rising demand for ammonia, Morocco has advanced multiple private sector development projects backed by Portugal, the Netherlands, Italy, and the EU.[73] Morocco's largest green ammonia project under development is the Irish-Portuguese HEVO facility, which is slated to have an initial annual capacity of 183,000 tons by 2026, equivalent to approximately 10% of OCP's production input requirements.[74] Rabat signed a

63. https://www.iai.it/sites/default/files/iaip2306.pdf

64. https://www.mei.edu/publications/moroccos-nuclear-option-russian-vs-us-technological-cooperation-power-its-water

65. https://www.theafricareport.com/124184/will-hydrogen-fuel-moroccos-industrial-projects-of-the-future/

66. https://medias24.com/2022/06/05/engrais-une-double-opportunite-pour-le-maroc/

67. https://www.ammoniaenergy.org/articles/ocps-green-ammonia-pilot-plant-and-the-african-institute-for-solar-ammonia/

68. https://ocpsiteprodsa.blob.core.windows.net/media/2021-08/OCP-Sustainability_report_2020-GRI_certified.pdf

69. https://www.bmwk.de/Redaktion/EN/Publikationen/Energie/the-national-hydrogen-strategy.pdf?__blob=publicationFile&v=6

70. https://www.maroc.ma/en/news/morocco-germany-sign-green-hydrogen-cooperation-agreement

71. https://www.theafricareport.com/124184/will-hydrogen-fuel-moroccos-industrial-projects-of-the-future/

72. https://www.dw.com/en/german-foreign-minister-visits-morocco-after-diplomatic-row/a-62923298

73. https://www.iai.it/sites/default/files/iaip2306.pdf

74. https://www.mei.edu/publications/moroccos-new-challenges-

memorandum of understanding (MoU) with Dutch oil trading giant Vitol to market the green ammonia in Europe.[75]

The Netherlands, the world's second largest food exporter and the EU's largest fertilizer user per hectare, itself provided loan guarantees in 2022 for the Dutch green hydrogen firm Proton Ventures to build a green ammonia plant at Morocco's Jorf Lasfar port.[76] The Dutch pilot green ammonia plant will have an annual production capacity of 1,460 tons,[77] the same as the first stalled German project. Also in 2022, the Dutch state-owned natural gas transmission network operator Gasunie, the Netherlands-headquartered bulk handling giant HES International, and the Dutch global leader in tank storage Vopak formed a consortium for the construction of a new green ammonia import terminal at Rotterdam's Maasvlakte port.[78] The terminal is intended to handle green ammonia imports to Europe and is expected to be operational by 2026. Further signs of Europe's eagerness to import Moroccan green hydrogen are the previously discussed green ammonia project in Guelmim-Oued Nour region being developed by Total Eren and an MoU signed by Saipem (controlled by Italian energy major Eni) and Italy-based Alboran Hydrogen to build a green ammonia plant in Morocco.[79]

For its part, OCP made public its plans in June 2023 to construct its own $7 billion green ammonia plant to help the company replace its annual import of $2 billion of gray ammonia with domestically produced green ammonia, expecting to have an initial annual production capacity of 200,000 tons by 2026.[80] The world's fourth largest fertilizer exporter is aiming to raise its own green ammonia production to 1 million tons by 2027 and reach 3 million tons by 2032. Thus, with the completion of the projects currently under consideration, Morocco could export over 1-3 million tons annually.[81] In addition to fertilizer production, the green ammonia can also be exported to Europe, and possibly more distant East Asia, for industrial manufacturing processes and as fuel ammonia.

Green mobility, in the form of EV manufacturing, constitutes the other major industrial pillar of Morocco's green energy ecosystem. Morocco's impressive automotive industry now accounts for about 25% of the kingdom's GDP and employs one-quarter of a million Moroccans.[82] The largest automaker in Africa, Morocco's annual production capacity is over 700,000 vehicles per year and is on its way to producing 1 million or more vehicles by 2025,[83] at least 250,000 of which will be EVs.[84] European automakers Groupe Renault and Groupe PSA (now part of the Stellantis conglomerate) operate manufacturing plants in the kingdom that are supplied by 250 international firms from the United States, Europe, Japan, China, and elsewhere, each with their own local plants to supply automotive components. As a consequence, Europe's two best-selling car models — the Peugeot 208 and Renault's Dacia Sandero — are made in

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75. https://www.argusmedia.com/en/news/2235820-morocco-outlines-plans-for-new-green-ammonia-project

76. https://medias24.com/2022/09/04/le-projet-pilote-de-production-dammoniac-vert-ouvre-de-grandes-perspectives-pour-le-maroc/

77. https://protonventures.com/press-release/um6p-and-proton-ventures-sign-an-agreement-for-the-construction-of-the-green-ammonia-pilot-in-jorf-lasfar/

78. https://energycapitalpower.com/chariots-3-5-billion-mauritania-based-green-hydrogen-project-secures-european-export-route/

79. https://leseco.ma/business/production-dhydrogene-vert-saipem-et-alboran-hydrogen-sactivent.html

80. https://www.reuters.com/sustainability/climate-energy/moroccos-ocp-plans-7-mln-green-ammonia-plant-avert-supply-problems-2023-06-20/

81. https://www.thenationalnews.com/opinion/comment/2023/12/13/africas-maritime-hydrogen-highways-could-enrich-the-continent-and-save-the-world/

82. https://northafricapost.com/73455-moroccos-neo-motors-launches-its-cars-in-the-market.html; https://www.morocconow.com/automotives

83. https://www.mei.edu/publications/moroccos-green-mobility-revolution-geo-economic-factors-driving-its-rise-electric

84. https://www.mei.edu/publications/moroccos-green-mobility-revolution-geo-economic-factors-driving-its-rise-electric

Morocco.[85] Now, Rabat has its sights on manufacturing their EV versions,[86] while Germany's Opel and Italy's Fiat have already begun producing EV models in Morocco.[87]

The key to Morocco's rise as a green mobility manufacturing giant will be expanding its automotive ecosystem to include local manufacture of lithium ion (Li-ion) batteries, which represent 30% to 40% of the cost of the average EV.[88] The urgency for Morocco is compounded by the fact that Europe is likely to be one of the centers of immediate EV growth, spurred by the European Commission's July 2021 directive to phase out all fossil fuel-powered vehicles in the EU by 2035.[89] Morocco cannot afford to lose its European market, which accounts for 90% of its exports.[90] Morocco's renewable energy also provides a competitive advantage as automakers like Renault have set carbon reduction goals for its EV batteries of 20% by 2025 and 35% by 2030, compared to 2020 levels.[91] Morocco can further reduce its carbon footprint through recycling of end-of-life batteries. In 2022, global mining and metal trading giant Glencore entered into a partnership with Managem to produce recycled cobalt from disused Li-ion batteries at Managem's hydrometallurgical refining facilities operated by its subsidiary Compagnie de Tifnout Tighanimine (CCT).[92] Glencore will provide CCT with so-called black mass, processed from dismantled and shredded Li-ion batteries. In addition to cobalt, the partnership is also seeking to extract lithium carbonate and nickel hydroxide from the black mass. If extracted in sufficient quantities, Morocco could locally source all of the major metals used in nickel manganese cobalt (NMC) Li-ion batteries and with a low carbon footprint if the processes are powered with renewable energy.

Morocco's massive phosphate reserves are a critical factor in its transformation into a green global-scale EV battery production hub. A growing trend in electric passenger cars is to replace NMC Li-ion batteries with lithium iron phosphate (LFP) batteries, substituting expensive cobalt and nickel as well as manganese for relatively cheaper phosphate and iron.[93] The increasing utilization of LFP batteries favors Morocco for EV battery production as the country is the world's second largest phosphate producer, after China.[94] Morocco is also a net exporter of iron ore.[95] By manufacturing LFP batteries for EVs instead of their NMC counterparts, Morocco would enjoy a cost advantage of upward of 70% per kilogram.[96] Since 2023, five Chinese EV battery manufacturers have made substantial investments in local EV battery production plants and battery metals recycling facilities, cementing Morocco's position in the EV battery supply chain. If these EV battery

85. https://www.autocar.co.uk/car-news/new-cars/best-selling-cars-europe-2022

86. https://www.mei.edu/publications/moroccos-green-mobility-revolution-geo-economic-factors-driving-its-rise-electric

87. https://www.thenationalnews.com/weekend/2023/08/25/brics-north-africa/

88. https://www.mei.edu/publications/moroccos-green-mobility-revolution-geo-economic-factors-driving-its-rise-electric

89. https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/071421-eu-set-to-sideline-ice-vehicles-by-2035-with-tougher-car-emissions-proposal

90. https://medias24.com/2022/08/10/voici-a-quoi-pourrait-ressembler-la-premiere-gigafactory-de-batteries-au-maroc/

91. https://www.latribune.fr/entreprises-finance/industrie/automobile/voiture-electrique-renault-securise-ses-approvisionnements-de-cobalt-au-maroc-920283.html

92. https://www.glencore.com/media-and-insights/news/glencore-and-managem-set-up-partnership

93. https://tesla-cdn.thron.com/static/TWPKBV_TSLA_Q3_2021_Quarterly_Update_SI1AKE.pdf?xseo=&response-content-disposition=inline%3Bfilename%3D%22TSLA-Q3-2021-Quarterly-Update.pdf%22

94. https://www.statista.com/statistics/681747/phosphate-rock-reserves-by-country/; https://pubs.usgs.gov/periodicals/mcs2022/mcs2022.pdf

95. https://www.mei.edu/publications/moroccos-new-challenges-gatekeeper-worlds-food-supply-geopolitics-economics-and

96. https://www.quantumscape.com/resources/blog/lithium-iron-phosphate-on-the-quantumscape-solid-state-lithium-metal-platform/

Photo above: Untreated phosphate being dropped off at the end of a conveyor belt at the OCP's Marca factory, near Laayoune, Western Sahara, on May 13, 2013. Photo by FADEL SENNA/AFP via Getty Images.

recycling ventures are powered with renewable energy, the country could further reduce the carbon footprint of its LFP batteries to achieve a significant market advantage.[97] Morocco will need to expand its phosphate and phosphoric acid production to make LFP EV batteries, especially to avoid demand pressure competition from fertilizer production. OCP's additional output of phosphates and phosphoric acid will need to be powered by renewable energy sources, creating green circular production for the battery component of EV manufacturing.

Morocco's electricity interconnections to Europe also play an important role in renewable energy development and the establishment of renewable energy supply chains. The most prominent example is the ambitious Morocco-to-UK Xlinks interconnector, which involves the construction of 11.5 GW of dedicated renewable power. The $20 billion project is developing 8 GW of solar power and 3.5 GW of wind power in the Guelmim-Oued Nour region that will supply the UK with electricity for more than 19 hours per day via a 3.6 GW interconnector.[98] The two 1.8 GW undersea cables will need to traverse 3,800 kilometers, but will supply about 8% of the UK's power demand. Despite the technological challenges, the Xlinks project is expected to be completed in 2030.[99]

97. https://www.reuters.com/business/autos-transportation/chinas-gotion-high-tech-set-up-13-billion-ev-battery-gigafactory-morocco-2024-06-06/; https://www.reuters.com/business/autos-transportation/chinas-hailiang-shinzoom-build-auto-battery-plants-morocco-2024-05-15/; https://www.reuters.com/business/china-ev-battery-maker-btr-build-cathode-plant-morocco-2024-03-29; https://battery-news.de/en/2023/09/21/cngr-to-build-battery-materials-factory-in-morocco/

98. https://xlinks.co/morocco-uk-power-project/; https://gwec.net/wp-content/uploads/2023/10/Status-of-Wind-in-Africa-Report-V4.pdf

99. https://www.agbi.com/energy/2023/07/morocco-invests-

Morocco already has two interconnections with Spain with a total exchange capacity of 800 MW; a third interconnector of 700 MW is now under development and is expected to be operational in 2026.[100] In December 2023, Morocco and Portugal signed a joint declaration to advance the feasibility studies for the establishment of an electricity connector between the two countries.[101] However, the Iberian Peninsula is a relatively isolated island in the EU electricity grid, as Spain's 2020 exchange with the EU system's was only 3% of its installed capacity, far below the EU minimum standard of 10% (which has since been raised to 15%).[102] Morocco's interconnections with Spain and Portugal are unlikely to provide sufficient access to the wider EU electricity market to spur investments in additional renewable energy infrastructure or to establish renewable energy supply chains. The political tensions between Morocco and Algeria further make it unlikely that the former could access the EU electricity market via trans-Mediterranean interconnection from the central Maghreb. Morocco's international renewable energy supply chains will be based primarily on green hydrogen as well as phosphates, minerals and metals, fertilizers, agri-food products, and EVs whose production was powered, in part or entirely, with renewable energy resources.

Egypt: Recharging Progress by Developing Diversified Renewable Energy Supply Chains

After almost a decade of considerable progress, Egypt's renewable energy development is at a crossroads. Egypt's 2035 Integrated Sustainable Energy Strategy aims to boost power production from renewable sources to 10 times the current level to comprise 42% of Egypt's installed power generation capacity by 2035.[103] Cairo's ambitious 2019 energy policy calls for 61 GW of installed capacity from renewables, of which 32 GW would be from PV solar power, 12 GW from CSP, and 18 GW from wind power. The plan was formulated after a successful five-year period of developing Egypt's energy infrastructure. The country's economic crisis, with its high inflation rate, shrinking foreign reserves, and crippling cost of debt servicing, has cast doubt on its ability to meet these targets. Nevertheless, the foundations that were established remain and still can be utilized to great effect. Egypt's development of a green energy ecosystem that more deliberately connects renewable energy production to a diversity of dedicated offtake mechanisms could help provide it with a path out of its current economic impasse.

With the discovery of the Zohr offshore natural gas field in 2015, the Mediterranean's largest find to date, Egypt devoted considerable resources to developing its natural gas sector and gas-fired power plants to ensure the country's energy security. In 2019, thanks to production from its large offshore natural gas deposits, Egypt achieved natural gas self-sufficiency and became a net energy exporter in the form of LNG. At the same time as it developed and installed the gas-fired power plants, Cairo also oversaw the construction of Egypt's flagship renewable power project — the massive Benban PV solar park outside of Aswan.[104] The $4 billion solar complex

6bn-in-clean-energy-projects/

100. https://www.ree.es/en/press-office/news/press-releases/2019/02/spain-and-morocco-agree-development-third-interconnection-between-both-countries; https://www.atalayar.com/en/articulo/economy-and-business/could-morocco-become-energy-provider-europe/20230308124149182087.html#google_vignette

101. https://www.maroc.ma/en/news/cop28-morocco-portugal-sign-joint-declaration-electricity-interconnection-project

102. https://www.atalayar.com/en/articulo/economy-and-business/could-morocco-become-energy-provider-europe/20230308124149182087.html#google_vignette

103. https://dailynewsegypt.com/2019/12/17/how-does-egypt-plan-to-produce-42-of-its-electricity-from-renewable-sources-by-2035/

104. https://www.eib.org/attachments/registers/65771943.pdf

has an installed capacity of 1.8 GW.[105] Egypt also built two wind power projects, the 580 MW Gabel el-Zait wind farm near Ras Ghareb (the country's largest, completed in 2018) and the onshore coastal 262.5 MW Gulf of Suez I wind farm (completed in 2019), with the 545 MW Zafarana wind farm having been completed much earlier in 2010.[106] By developing natural gas in conjunction with renewables, Egypt had reversed its 6 GW electricity generation capacity deficit into a surplus of 15 GW between 2016 and 2022.[107]

To cope with the 2023 economic crisis, the government reintroduced rolling power cuts in Egypt so that the natural gas not used for domestic power generation could be sold as LNG exports, bringing $300 million per month into the cash-strapped state coffers but eliminating Egypt's electricity surplus.[108] Natural gas supplies to Egypt's fertilizer sector were reportedly cut by 30%.[109] The situation is exacerbated by an annual deficit of 30-35 billion cubic meters of water, equivalent to about 60% of what the Nile River contributes to Egypt's water supply.[110] The water deficit is a main contributor to the country's need for food imports, which requires the government to go further into debt by spending precious foreign reserves to purchase imported food and then subsidizing it to make it affordable for Egypt's citizens.[111] To address the problem, Egypt has adopted the National Water Resources Plan 2017-2037 whose large-scale infrastructure program would cost $50 billion, including the building of 21 desalination plants at a cost of $8 billion.[112] These plants will need to be powered by electricity generated from either additional hydrocarbon or renewable energy resources.

Egypt's current dilemma shows that offtake for renewable energy by electricity interconnection alone is insufficient for sustained green energy development. Renewable energy also needs to be dedicated to high-value-added production for foreign export revenues or production for domestic consumption that would reduce the need for expensive imports (such as the use of renewable powered water desalination and fertilizer production to support the production of staple food crops). Green industrial manufacturing and agrifood production are necessary components of a green energy ecosystem to ensure the resilience and expansion of renewable energy production. Green hydrogen in the form of green ammonia constitutes a versatile energy carrier that could allow Egypt to achieve both value-added export revenues and import replacement.

Egypt's nascent green hydrogen industry, as in the case of Morocco, is primarily focused on green ammonia. Before the 2023 economic crisis, Egypt was the world's seventh largest ammonia producer, just behind Saudi Arabia, the leading Middle Eastern producer.[113] Already a major gray ammonia producer, Egypt can utilize its existing ammonia storage and transportation infrastructure for green ammonia. As such, green ammonia is likely to form

105. https://www.nsenergybusiness.com/projects/benban-solar-park

106. https://sdgs.un.org/partnerships/gabel-el-zeit-wind-farm-complex-ensuring-access-affordable-reliable-and-modern-energy; https://www.smart-energy.com/renewable-energy/egypts-largest-wind-energy-farm-is-now-operational/.; https://energycapitalpower.com/biggest-solar-energy-wind-projects-egypt/

107. https://www.dailynewsegypt.com/2022/07/27/could-egypt-make-use-of-its-energy-surplus/

108. https://www.shorouknews.com/news/view.aspx?cdate=30092023&id=281db9fd-88dd-4bbd-aa23-bd10351d5aea

109. https://english.ahram.org.eg/NewsContent/3/12/511318/Business/Economy/Egypt-lowers-gas-supply-to-fertilizer-companies-am.aspx

110. https://gate.ahram.org.eg/News/3975826.aspx

111. https://www.dailynewsegypt.com/2019/12/17/how-does-egypt-plan-to-produce-42-of-its-electricity-from-renewable-sources-by-2035/

112. https://english.ahram.org.eg/NewsContent/1/2/484408/Egypt/Society/Egypt-imports-water-consuming-foods-as-it-faces-an.aspx; https://www.reuters.com/markets/commodities/egypt-build-21-desalination-plants-phase-1-scheme-sovereign-fund-2022-12-01/

113. https://www.statista.com/statistics/1266244/global-ammonia-production-by-country/

Photo above: A liquefied natural gas tanker sails northbound on the Suez Canal in Ismailia, Egypt, on Dec. 11, 2007. Photo by Dana Smillie/Bloomberg.

a central part of Egypt's low carbon hydrogen strategy for both domestic use and exports. In addition to helping Cairo reach its 2035 energy transition goals, reducing the amount of natural gas required for domestic ammonia production will also free up supplies to be sold as LNG.

In 2021, Cairo had already set into motion a few initial green hydrogen projects that led to a spate of additional proposals. The Egyptian Electricity Holding Company (EEHC) signed an MoU in August 2021 with Siemens, which built the country's gas power plants, to jointly develop a hydrogen-based industry in Egypt with export capabilities, intended to maximize hydrogen production based on renewable energy sources.[114] In 2021, Egypt also signed an agreement with the Belgian conglomerate DEME to conduct feasibility studies for the production and export of green hydrogen.[115] Already involved in coastal land reclamation for Egypt's Mediterranean port capacity expansion, DEME will reportedly help to determine the optimal locations for hydrogen production hubs.[116] Locating Egypt's green hydrogen facilities is a critical task. The country's estimated 2019 "gray" hydrogen production totaled 1.82 million tons.[117] To produce this amount as green hydrogen would require

114. https://press.siemens-energy.com/mea/en/pressrelease/siemens-energy-supports-egypt-develop-green-hydrogen-industry

115. https://www.egypttoday.com/Article/3/99297/Egypt-cooperates-with-Belgian-DEME-to-start-producing-exporting-green

116. https://www.afrik21.africa/en/egypt-belgiums-deme-signs-with-the-authorities-for-green-hydrogen-studies/

117. https://a9w7k6q9.stackpathcdn.com/wpcms/wp-content/uploads/2021/11/Egypts-Low-Carbon-Hydrogen-Development-Prospects-ET04.pdf

approximately 16.22 million cubic meters (mcm) of water. Although water consumption accounts for only a small share of the total cost of green hydrogen production, the supply of water as an input is a critical issue in water-scarce Egypt. Given average annual rainfall of only 33.3 mm and a lack of permanent surface water across large swaths of the country,[118] coastal green hydrogen production sites with dedicated water desalination units also powered by renewable energy are a necessity.

In July 2021, Italian energy major Eni, one of Egypt's natural gas partners and the lead operator of the Zohr field, signed an agreement with EEHC to assess the technical and commercial feasibility of producing both green hydrogen and blue hydrogen.[119] For the latter, Eni is eyeing the possibility of using Egypt's depleted natural gas fields for the storage of CO_2 produced by carbon capture. The country is currently the world's sixth largest producer of urea, also used in nitrogen-based fertilizers, and could relatively easily use the captured CO_2 for urea manufacture.[120]

One of Egypt's most promising early green hydrogen projects will be constructed on the western shore of the Gulf of Suez. The Norwegian renewable energy company Scatec and Dutch-Emirati fertilizer producer Fertiglobe, in partnership with the Sovereign Fund of Egypt, are building a green hydrogen facility in the industrial zone of the Red Sea port of Ain Sokhna, near Fertiglobe's subsidiary Egypt Basic Industries Corporation (EBIC).[121] Scatec will build and operate the facility with Fertiglobe enjoying a long-term offtake agreement for its green hydrogen output as a feedstock for EBIC's green ammonia production.[122]

For Egypt to replace its entire gray hydrogen production with domestically produced green hydrogen, the country would need an estimated 21 GW of electrolyzer capacity,[123] making Cairo likely to opt for a combination of green and blue hydrogen as it seeks to capture market share in the European and Asian markets. Ultimately, Cairo aims to capture around 5-8% of the global market for green hydrogen, as the value of the clean hydrogen market is expected to surpass that of the LNG trade by 2030 and continue to grow to $1.4 trillion by 2050.[124]

In October 2022, in the run-up to Egypt's hosting of the United Nations Climate Change Conference (27th Conference of the Parties, COP27) in November 2022, the European Bank for Reconstruction and Development granted Egypt an equity bridge loan of up to $80 million for developing its green hydrogen production infrastructure.[125] At COP27, Egypt's minister of energy announced an outline for the country's national clean hydrogen strategy and signed framework agreements with Fortescue Future Industries (the green energy arm of Australian metals giant Fortescue), India's ReNew Power, Dubai-based AMEA Power, Saudi project developer Alfanar, the London-headquartered, Africa-focused green energy developer

118. https://climateknowledgeportal.worldbank.org/sites/default/files/2021-04/15723-WB_Egypt%20Country%20Profile-WEB-2_0.pdf

119. https://www.eni.com/en-IT/media/press-release/2021/07/cs-eni-firma-accordo-produzione-idrogeno-egitto.html

120. https://www.egypttoday.com/Article/3/111326/Egypt-6th-in-world-in-urea-production-produces-7-8M#:~:text=CAIRO%20%2D%2028%20December%202021%3A%20Egypt,production%20with%206.7%20million%20tons

121. https://scatec.com/2021/11/24/scatecs-green-hydrogen-consortium-in-egypt-selects-plug-power-for-delivery-of-100-mw-electrolyser/

122. https://scatec.com/2021/10/14/scatec-partners-with-fertiglobe-and-the-sovereign-fund-of-egypt-to-develop-green-hydrogen-as-feedstock-for-ammonia-production-in-egypt/

123. https://www.mei.edu/publications/egypts-synergy-between-natural-gas-and-green-energy-transition-cairos-advances-lng-and#:~:text=However%2C%20for%20Egypt%20to%20replace,the%20capacity%20currently%20under%20construction

124. https://www.thenationalnews.com/opinion/comment/2023/12/13/africas-maritime-hydrogen-highways-could-enrich-the-continent-and-save-the-world/; https://www.deloitte.com/global/en/about/press-room/new-deloitte-report-emerging-green-hydrogen-market.html

125. https://www.ebrd.com/work-with-us/projects/psd/53558.html

Globeleq, Total Energies, EDF, and Scatec.[126] Most of the agreements concerned project development around the Ain Sokhna port and the Suez Canal Economic Zone (SCZone), with some building upon pre-existing projects. Energy China signed an MoU to invest approximately $7 billion in the SCZone as well.[127]

Also on the sidelines of COP27, a Masdar-led consortium with Emirati-Egyptian joint venture Infinity Power and Egypt's Hassan Allam Utilities signed a framework agreement for the construction of a 2 GW green hydrogen facility in the SCZone, set to be operational in 2026.[128] The framework agreement, signed with NREA, EETC, and the Sovereign Fund of Egypt, follows two April 2022 MoUs inked by Egypt with the Masdar-led consortium to construct two green hydrogen facilities with a combined electrolyzer capacity of 4 GW. The other green hydrogen facility is to be built on Egypt's Mediterranean coast, with the 2030 target of a combined annual green hydrogen output from both facilities of 480,000 tons.[129] The week prior, the same consortium of Masdar, Infinity Power, and Hassan Allan Utilities signed an agreement for the development of 10 GW wind project, potentially saving about $5 billion in natural gas costs per year.[130] The electric output would also be sufficient to power the green hydrogen production facilities while providing electricity for other industrial or residential power needs.

The collaboration between Masdar and Infinity Power, along with its Egyptian partners reflects Cairo and Abu Dhabi's mutual interest in Egypt's emergence as a regional hub for green hydrogen exports to both European and Asian markets.[131] Speaking at the signing ceremony for the framework agreement for the SCZone green hydrogen plant, Infinity Power's chairman said the project would "help position Egypt as a Green Fuel Hub, propelling the country forward on its journey in becoming a green economy."[132]

In August 2023, Egypt established a National Council for Green Hydrogen and its Derivatives to monitor the implementation of its National Green Hydrogen Strategy and ensure its regional and international competitiveness in the sector, particularly in overcoming obstacles to attracting investment.[133] Subsequently, Egypt's minister of electricity announced that Cairo's goal was to capture 5-8% of the global commercial market for green hydrogen,[134] while the minister of finance announced that it would offer tax incentives ranging from 33% to 55% and use other financing mechanisms to encourage green hydrogen investment.[135]

China's push to develop a manufacturing base in Egypt through the appliance manufacturing sector may also open possibilities for Cairo to develop a more diversified green energy ecosystem via green hydrogen or dedicated renewable power infrastructure. In 2023, Chinese home appliance giant Haier completed the first phase of its factory build-out in Egypt and it plans to start production of air conditioners, washing machines, and televisions in 2024. With the additional of refrigerators and freezers, Haier expects to produce

126. https://www.reuters.com/world/middle-east/egypt-signs-framework-deals-bid-launch-hydrogen-industry-2022-11-15/

127. https://sczone.eg/sczone-converts-7-billion-mou-with-energy-china-into-a-framework-agreement-soon/

128. https://news.masdar.ae/en/press-Release?News/2022/11/16/08/41/Masdar-led-consortium-strengthens-partnership

129. https://news.masdar.ae/en/press-Release?News/2022/11/16/08/41/Masdar-led-consortium-strengthens-partnership

130. https://masdar.ae/en/news/newsroom/uae-and-egypt-advance-development-of-africas-wind-farm

131. See the discussion of the UAE's green hydrogen strategy further on in the text.

132. https://news.masdar.ae/en/press-Release?News/2022/11/16/08/41/Masdar-led-consortium-strengthens-partnership

133. https://english.ahram.org.eg/News/507526.aspx

134. https://www.egypttoday.com/Article/3/127541/Egypt-aims-for-5-8-share-in-global-green-hydrogen

135. https://www.egypttoday.com/Article/3/127641/Egypt-to-provide-new-Incentives-for-green-hydrogen-production

1 million home appliances per year in Egypt.[136] Chinese firms are also beginning to develop a manufacturing base for industrial products that could serve as inputs, such as iron, steel, and chemicals, all of which could possibly be powered with green hydrogen.

Electricity interconnection remains a potential mechanism for Egypt to establish renewable energy supply chains, and the progress in advancing proposals for Egypt's trans-Mediterranean interconnection with Europe as well as the expanded interconnections constructed with Saudi Arabia and Sudan should not be overlooked. Egypt could access wider EU markets via the proposed 2 GW Euro-Africa interconnector to transport electricity from Egypt to Europe via Cyprus and Greece or the proposed 3 GW direct Greece-Egypt (GREGY) interconnector.[137] The soon-to-be operational $1.6 billion, 3 GW interconnection between Egypt and Saudi Arabia could be used to bolster electricity exports to Europe through Saudi contributions.[138] The planned expansion of Egypt's interconnection with Jordan from 300 MW to 2 GW could also enable Egyptian electricity exports to the kingdom, bolstering Jordan's own exports to Lebanon, Syria, and Iraq (see discussion below).[139]

Egypt has made significant upgrades to its electricity interconnections with Africa as well. In December 2019, Egypt announced that it was prepared to export 20% of its surplus electricity to African nations.[140] Sudan, Egypt's neighbor to the south, has a 60% rate of access to electricity.[141] Egypt and Sudan's grid connection became operational in April 2020, and will reach 300 MW upon completion.[142] Egypt could theoretically export electricity to other neighboring countries facing power shortages, like Chad.

Despite Egypt's progress in establishing interconnections on three continents, Egypt must first return to generating electricity surpluses before it can export significant amounts of power. Under these circumstances, renewable energy supply chains via interconnection are unlikely to materialize soon unless the interconnections are accompanied by dedicated renewable power infrastructure.

Sudan: The Potential for Renewable Energy Supply Chains

While Egypt has been eyeing electricity exports to Sudan, the Egypt-Sudan interconnection could also provide a means for Sudan to establish renewable energy supply chains to Egypt and beyond to Europe and the Middle East. Approximately 44% of Sudan's total installed capacity for power generation comes from hydroelectric power,[143] producing around 60% of its power.[144] Solar power infrastructure is virtually nonexistent, providing about 0.18% of its electricity, while there is no installed capacity from wind power.[145] However, the present state of solar and wind power in Sudan stands in stark contrast to the enormous potential of its resources. The deserts of Sudan's northern and central regions receive similar levels

136. https://www.thenationalnews.com/weekend/2023/08/25/brics-north-africa/

137. https://balkangreenenergynews.com/eu-adds-greece-egypt-power-interconnection-project-to-pci-pmi-list-proposal/

138. https://www.ispionline.it/en/publication/egypts-prospects-energy-export-hub-across-three-continents-27408; https://www.iea.org/policies/14291-egypt-saudi-electricity-interconnection-project

139. https://www.arabfund.org/default.aspx?pageId=454

140. https://almalnews.com/السيسي-مصر-مستعدة-لنقل-20-من-الكهرباء-ألـ/

141. https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=SD-TD-LY

142. https://dailynewsegypt.com/2020/04/05/egypt-sudan-electricity-interconnection-officially-operates-at-70mw-capacity/

143. https://www.eia.gov/international/analysis/country/SDN

144. https://ourworldindata.org/grapher/share-elec-by-source?country=~SDN

145. https://ourworldindata.org/grapher/share-elec-by-source?country=~SDN; https://www.irena.org/-/media/Files/IRENA/Agency/Statistics/Statistical_Profiles/Africa/Sudan_Africa_RE_SP.pdf

of solar irradiation as Egypt's Benban mega-solar power complex, while 50% of Sudan's territory is suitable for wind power.[146]

Beyond electricity interconnection, green ammonia production for export or to power mining and manufacturing in Sudan are likely to incentivize foreign investment in solar and wind power infrastructure development. Sudan's conditions are roughly parallel to those of Mauritania, in which companies from the UAE, Egypt, Germany, France and the UK have already invested in constructing green ammonia plants.[147] One of the Mauritanian plants has already signed an MoU with the Port of Rotterdam for offtake of up to 600,000 tons of green hydrogen annually for sale in European markets.[148] With its Red Sea ports, Sudan could similarly serve European markets as well as accessible Asian markets, although for now the ongoing civil war will remain a major deterrent to investment. As will be discussed below, the Amman-headquartered Iraqi firm Mass Group Holding (MGH) that operates a cement plant in Sudan is exploring the establishment of a green ammonia production plant in Jordan. A comparable facility could be established in Sudan to power cement production as well as for green ammonia exports.

Algeria and Tunisia: Challenges and Opportunities in the Central Maghreb

Despite its tremendous potential, Algeria's renewable energy sector is woefully underdeveloped, accounting for just 0.8% of the country's electricity generation in 2021.[149] In 2022, Algeria's installed capacity for power generation stood at 698 MW, comprised of 460 MW of solar power, 228 MW of hydroelectric power, and 10 MW of wind power.[150] The 2030 target for Algeria's Renewable Energy and Energy Efficiency Development Plan is 22 GW of installed renewable power generation capacity.[151] Originally promulgated in 2011, the plan would require a thirtyfold increase in overall renewable capacity within six years, raising solar and wind power capacity to 15.58 GW and 5.01 GW respectively. The plan also designates 10 GW of the total renewable capacity for exports.[152]

Africa's largest natural gas exporter, Algeria's oil and gas sector accounts for 94% of its export revenues and dominates the economy.[153] Like other industries outside the hydrocarbon sector, the development of Algeria's solar power sector has been set back by institutional challenges that have hampered foreign private sector engagement.[154] Renewable energy development could be incentivized in Algeria to reduce the carbon footprint of oil, gas, and petrochemicals production. In 2018, Eni and Sonatrach, Algeria's state-owned energy company, built a 10 MW PV plant to support greenhouse gas capture in their Bir Rebaa North upstream oil and gas operations.[155] Similar renewable power projects to "green" the fossil fuel

146. https://solargis.com/maps-and-gis-data/download/sudan; https://www.sciencedirect.com/science/article/abs/pii/S0960148199000543

147. https://www.ntu.edu.sg/cas/news-events/news/details/can-singapore-unlock-africa-s-green-hydrogen-potential

148. https://www.ntu.edu.sg/cas/news-events/news/details/can-singapore-unlock-africa-s-green-hydrogen-potential

149. https://www.iea.org/countries/algeria

150. https://www.irena.org/-/media/Files/IRENA/Agency/Statistics/Statistical_Profiles/Africa/Algeria_Africa_RE_SP.pdf; https://www.statista.com/topics/10656/renewable-energy-in-algeria/#topicOverview

151. https://www.energy.gov.dz/?rubrique=energies-nouvelles-renouvelables-et-maitrise-de-lrenergie#:~:text=Le%20programme%20des%20%C3%A9nergies%20renouvelables%20dans%20sa%20version%20actualis%C3%A9e%2C%20consiste,conditions%20du%20march%C3%A9%20le%20permettent

152. https://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2015/05/ALGERIA.pdf

153. https://thedocs.worldbank.org/en/doc/65cf93926fdb3ea23b72f277fc249a72-0500042021/related/mpo-dza.pdf

154. https://www.iai.it/sites/default/files/iaip2120.pdf

155. https://www.eni.com/en-IT/media/press-release/2018/11/eni-and-sonatrach-inaugurate-the-10-mw-bir-rebaa-north-photovoltaic-plant-and-sign-agreements-in-the-renewable-energy-sector.html

Photo above: Signing ceremony for the SoutH2 Corridor memorandum of understanding at the 12th Africa & Mediterranean Energy & Hydrogen Exhibition and Conference (NAPEC 2024) in Oran, Algeria, on Oct. 14, 2024. Photo by APP/NurPhoto via Getty Images.

industry seem likely and could potentially serve as part of the foundation for a green energy ecosystem.

In 2020, Italy's Fimer, Algeria's lead foreign partner in the realization of its 2030 renewable energy production goals,[156] installed inverters for one of Algeria's showcase solar projects — the rooftop solar power system at Oran's Ahmed Ben Bella International Airport.[157] Africa's largest rooftop PV installation, the 3.04 GW system will supply approximately 30% of the airport's electricity, helping to move toward its 2030 objective of installing 13.5 GW in PV production capacity.[158] However, Algeria's flagship renewable energy project, the $3.6 billion, 4 GW Tafouk1 solar power complex, has floundered for lack of foreign investment, despite Algiers suspending its requirement to cap foreign stakeholders at 49%. Algeria could opt for numerous, small-scale independent power projects, an approach that has met with some initial success in neighboring Tunisia (see below).

Algeria's development of a green energy ecosystem has been hampered by the country's general difficulties in developing a local manufacturing base, as evidenced by the inability of its nascent automotive sector and of its foreign partners to establish a reliable automotive

156. https://jiac.it/blog/2018/08/02/algeria-italia-fimer-fotovoltaico/; https://www.infoafrica.it/2018/08/02/litaliana-fimer-ottiene-contratto-per-impianti-fotovoltaici-in-algeria/

157. https://www.fimer.com/fimer-chosen-largest-solar-pv-airport-installation-africa

158. https://www.fimer.com/fimer-chosen-largest-solar-pv-airport-installation-africa

manufacturing value chain locally.[159] The country's relatively successful iron and steel industry, with factories run by Qatari and Turkish firms,[160] may be one of the most conducive industries outside the hydrocarbon sector for developing the use of renewable power, either directly or via green hydrogen.

In March 2023, Algeria unveiled its first hydrogen roadmap, which was developed with considerable assistance from the German development agency GIZ.[161] However, the 30-year framework makes no commitments to specific types of hydrogen, making the roadmap consistent with Algeria's desire to sell gray and blue hydrogen to Europe. Four months prior to the release of the roadmap in December 2022, Algeria signed a declaration of intent with Germany's VNG, a subsidiary of German utility EnBW, to develop a pilot green ammonia plant. Although Germany's KfW agreed to finance the 50 MW pilot green hydrogen facility,[162] the agreement appears to have been a precursor to clearing a path for German purchases of Algerian natural gas. In early February 2024, VNG — formerly a major purchaser of Russian natural gas for German businesses — signed a landmark deal with Sonatrach to become the first German company to buy Algerian pipeline gas.[163] While Algeria eyes capturing 10% of the European hydrogen market, the Ministry for Energy and Mines made clear the primacy of blue hydrogen in the short and medium term, declaring it an important step toward the development of green hydrogen.[164] The greatest obstacle to green hydrogen development in Algeria may not be blue hydrogen but rather the insistence of Algeria and its European partners on transporting hydrogen via the existing natural gas pipeline network. The approach is being led by Italy, Germany, and Austria, which are seeking to create the "SoutH2 Corridor" that envisions using the undersea gas pipeline interconnection between Tunisia and Italy and Italy's gas transmission system to transport hydrogen produced in the central Maghreb to Italy and central Europe.[165] However, the technical and commercial viability of a trans-Mediterranean hydrogen pipeline is suspect and the project will likely either be highly climate unfriendly or economically infeasible if sufficient measures are taken to mitigate environmental damage and the release of greenhouse gases.[166]

When hydrogen is transported through undersea natural gas pipelines, the molecules severely degrade the hard steel. Unlike significantly larger natural gas molecules, the small hydrogen molecules can permeate the micro-fissures that develop in the pipe due to repeated changes of pressure,[167] with the weld parts of the pipe even more susceptible to the formation and expansion of micro-fissures. While natural gas pipelines typically have a methane emission rate of 3.5%, the emission rate for the much smaller hydrogen molecules will be significantly higher.[168] The released hydrogen would have a global warming potential 7.9 times that of the CO_2 it is intended to replace.[169]

159. https://www.iai.it/en/pubblicazioni/europe-africa-connectivity-outlook-2021-post-covid-19-challenges-and-strategic

160. https://www.swpberlin.org/publications/products/arbeitspapiere/CATS_Working_Paper_Nr_3_Michael_Tanchum_Turkeys_Maghreb_West_Africa_Economic_Architecture.pdf

161. https://www.aps.dz/economie/153601-feuille-de-route-de-developpement-de-l-hydrogene-fournir-au-marche-europeen-10-de-ses-besoins-a-l-horizon-2040

162. https://renewablesnow.com/news/germany-to-back-50-mw-green-hydrogen-project-in-algeria-837675/

163. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/natural-gas/020924-germanys-vng-to-begin-algerian-gas-imports-under-mid-term-deal-with-sonatrach

164. https://www.ambalgzagreb.com/hydrogen-production-algeria-in-position-to-play-leading-regional-role/

165. https://www.south2corridor.net/south2

166. https://www.bloomsbury.com/us/energy-transitions-in-the-middle-east-9780755650378/

167. https://cleantechnica.com/2022/03/01/paul-martin-talks-h2-science-coalition-more-problems-with-hydrogen/

168. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/natural-gas/081221-blue-hydrogen-20-worse-for-ghg-emissions-than-natural-gas-in-heating-study

169. https://assets.publishing.service.gov.uk/government/

Aside from the pipeline material, the added compression costs to ship hydrogen through natural gas pipelines make the transmission of questionable commercial feasibility. Being 8.5 times less dense than natural gas, hydrogen is more difficult to move and therefore less energy efficient. For the same quantity of heat energy, hydrogen requires 200% more energy to compress than natural gas.[170] The compressors in the existing natural gas pipeline network would need to be replaced with units three times as powerful, with three times the suction displacement, and with special capabilities to prevent the smaller hydrogen molecules from leaking.[171] The capital expenditures and operating costs of transportation alone mean that replacing Algeria's natural gas exports to Europe with hydrogen sent via pipeline would be over three times more expensive. [172]

The proposal of transporting a blend of 20% hydrogen and 80% natural gas would not sufficiently resolve the transportation problems. Furthermore, even if green hydrogen were used, the blend would not be even "20% green." The 80-20 proportion is by volume and contains only 86% of the energy content of the same amount of natural gas alone. The 80-20 blend requires 14% more of the blend to produce the same amount of energy as natural gas. Therefore, the greenhouse gas reduction of a blend with 20% green hydrogen would be closer to 6% or even less when accounting for the fact that the 80-20 blend would require 13% more energy to compress.[173] The extent to which Algeria and its international partners succeed in the attempt to ship green hydrogen via undersea pipelines will determine the fate of Algeria's green hydrogen industry, unless Algiers and its European partners can be convinced to opt for green ammonia. In the absence of green hydrogen or the manufacture of export products in Algeria powered by renewable energy, trans-Mediterranean electricity interconnection via Tunisia will be Algeria's only export offtake option for its renewable energy production.

In 2022, Tunisia possessed 472 MW of installed power generation capacity from renewable sources, accounting for 8% of its total.[174] Wind power accounted for the largest amount of renewable capacity with 244 MW, while solar power stood at 166 MW and hydroelectric power at 62 MW. In the same year Tunisia revised its 2030 target upwards from renewable power comprising 30% of total power generation capacity to 35%, as an intermediate step toward reaching 80% by 2050.[175] Representing an almost 900% increase in renewable power capacity, the immediate focus of the Tunisian government is finding foreign companies to build a large number of small renewable facilities as independent power projects, with an emphasis on PV solar power. In 2023, Tunisia initiated tender offerings for 18 projects with a combined capacity of 1.7 GW — ten 100 MW solar power projects and eight 75 MW wind power projects.[176] Given Tunisia's comparatively small population, these projects collectively could have some export offtake potential. By themselves, they are insufficient to create a green energy ecosystem or international renewable energy supply chains, but they could provide a vital foundation for the development of both.

Tunisia's recent efforts to expand its renewable capacity are built upon the government's push to revise the legal framework to attract foreign direct investment (FDI) in

uploads/system/uploads/attachment_data/file/1067144/atmospheric-implications-of-increased-hydrogen-use.pdf

170. https://cleantechnica.com/2020/12/14/can-hydrogen-replace-natural-gas-looking-at-the-numbers/

171. https://cleantechnica.com/2020/12/14/can-hydrogen-replace-natural-gas-looking-at-the-numbers/

172. https://cleantechnica.com/2020/12/14/can-hydrogen-replace-natural-gas-looking-at-the-numbers/

173. https://cleantechnica.com/2020/12/14/can-hydrogen-replace-natural-gas-looking-at-the-numbers/

174. https://www.iea.org/countries/tunisia

175. https://www.gfse.at/news/renewable-energy-in-tunisia#:~:text=The%20Tunisian%20Solar%20Plan%20foresees,amounts%20in%20solar%20and%20Hydropower

176. https://www.enerdata.net/publications/daily-energy-news/tunisia-launches-tender-17-gw-renewables.html; https://www.agbi.com/energy/2023/01/tunisia-steps-up-solar-ambitions-with-launch-of-new-tenders/

Photo above: A farmer holds a handful of soil parched because of drought in Tunisia's east-central area of Kairouan, on Oct. 20, 2021. Photo by ANIS MILI/AFP via Getty Images.

the development of renewable energy infrastructure.[177] The success of the new concessions regime to encourage the completion of these projects and the network of partnerships with foreign companies that emerge from that success will determine whether Tunisia will realize its renewable energy potential. The initial results offer some cause for optimism. In 2023, the UAE-headquartered renewable energy developer AMEA Power reached its final close on a 120 MW solar power plant in Tunisia's Kairouan governate.[178] Winning the project in December 2019 in a previous tender program launched by Tunis, the government signed the concession agreement and power purchase agreement in June 2021 under the new concessions regime for projects over 10 MW.[179] Financed by the International Finance Corporation and the African Development Bank, the Kairouan Solar Plant is the first solar project to reach financial close under the new concessions regime.

To further enhance the effectiveness of Tunisia's new concessions regime, the government will need to overhaul the fiscal health and transparent functioning of the state-owned energy production and distribution company STEG (Société tunisienne de l'électricité et du gaz), which oversees the development of offtake mechanisms that will be vital to Tunisia's formation of international renewable energy supply chains, both via green hydrogen and electricity interconnection. How Tunis engages international financial institutions to help achieve

177. https://legalcommunitymena.com/unlocking-solar-and-wind-potential-streamlining-authorization-for-foreign-investors-in-tunisias-renewable-energy-sector/

178. https://www.ameapower.com/amea-power-reaches-financial-close-on-the-120mw-solar-power-plant-in-tunisia/

179. https://www.ameapower.com/amea-power-reaches-financial-close-on-the-120mw-solar-power-plant-in-tunisia/

accountability in bills payment and a workable balance of tariffs, revenue requirements, and subsidies will greatly impact the country's success going forward.[180]

Tunisia's National Green Hydrogen Strategy aims to produce 8.3 million tons of green hydrogen, 6 million of which are slated for export.[181] Although Tunisia has strong potential for green hydrogen production, the limited efforts to develop the sector have occurred within a development aid framework. Both the SoutH2 Corridor project and green ammonia development are hampered by this limitation. The concept of the SoutH2 Corridor builds on a 2021 study published by GIZ assessing the potential of Tunisia's hydrogen industry that did not address the previously discussed challenges involved in transmitting hydrogen through undersea natural gas pipelines.[182] Spearheading Tunisia's green hydrogen program is TuNur, a joint venture between Tunisian investment group Top Group and UK-based firm Nur Energie, which came to prominence through the endorsement of the Desertec project.[183]

Green ammonia development in Tunisia was kickstarted in December 2020, when Tunisia received a $36 million development grant from Germany for the construction of a pilot green hydrogen project now known as H2 Vert.[184] Officially launched in June 2022, the small-scale plant is slated to produce 1,500 tons of green ammonia per year, with GIZ designated to oversee project implementation.[185] The economic logic for Tunisia to develop a green ammonia industry linked to fertilizer production, along lines similar to Morocco's engagement with foreign private sector investors, is more compelling. Faced with similar agri-food production problems as Egypt, Tunisia can only satisfy 25% of its domestic fertilizer demand.[186] Replacing imported gray ammonia with locally produced green ammonia would boost Tunisia's domestic fertilizer industry. With a total population three times smaller than that of Morocco, Tunisia would be well-positioned to develop an export industry for surplus green ammonia or possibly higher-value fertilizer, given the supply shortages in Europe and Africa.

As in the rest of North Africa, water scarcity poses a significant challenge for green hydrogen production in Tunisia, where about 80% of the diminishing water resources are used for agriculture.[187] Plagued by drought, Tunisia's situation has been exacerbated by the poor stewardship of its scant water resources.[188] The food and water problems are not insurmountable and their amelioration could be accelerated by the development of a green ammonia industry if sufficient desalination plants and the renewable energy infrastructure to power them are constructed. Green ammonia exports could incentivize the significant foreign investment required to achieve these solutions, as has occurred with the development of large-scale green ammonia production in Mauritania.[189] The success of the most recent tenders for solar and wind power under Tunisia's new concessions regime could form

180. https://blogs.worldbank.org/arabvoices/tunisias-energy-sector-can-become-engine-for-green-growth#:~:text=The%20government%20aims%20to%20increase,solar%20or%20wind%20power%20plants

181. https://www.tunur.tn/tunisias-national-green-hydrogen-strategy

182. https://energypedia.info/images/0/0c/Potential_Study_PtX_in_Tunisia_2021.pdf

183. https://nawaat.org/2014/08/22/under-the-tunisian-sun-expanding-solar-energy-production-for-autoconsumption-and-export/#:~:text=%C2%ABThe%20DESERTEC%20Foundation%20is%20endorsing,model%2Dfor%2Dthe%2Drest

184. https://www.tunur.tn/wp-content/uploads/2021/06/TuNur-PtX-Dialogue-VF2.pdf

185. https://www.zawya.com/en/business/energy/tunisia-launches-h2vert-project-to-develop-green-hydrogen-industry-mk5bnmid

186. https://www.fao.org/giews/countrybrief/country.jsp?code=TUN

187. https://www.reuters.com/article/us-tunisia-water-land-feature-trfn-idUSKBN1XB2X.1

188. https://www.reuters.com/article/us-tunisia-water-land-feature-trfn-idUSKBN1XB2X.1

189. https://www.ntu.edu.sg/cas/news-events/news/details/can-singapore-unlock-africa-s-green-hydrogen-potential

an avenue for attracting foreign private sector partners for Tunisia's green ammonia development. An opportunity exists for Morocco, Egypt, and Arab Gulf hydrogen actors to cooperate with Tunisia as well. The opportunity is enhanced by the fact that green ammonia is traded via seaborne exports and would not require overland pipeline or electricity interconnection transit over Algerian or Libyan territory.

Beyond green ammonia and fertilizer exports, Tunisia's automotive components industry could support the development of an international renewable energy supply chain, if the manufacturing processes were powered by renewable energy. Tunisia's automotive parts sector accounts for about 14% of its exports and employs over 90,000 Tunisians.[190] With top export markets being Germany, France, Romania, and Italy, Tunisian automotive components manufactured using renewable power would establish an import Tunisia-to-Europe renewable energy supply chain.[191] Tunisia's flagship company, the automotive wire and cable manufacturer Coficab, is an industry leader, positioning the company at the forefront of automotive electrical system supply chains for EV production. Coficab operates a factory in Morocco to supply its auto manufacturing ecosystem, creating an opportunity for synergy with the neighboring state in creating an industrial renewable energy supply chain.

Trans-Mediterranean interconnection forms an important offtake mechanism for Tunisia, which is partnering with Italy to interconnect their electricity grids via a 192-km-long, 600 MW undersea cable between Tunisia and Sicily.[192] Known as the ElMed interconnector, the project was scheduled for completion in 2025, but now is on track to be completed in 2028 thanks to the financial infusions of €308 million and $268 million respectively by the European Commission in December 2022 and the World Bank in June 2023.[193] In contrast to Morocco's interconnections with Spain and Portugal, Tunisia's interconnection with Italy will enable power exports to the wider EU electricity market.

Arabian Peninsula

The Arabian Peninsula has long been a leading production center for the oil and natural gas traded on global markets. Among the countries on the peninsula that form the membership of the Gulf Cooperation Council (GCC) are the world's leading oil and natural gas producers with almost 100 years of experience as hydrocarbon fuel exporters. At the same time, these countries possess solar energy resources almost at the same level as the nations of North Africa. Shaped by their experience in international hydrocarbon value chains, most of the GCC states have placed international renewable energy supply chains at the forefront of their respective approaches to developing their own renewable power infrastructure for a post-hydrocarbon age.

At the same time, several of the GCC nations are using the energy transition as an opportunity to diversify their economies by developing 21st century, climate-smart industrial manufacturing and agri-food production. The UAE has been at the forefront of developing a green energy ecosystem, while Saudi Arabia is seeking to emulate the Emirati approach in a manner appropriate to its own needs and often on a grander scale. Global LNG giant Qatar is charting its own similar course while Oman aspires to use the opportunity to expand its international footprint. Especially in the case of the UAE and Saudi Arabia, the two countries are using their experience and capital to become an engine driving the development of renewable energy infrastructure and green energy ecosystems in Europe, Asia, and Africa as well as in their own countries. These efforts are placing the Arabian Peninsula at the center of an emerging pattern of renewable energy supply chains.

190. https://lapresse.tn/115069/industrie-des-composants-automobiles-le-cout-de-la-main-doeuvre-un-element-de-differentiation-de-la-destination-tunisie/

191. https://www.iai.it/sites/default/files/9788893682732.pdf

192. https://industryeurope.com/italian-tunisian-elmed-interconnector-given-go-ahead/

193. https://www.enerdata.net/publications/daily-energy-news/eu-grants-eu307m-600-mw-italy-tunisia-power-interconnection-project.html; https://www.worldbank.org/en/news/press-release/2023/06/22/world-bank-approves-268-million-project-linking-tunisia-s-energy-grids-with-europe

UAE: A Green Energy Ecosystem as an Emerging Hub for Renewable Energy Supply Chains

The UAE is home to one of the MENA region's most rapidly developing green energy ecosystems. A signatory to the 2015 Paris Climate Accord and committed to achieve net zero by 2050, the UAE has been investing extensively in energy transition, both at home and abroad, since it ratified the Kyoto Protocol in 2005. The UAE's cumulative investment in clean energy projects from 2005 to 2023 totals over $40 billion.[194] Beyond its borders, the UAE has invested in renewable energy projects across 70 countries worth a total of $16.8 billion.[195] These extensive foreign investments reflect the Emirati approach, which regards its own green energy ecosystem as a central connectivity node in a nexus of international green energy ecosystems. With this outlook, the UAE has been positioning itself to become a hub for inter-regional, renewable energy supply chains.

The UAE is accelerating its development of power generation from renewable energy, a process that in the short term frees up natural gas for industrial use and export to help maintain favorable foreign trade balances and robust GDP growth while the country implements its energy transition. The UAE's forward-leaning policies have succeeded in making it home to the largest renewable energy power generation capacity in the Arab Middle East. In 2022, the UAE boasted installed solar power capacity of 3.04 GW, accounting for over 99% of the Emirates' renewable energy capacity.[196] In July 2023, the UAE announced its updated National Energy Strategy to achieve in 2050 an energy mix of 44% renewable energy, 38% natural gas, 12% "clean coal," and 6% nuclear energy.[197] With the interim goal of tripling the share of "clean energy" in its power mix by 2030 to 30%, the UAE is embarking on $54.5 billion in renewable energy investments.[198] By 2030, UAE is aiming to achieve a 19.8 GW "clean energy" power generation capacity,[199] including 14.2 GW of renewable energy, quadrupling its 2022 renewable energy capacity.[200] Most of the 14.2 GW will come from the expansion of the UAE's solar energy capacity, with a combined 470 MW coming from waste-to-energy and pumped-storage hydropower.[201]

The Emirati efforts to develop its green energy ecosystem have benefited from the skillful leveraging of the country's experience in oil, natural gas, and petrochemicals production and export, encouraging collaboration between its national oil companies, firms engaged in renewable energy development such as Masdar (Abu Dhabi Future Energy Company), and the country's various power authorities. This collaboration has been facilitated by the bureaucratic integration of state-owned enterprises across the country's seven emirates. In 2018, the UAE's four power authorities — the Abu Dhabi Water and Electricity Authority (ADWEA), the Dubai Electricity and Water Authority (DEWA), the Sharjah Electricity and Water Authority (SEWA), and Etihad Water and Electricity (EWE), which supplies electricity in Fujairah, Ras al-Khaimah, Ajman, and Umm al-Quwain — were integrated into the then newly created national Ministry of Energy and

194. https://u.ae/en/information-and-services/environment-and-energy/climate-change/theuaesresponsetoclimatechange/uae-net-zero-2050

195. https://u.ae/en/information-and-services/environment-and-energy/climate-change/theuaesresponsetoclimatechange/uae-net-zero-2050

196. https://mc-cd8320d4-36a1-40ac-83cc-3389-cdn-endpoint.azureedge.net/-/media/Files/IRENA/Agency/Publication/2023/Mar/IRENA_RE_Capacity_Statistics_2023.pdf?rev=d2949151ee6a4625b65c82881403c2a7

197. https://u.ae/en/information-and-services/environment-and-energy/water-and-energy/about-uae-energy-sector

198. https://gulfbusiness.com/uae-to-generate-19gw-clean-energy-2030-almazrouei/

199. https://gulfbusiness.com/uae-to-generate-19gw-clean-energy-2030-almazrouei/

200. https://www.eiu.com/n/uae-raises-targets-for-sustainable-energy-in-2030/

201. https://www.dewa.gov.ae/en/about-us/strategic-initiatives/hatta-project

Infrastructure.[202] The consolidation served to streamline strategic planning by bringing state-owned energy companies into a national framework. For example, the integration of ADWEA saw the Abu Dhabi National Energy Company (TAQA) — 74.1% of which was owned by ADWEA — and ADWEA's then 10 power and water desalination plants come under the new ministry's authority.[203]

An important coordinating role has been played by the country's various sovereign wealth funds, such as the state-owned holding companies Mubadala Investment Company (Mubadala) and the Abu Dhabi Developmental Holding Company (ADQ). Masdar has emerged as one of the premier developers of clean energy projects and green hydrogen. Active in the UAE and over 40 countries, Masdar's cumulative global investments in 2022 exceeded $30 billion.[204] In a continuing bureaucratic rationalization of the UAE's green energy ecosystem, TAQA, Mubadala, and ADNOC became the shareholders of Masdar in December 2022.[205] As part of the 2018 consolidation, the Emirates Water and Electricity Company (EWEC) was formed to succeed the Abu Dhabi Water and Electricity Company as the sole procurer of water and power within the Emirate of Abu Dhabi and beyond through partnering with plants across the UAE.[206] In February 2023, it met 80% of its power demand using renewable and clean energy from its solar and nuclear plants, equivalent to 6.2 GW.[207] The achievement reflects the fact that EWEC is wholly owned by ADQ, one of the UAE's primary long-term investors in the non-fossil fuel economy.

202. https://www.reuters.com/article/emirates-adwea-idUSL8N1R7040; https://reglobal.co/uaes-power-sector-transitioning-to-a-clean-and-smart-grid/

203. https://www.reuters.com/article/emirates-adwea-idUSL8N1R7040

204. https://www.forbesmiddleeast.com/lists/the-middle-easts-sustainable-100/abu-dhabi-future-energy-company-masdar/

205. https://www.taqa.com/press-releases/taqa-adnoc-and-mubadala-complete-landmark-transaction-for-stake-in-masdar-clean-energy-powerhouse/

206. https://www.ewec.ae/en/power-plant/al-dhafra-solar-pv

207. https://www.forbesmiddleeast.com/lists/the-middle-easts-sustainable-100/emirates-water-and-electricity-company-ewec/

The high degree of integration is also reflected in the multiple positions held by various national government ministers involved with the development of the UAE's renewable energy infrastructure. The current minister of energy and infrastructure is also the chairman of the board of EWE and the Emirates General Petroleum Corporation (Emarat) as well as a board member of ADNOC and Mubadala.[208] The current minister of infrastructure and advanced technology is also the CEO of ADNOC and previously served seven years as the CEO of Masdar, which he had helped create while serving as the CEO of Mubadala's energy platform.[209] Replicated across many key positions, this phenomenon contributes to institutional cohesion in the formation and implementation of a coherent energy transition strategy.

Among the UAE's seven emirates, Dubai and Abu Dhabi account for at least 90% of the country's renewable energy capacity.[210] In 2022, DEWA operated an installed capacity of 1.627 GW of power generation from renewable energy.[211] The massive $13.6 billion Mohammed bin Rashid Al Maktoum (MBR) solar complex is the UAE's flagship renewable energy project, located around 50 km south of the city of Dubai.[212] Touted as the "largest single-site solar park in the world," MBR is slated to have an installed capacity of 5 GW by 2030.[213] The project has six development phases:

- Phase I with a PV installed capacity of 13 MW became operational in 2013;

208. https://www.moei.gov.ae/en/about-ministry/about-minister.aspx

209. https://moiat.gov.ae/en/his-excellency-dr-sultan-bin-ahmed-al-jaber

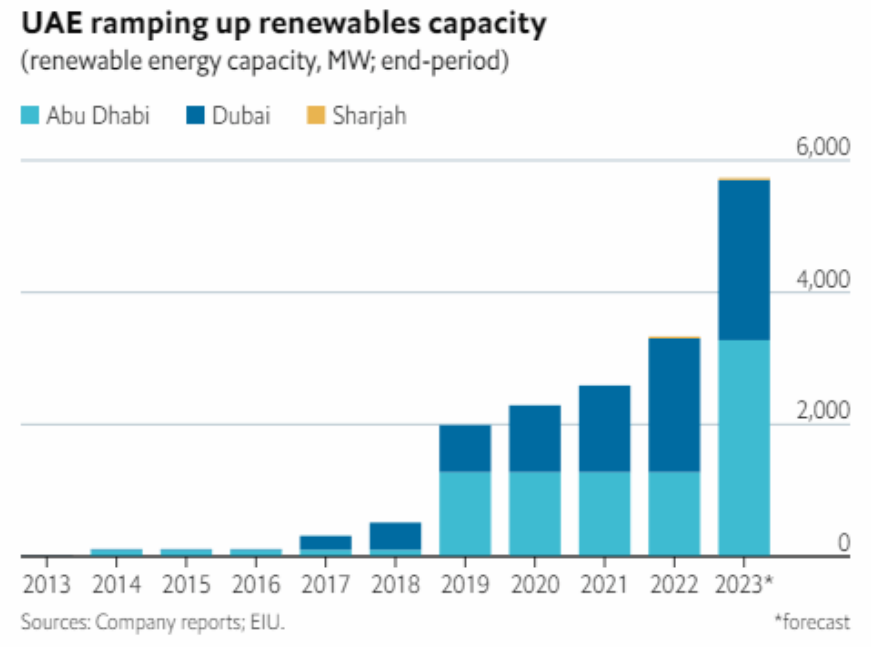
210. https://www.trade.gov/energy-resource-guide-united-arab-emirates-renewable-energy

211. https://www.forbesmiddleeast.com/lists/the-middle-easts-sustainable-100/dubai-electricity-and-water-authority-dewa/

212. https://www.pv-tech.org/uae-inaugurates-900mw-fifth-phase-of-mohammed-bin-rashid-al-maktoum-solar-park/

213. https://masdar.ae/Masdar-Clean-Energy/Projects/Mohammed-bin-Rashid-Al-Maktoum-Solar-Park-Phase-3

- Phase II (200 MW) was developed by a consortium led by Saudi Arabia's ACWA Power and became operational in 2017;
- Phase III (800 MW) was developed by a consortium led by Masdar and became operational in 2020;
- Phase IV (900 MW, 750 MW of which is CSP with a molten salt technology tower) is being developed by a project company led by DEWA (51%) with ACWA Power (25%) and the Silk Road Fund (24%);
- Phase V (900 MW) is being developed by DEWA (60%) and a consortium (40%) led by ACWA Power and the Kuwaiti Gulf Investment Corporation; and
- Phase VI (1.8 GW) is under construction and expected to be fully operational by 2026.[214]



The participation of companies from Saudi Arabia and Kuwait in the MBR project builds regional stakeholder interest in the Emirati approach of developing the UAE as a hub in a wider MENA green energy ecosystem.

Abu Dhabi's two major solar power mega-projects, by contrast, have focused on developing partnerships in Asia and Europe, further widening international stakeholder interest. EWEC's major renewable energy facility is the Noor Abu Dhabi solar power complex in Sweihan in the Al Ain region. The 935 MW PV facility has been operational since 2019. TAQA owns a 60% stake in Noor Abu Dhabi with Japan's Marubeni and China's JinkoPower each holding 20%.[215] The major project in the Emirate of Abu Dhabi is the 1.5GW al-Dhafra solar complex currently under construction. Located in the Dhafra region about 35 km from the city of Abu Dhabi, the facility is touted as the world's largest single-site PV solar facility and will boost Abu Dhabi's installed solar capacity to 2.5 GW. Al-Dhafra's leading stakeholder is TAQA (40%) with Masdar, France's EDF Renewables, and JinkoPower each holding 20%.[216]

The UAE's updated National Energy Strategy has adopted a green energy ecosystems approach with a National Hydrogen Strategy that calls for the country to become a leading producer and exporter of low-carbon hydrogen, with the target of producing 1.4 million tons per year by 2031 and 15 million tons by 2050.[217] The UAE's strategy aspires to a 25% market share of the major hydrogen markets in Europe and Asia.[218] As seen above in the discussion of the UAE's green ammonia activities in Egypt, the advancement of renewable energy and green hydrogen has been incentivized through the UAE's chemicals and fertilizers industry. In contrast to hydrocarbon-poor Morocco, which has focused exclusively on green hydrogen, the UAE includes a major role in its strategy for blue hydrogen, whose value in combatting climate change has been contested. The UAE has also floated the idea of producing so-called pink hydrogen, in which nuclear

214. https://www.dewa.gov.ae/en/about-us/strategic-initiatives/mbr-solar-park

215. https://www.ewec.ae/en/power-plants/noor-abu-dhabi

216. https://www.ewec.ae/en/power-plant/al-dhafra-solar-pv

217. https://gulfbusiness.com/uae-to-generate-19gw-clean-energy-2030-almazrouei/

218. https://gulfbusiness.com/uae-completes-first-phase-of-national-hydrogen-strategy/

energy is used to generate the electricity to power the electrolyzers that split water into its oxygen and hydrogen components.[219] The UAE's National Hydrogen Strategy calls for the establishment of two "hydrogen oases" by 2031 and five by 2050.[220]

The production of green hydrogen within the UAE itself will be about half of the green hydrogen produced by Emirati green hydrogen investments globally. While the MBR solar power complex includes a pilot green hydrogen plant constructed by DEWA and Germany's Siemens,[221] Masdar is spearheading most of the UAE's green hydrogen development. Masdar's 2030 target is to produce a combined total of 1 million tons of green hydrogen and derivatives from its various operations across the MENA region.[222] By leveraging ADNOC's infrastructure and experience in the petrochemicals industry, Masdar seeks to make the UAE a central international node in the nexus of green hydrogen value chains, both in terms of production and export flows. The UAE's 2030 annual green hydrogen demand is forecast to be 200,000 tons.[223] The remaining 300,000 tons produced locally and the 500,000 tons produced abroad will be exported internationally.[224] Masdar via ADNOC and the Emirati-Dutch joint fertilizer platform Fertiglobe are already involved in sizable green ammonia operations in Egypt, as discussed above, as well as in Mauritania. In March 2023, Masdar, through the Emirati-Egyptian joint venture Infinity Power Holding, partnered with Germany's Conjuncta to construct a $34 billion green hydrogen complex in Mauritania that will produce 8 million tons of green hydrogen or its green ammonia equivalent.[225] While possessing solar and wind energy resources similar to Morocco's, Mauritania's population of about 5 million is 7 times smaller, enabling the sparsely inhabited nation to more easily serve export markets while providing for the green energy needs of its own population.[226] Masdar has expressed interest in both Egypt and Morocco becoming regional export hubs.[227] The combined export volumes of green ammonia from Morocco and Mauritania transported via Morocco's already existing export infrastructure would provide commercial advantages that would advance a western Maghreb and West Africa green hydrogen supply chain. Masdar is looking at other "key geographies," such as Saudi Arabia and Oman, the former of which Masdar enjoys strong partnerships through ACWA Power's role in constructing the UAE's solar power infrastructure.[228]

With its focus on low-carbon hydrogen, the UAE is developing green and blue hydrogen production capacity in tandem. In 2021, Masdar signed a "strategic alliance agreement" with France's multinational utility giant ENGIE to explore the co-development of a "UAE-based green hydrogen hub."[229] As the core of the hub, the two companies are eyeing a $5 billion investment to develop a minimum capacity of 2 GW by 2023.[230] Also in 2021, BP signed framework agreements with Masdar and ADNOC

219. See comments by Sharif Al Olama, Under-Secretary of the Ministry of Energy and Infrastructure for Energy and Petroleum Affairs.

220. https://u.ae/-/media/MoEI-recent-docs/Updated-UAE-Energy-Strategy-2050-Eng.ashx

221. https://reglobal.co/uaes-power-sector-transitioning-to-a-clean-and-smart-grid/

222. https://masdar.ae/en/news/newsroom/masdar-accelerates-green-hydrogen-ambitions

223. https://masdar.ae/en/news/newsroom/masdar-accelerates-green-hydrogen-ambitions

224. https://masdar.ae/en/news/newsroom/masdar-accelerates-green-hydrogen-ambitions

225. https://www.ntu.edu.sg/cas/news-events/news/details/can-singapore-unlock-africa-s-green-hydrogen-potential

226. https://www.ntu.edu.sg/cas/news-events/news/details/can-singapore-unlock-africa-s-green-hydrogen-potential

227. https://masdar.ae/en/news/newsroom/masdar-accelerates-green-hydrogen-ambitions

228. https://masdar.ae/en/news/newsroom/masdar-accelerates-green-hydrogen-ambitions

229. https://www.engie.com/en/journalists/press-releases/engie-and-masdar-form-us-5-billion-strategic-alliance-to-drive-uae-s-green-hydrogen-economy

230. https://www.engie.com/en/journalists/press-releases/engie-and-masdar-form-us-5-billion-strategic-alliance-to-drive-uae-s-green-hydrogen-economy

for the development of "clean" hydrogen hubs in the UK and the UAE based on a mix of green and blue hydrogen, by utilizing the UAE's position as an investor in UK offshore wind power projects for green hydrogen while developing joint collaboration in greenfield carbon capture and underground storage for blue hydrogen.[231] Subsequently in 2022, ADNOC acquired a 25% stake in the design stage of BP's H2Teesside blue hydrogen project, making it ADNOC's first UK investment.[232] The H2Teesside project is slated to construct two 500 MW hydrogen production units by 2030. Concurrently, Masdar signed an MoU to acquire a stake in BP's proposed green hydrogen project, HyGreen Teesside, intended to reach 500 MW of electrical input (MWe) by 2030.[233]

The UAE's National Hydrogen Strategy emerged from the need to coordinate low-carbon hydrogen projects into a coherent program to pave the way for the country's development as a regional hydrogen hub. Similar to the early role Germany played in the original development of Morocco's green hydrogen program and in the programs of the other nations across North Africa, the Emirates' National Hydrogen Strategy arose out of the prominence of Emirati-German cooperation in the low-carbon hydrogen and green energy sectors. In 2022, the UAE's Ministry of Energy and Infrastructure contracted the multinational technical services firm GHD, in partnership with the Germany-based Fraunhofer Gesellschaft, the parent entity of the Fraunhofer Institute that helped initiate Morocco's green hydrogen development, to develop the UAE's National Hydrogen Strategy.[234]

In 2022, Germany received its first consignment of Emirati-produced blue hydrogen.[235] This was delivered in the form of blue ammonia produced by Fertiglobe at its Fertil plant in the Ruwais industrial complex in Abu Dhabi.[236] Although produced by the UAE's fertilizer sector, the blue ammonia exported to Germany was intended to serve as proof of concept for the use of blue hydrogen in industrial manufacturing, with the demonstration cargo being delivered to Aurubis, a European leader in the production of non-ferrous metals.[237] The Hamburg-headquartered company plans to utilize the Emirati blue ammonia in its copper wire rod plant.[238] Proof of concept of the use of blue hydrogen could pave the way for the eventual use of green hydrogen, delivered as green ammonia, in the energy-intensive manufacturing processes used in multi-metal production. Aurubis is one of the world's largest copper recyclers and it also produces a variety of battery metals. The company's use of low-carbon hydrogen enhances the prospects for the circular production of new green energy infrastructure, in which the metal and other inputs are supplied from recycled green energy infrastructure with the recycling process being fueled by green hydrogen produced from renewable energy.

The circular production of green energy infrastructure would mostly like begin with the aluminum industry in the UAE, the world's fifth largest aluminum producer.[239] In 2021, the UAE started the world's first green aluminum production when DEWA began the transmission of 560,000 MWh of annual supply of solar power from the MBR complex to the state-

231. https://www.adnoc.ae/en/news-and-media/press-releases/2021/adnoc-bp-and-masdar-agree-to-expand-uae-uk-new-energy-partnership

232. https://www.bp.com/en/global/corporate/news-and-insights/press-releases/abu-dhabis-adnoc-and-masdar-to-join-bps-uk-hydrogen-projects.html

233. https://www.bp.com/en/global/corporate/news-and-insights/press-releases/abu-dhabis-adnoc-and-masdar-to-join-bps-uk-hydrogen-projects.html

234. https://www.ise.fraunhofer.de/en/press-media/news/2022/fraunhofer-ise-and-ghd-are-developing-the-national-hydrogen-strategy-of-the-united-arab-emirates.html; https://www.ghd.com/en/about-ghd/news/28-07-2023-ghd-and-fraunhofer-join-forces-with-uaes-ministry

235. www.aurubis.com

236. https://adnoc.ae/en/news-and-media/press-releases/2022/adnoc-sends-first-low-carbon-ammonia-shipment-from-the-uae-to-germany

237. www.aurubis.com

238. www.aurubis.com

239. https://investingnews.com/daily/resource-investing/industrial-metals-investing/aluminum-investing/aluminum-producing-countries/

Photo above: Visitors look at screens displaying images of the Mohammed bin Rashid Al Maktoum Solar Park on March 20, 2017, at the solar plant in Dubai. Photo by STRINGER/AFP via Getty Images.

owned aluminum manufacturer Emirates Global Aluminum (EGA).[240] Jointly owned by Mubadala and the Investment Corporation of Dubai, EGA is the UAE's largest manufacturing company outside the oil and gas sector and a world leader in premium aluminum production.[241] The amount of solar power supplied by MBR was sufficient for EGA's smelter to produce 40,000 tons of aluminum.[242] The first consignment of aluminum produced with solar power, marketed under the brand name CelestiAL solar aluminum, was sold to German automaker BMW.[243] In 2022, EGA signed an agreement with Austrian-headquartered Hammerer Aluminum Industries to supply CelestiAL solar aluminium from which Hammerer will manufacture aluminum automotive components for German carmaker Mercedes-Benz.[244] In late 2022, EGA purchased Clean Energy Certificates for 1.1 million MWh of electricity from EWEC supplied by the Noor Abu Dhabi solar power plant for the production of about 80,000 tons of CelestiAL solar aluminum.[245]

240. https://www.pv-magazine.com/2021/01/18/uae-says-mohammed-bin-rashid-solar-park-is-powering-aluminum-production/

241. https://www.pv-magazine.com/2021/01/18/uae-says-mohammed-bin-rashid-solar-park-is-powering-aluminum-production/

242. https://www.pv-magazine.com/2021/01/18/uae-says-mohammed-bin-rashid-solar-park-is-powering-aluminum-production/

243. https://www.pv-magazine.com/2021/01/18/uae-says-mohammed-bin-rashid-solar-park-is-powering-aluminum-production/

244. https://media.ega.ae/ega-to-supply-celestial-solar-aluminium-to-parts-maker-hammerer-aluminum-industries-tier-1-supplier-of-a-premium-car-manufacturer/

245. https://media.ega.ae/ega-purchases-clean-energy-

The Emirati aviation industry is also participating in the UAE's green energy ecosystem as an offtake market for green hydrogen. A global leader, the UAE's aviation sector is an important pillar of the Emirati economy, earning about $47 billion[246] and accounting for around 13% of GDP.[247] Masdar is spearheading an initiative in partnership with French energy giant TotalEnergies, Germany's Siemens Energy and Japan's Marubeni to develop and produce sustainable aviation fuel (SAF) from green hydrogen.[248] The UAE's Etihad Airways and Germany's Lufthansa are also involved in the effort. In early 2023, Masdar, ADNOC, and Etihad Airways, along with Tadweer (Abu Dhabi Waste Management Company) are also partnering with BP to explore the development of SAF using municipal solid waste and green hydrogen.[249]

Beyond green fuels for aircraft and shipping, green mobility is also emerging as an important component of the UAE's green energy ecosystem. The updated National Energy Strategy calls for hybrid and electric cars to constitute 53% of passenger vehicles by 2050 and electric and hybrid buses to constitute 60% of all buses in service in the country. With 879 charging stations expected to be in place by the end of 2023, the updated strategy has targeted the installation of 30,000 charging stations by 2050.[250] In October 2022, the UAE's M Glory holding company opened the al-Damani Electric Vehicle Factory, the country's first electric car manufacturing plant. The $408 million facility will have an initial production capacity of 10,000 EVs per year.[251] With capacity expansion, the plant is expected to produce 55,000 EVs annually for sale in the UAE and export to other GCC and African markets.[252] The establishment of EV manufacturing in the UAE makes local circular green production possible. EVs are currently composed of 25-27% more aluminum than their internal combustion engine counterparts,[253] and this is likely to greatly increase as manufacturers seek to reduce EV weight and production times.[254] Domestically produced green aluminum, such as CelestiAL solar aluminum, could provide a significant advantage for the further development of EV manufacturing in the UAE.

While the Emirates' embryonic EV manufacturing industry currently does not warrant the creation of an EV battery manufacturing sector, it could emerge through EV battery recycling. In 2023, Beeah Recycling, a subsidiary of the Sharjah-based Beeah Group focused on waste recycling, signed an agreement with the Ministry of Energy and Infrastructure to open the UAE's first recycling plant for end-of-life EV batteries.[255] Beeah Group jointly runs a waste-to-power facility with Masdar. With the UAE EV market expected to grow at a 30% compound annual growth rate through 2028,[256] domestic EV battery

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certificates-for-11-million-megawatt-hours-of-electricity-supplied-by-ewec-to-support-production-of-celestial-solar-aluminium/

246. https://www.businesstraveller.com/features/the-rising-fortunes-of-commercial-aviation-in-the-middle-east/

247. https://www.thenationalnews.com/business/2021/11/28/uae-at-50-aviation-industry-flies-towards-sustainable-and-tech-driven-growth/

248. https://news.masdar.ae/en/News/2023/01/25/11/17/Novel-pathway-to-make-SAF-from-methanol

249. https://gulfbusiness.com/saf-production-in-uae-to-be-explored/

250. https://u.ae/-/media/MoEI-recent-docs/Updated-UAE-Energy-Strategy-2050-Eng.ashx

251. https://www.thenationalnews.com/business/road-to-net-zero/2022/10/05/m-glorys-electric-vehicle-manufacturing-plant-opens-in-dubai/

252. https://www.thenationalnews.com/business/road-to-net-zero/2022/10/05/m-glorys-electric-vehicle-manufacturing-plant-opens-in-dubai/

253. https://www.mining-technology.com/contractors/project-management-and-consultancy/cru-group/pressreleases/evs-aluminium-demand/

254. https://www.metalswarehouse.co.uk/the-use-of-aluminium-in-the-ev-market/

255. https://www.beeahgroup.com/beeah-recycling-uae-ministry-of-energy-infrastructure-and-american-university-of-sharjah-to-launch-uaes-first-ev-battery-recycling-facility/#:~:text=The%20EV%20battery%20recycling%20facility,highest%20in%20the%20Middle%20East

256. https://www.beeahgroup.com/beeah-recycling-uae-

recycling will form a significant part of the UAE green energy ecosystem if the recycling process is powered by renewable energy. The availability of affordable renewable energy could also see the UAE become a regional hub for battery recycling.

In addition to the renewable energy supply chains that emerge from the many facets of the UAE's expanding green energy ecosystem, electricity exports via inter-regional undersea interconnectors represent a further possible mechanism to reach offtake markets for renewable energy produced in the UAE. The Emirates National Grid is interconnected via the GCC regional grid system to the national grid of Saudi Arabia,[257] which in turn is interconnected with Egypt's national grid. When a trans-Mediterranean interconnection between Egypt and Greece is completed, UAE-produced renewable energy could theoretically reach the EU electricity market. The UAE is increasing its investment footprint in inter-regional electricity interconnectors. In 2023, TAQA invested $31.1 million in the Xlinks project to transport renewable energy produced in Morocco to the UK via undersea HVDC cables.[258] TAQA also signed an MoU to explore the possibility of becoming a shareholder in the development of an electricity interconnector between Cyprus and Greece that could serve as the end link for Arab Gulf state electricity exports to reach the EU via the Israel-based Great Sea Interconnector (see below).[259] In January 2023, India announced that it was in serious negotiations with the UAE to establish an underwater electricity interconnection across the Arabian Sea for the transport of renewable energy.[260] Utilizing the time difference between the two countries, electricity produced from solar energy during daylight hours in each country could be traded with the other.[261] Expanding the scope of the project to include other Gulf producers, India's state-run electricity grid operator began advanced discussions with the UAE, Saudi Arabia, and Oman to establish a 2.5 GW electricity interconnector across the Arabian Sea that could transport renewable energy to India, a market opportunity for the Gulf countries on a similar scale to that of the EU.[262]

Saudi Arabia: A Promising Green Energy Ecosystem Approach to an Ambitious Energy Transition Program

Saudi Arabia generates more electric power than any other country in the MENA region, totaling 401.6 TWh in 2022.[263] For perspective, Saudi Arabia's electricity production was twice that of Egypt, whose population is three times the size.[264] Saudi Arabia's electricity production exceeded the UAE's 2.6-fold.[265] The kingdom relies on oil and natural gas for 99.8% of its power generation, with highly pollutive and inefficient oil making up 32.7% of the fuel supply mix.[266] Unsustainable in the long term, energy transition forms

ministry-of-energy-infrastructure-and-american-university-of-sharjah-to-launch-uaes-first-ev-battery-recycling-facility/#:~:text=The%20EV%20battery%20recycling%20facility,highest%20in%20the%20Middle%20East

257. https://reglobal.co/uaes-power-sector-transitioning-to-a-clean-and-smart-grid/

258. https://www.thenationalnews.com/business/energy/2023/04/26/abu-dhabis-taqa-invests-31m-in-british-start-up-xlinks-first/

259. https://www.offshore-energy.biz/taqa-eyes-joining-900-kilometer-european-interconnector/

260. https://www.reuters.com/business/energy/india-uae-close-deal-renewable-electricity-grid-link-indian-minister-2023-01-15/

261. https://economictimes.indiatimes.com/news/india/india-uae-hold-talks-to-link-grids-through-subsea-cables/articleshow/101027556.cms?from=mdr, [

262. https://www.business-standard.com/companies/news/power-grid-planning-rs-40-000-cr-undersea-interconnection-with-middle-east-124072900860_1.html

263. https://www.energyinst.org/__data/assets/pdf_file/0004/1055542/EI_Stat_Review_PDF_single_3.pdf

264. https://www.energyinst.org/__data/assets/pdf_file/0004/1055542/EI_Stat_Review_PDF_single_3.pdf

265. https://www.energyinst.org/__data/assets/pdf_file/0004/1055542/EI_Stat_Review_PDF_single_3.pdf

266. https://ourworldindata.org/grapher/share-elec-by-source?country=~SAU

a fundamental requirement for Saudi Arabia's ambitions to develop a 21st century diversified economy. For this reason, the kingdom's much vaunted Vision 2030 plan aspires to generate 50% of Saudi Arabia's power from renewable energy sources by 2030.[267] To achieve this ambitious goal, Riyadh aims for a 2030 installed capacity of 58.7 GW from renewable energy sources — 40 GW from PV solar power, 16 GW from wind power, and 2.7 GW from CSP.[268] While the kingdom's ability to reach its 2030 targets remains in doubt, Saudi Arabia's longer-term prospects to achieve energy transition are strong due to the green energy ecosystem approach that Riyadh has recently started adopting.

To achieve the renewable energy targets laid out in Vision 2030 and the King Salman Renewable Energy Initiative (launched in 2016), Riyadh established the National Renewable Energy Program (NREP) in 2017 to "maximize the potential of renewable energy in Saudi Arabia."[269] In 2022, Saudi Arabia's total installed capacity for power generation from renewable sources stood at 443 MW — 440 MW from solar power and 3 MW from wind power.[270] Marking a significant increase over the 2013 installed capacity of 22 MW,[271] Riyadh continued to bring new capacity online, achieving 2.8 GW of operational renewable power production by the end of 2023.[272] While an impressive acceleration in absolute terms, the kingdom's 2023 installed capacity from renewables was only one-tenth of Vision 2030's interim 2023 target of 27.3 GW. In 2023, Saudi Arabia was developing 13 renewable energy projects with a combined capacity of 11.3 GW.[273]

Saudi Arabia's largest project under way is the 2.06 GW solar power complex in al-Shuaibah, in Mecca province, and is expected to be operational in Q4 2025.[274] In November 2022, ACWA Power and Badeel, the Water and Electricity Holding Company subsidiary of Saudi Arabia's Public Investment Fund (PIF), agreed to develop the $2.2 billion solar power facility as a 50-50 joint venture with a 35-year power purchase agreement with the Saudi Power Procurement Company (SPPC).[275] In August 2022, the Saudi Ministry of Finance and Ministry of Energy fully nationalized the SPPC.[276] A key measure of the kingdom's efforts to reform and restructure the electricity sector to coordinate the rapid deployment of renewable power generation, SPPC is responsible for planning electric power generation infrastructure, concluding wholesale and electric power purchase agreements, and developing energy trading markets. In May 2023, Badeel and ACWA Power (of which, PIF is a 44% stakeholder) signed 35-year power purchase agreements connected to the development of three additional jointly developed PV solar power plants with a combined installed capacity of 4.55 GW.[277] Currently, PIF and its partners are constructing

267. https://www.vision2030.gov.sa/v2030/v2030-projects/saudi-green-initiative/

268. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/082023-saudi-arabia-moves-ahead-with-its-largest-solar-power-project

269. https://powersaudiarabia.com.sa/web/index.html

270. https://mc-cd8320d4-36a1-40ac-83cc-3389-cdn-endpoint.azureedge.net/-/media/Files/IRENA/Agency/Publication/2023/Mar/IRENA_RE_Capacity_Statistics_2023.pdf?rev=d2949151ee6a4625b65c82881403c2a7

271. https://mc-cd8320d4-36a1-40ac-83cc-3389-cdn-endpoint.azureedge.net/-/media/Files/IRENA/Agency/Publication/2023/Mar/IRENA_RE_Capacity_Statistics_2023.pdf?rev=d2949151ee6a4625b65c82881403c2a7

272. https://www.greeninitiatives.gov.sa/knowledge-hub/saudi-arabia-announces-300-increase-in-installed-renewables-capacity-439-million-trees-planted-since-launch-of-saudi-green-initiative/

273. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/082023-saudi-arabia-moves-ahead-with-its-largest-solar-power-project

274. https://www.acwapower.com/news/pif-subsidiary-badeel-and-acwa-power-to-develop-the-mena-regions-largest-solar-energy-plant-in-saudi-arabia/

275. https://www.acwapower.com/news/pif-subsidiary-badeel-and-acwa-power-to-develop-the-mena-regions-largest-solar-energy-plant-in-saudi-arabia/

276. https://www.arabnews.com/node/2139186/business-economy

277. https://www.acwapower.com/news/pifs-wholly-owned-

five projects at a cost of over $6 billion with an aggregate capacity of 8 GW. [278] Operating within the NREP framework, SPPC initiated the process of developing three additional wind energy plants with a combined installed capacity of 1.8 GW.[279]

The strength of the current Saudi approach is Riyadh's focus on creating renewable energy value chains through the development of a robust and diversified green energy ecosystem, with the use of hydrogen as a renewable energy carrier playing a prominent role in that process. Like the UAE, Saudi Arabia is looking to supply European and Asian markets with low-carbon ammonia for use in industrial manufacturing and as fuel ammonia in co-firing plants. Similar to Abu Dhabi's approach, Riyadh is leading with blue ammonia while eyeing the longer-term development of green ammonia markets. Indicative of Riyadh's efforts, Saudi Aramco signed a letter of intent in October 2023 with Korea Electric Power Corporation, Korean steelmaker POSCO Holdings, and Korea's Lotte Chemical for investments and purchases related to the development of $15 billion blue ammonia production plant in the kingdom.[280]

Saudi Arabia's efforts to develop a robust green hydrogen industry are anchored in the futuristic NEOM mega-city project. The $500 billion city is slated to be powered entirely by renewable energy based on solar and wind power[281] to create a carbon-free urban ecosystem.[282] Beyond electricity produced from solar and wind resources to power its advanced technology industries and the residential needs of its anticipated 9 million inhabitants,[283] NEOM will feature an $8.4 billion green hydrogen plant, touted to become the world's largest when operational in 2026.[284] Construction and operation of the plant is being managed by the NEOM Green Hydrogen Company (NGHC), an equal joint venture among NEOM, ACWA Power, and the US-based industrial chemicals and gases giant Air Products. The NGHC plant's initial production capacity will be 1.2 million tons of green ammonia per year powered by a combined 4 GW from both solar and wind power.[285] In 2023, NGHC signed an engineering, procurement, and construction agreement with Air Products as well as a 30-year offtake agreement for all the green ammonia produced at the plant that will make Saudi Arabia a player in global green hydrogen value chains.[286]

A central element in Saudi Arabia's emerging green energy ecosystem is the mining and processing of minerals and metals. A key pillar of the kingdom's economic diversification agenda under the Vision 2030 plan, the development of the sector has been spearheaded by Ma'aden, whose meteoric rise over the past decade has seen it become one of the world's top mining companies by market capitalization.[287] The largest multi-commodity and mining and metals company in the Middle East, Ma'aden

company-badeel-and-acwa-power-invest-sar122-billion-into-three-new-solar-projects-in-saudi-arabia/

278. https://www.acwapower.com/news/pifs-wholly-owned-company-badeel-and-acwa-power-invest-sar122-billion-into-three-new-solar-projects-in-saudi-arabia/

279. https://sp.spa.gov.sa/viewfullstory.php?lang=en&newsid=238696

280. https://www.icis.com/explore/resources/news/2023/10/24/10936695/s-korea-saudi-arabia-firms-sign-46-pacts-includes-blue-ammonia-project/

281. https://enowa.neom.com/sectors.html

282. https://www.neom.com/en-us/our-business/sectors/energy

283. https://www.neom.com/en-us/regions/theline

284. https://www.neom.com/en-us/newsroom/neom-green-hydrogen-investment#:~:text=An%20equal%20joint%20venture%20between,the%20transportation%20and%20industrial%20sectors

285. https://www.neom.com/en-us/newsroom/neom-green-hydrogen-investment#:~:text=An%20equal%20joint%20venture%20between,the%20transportation%20and%20industrial%20sectors

286. https://www.neom.com/en-us/newsroom/neom-green-hydrogen-investment#:~:text=An%20equal%20joint%20venture%20between,the%20transportation%20and%20industrial%20sectors

287. https://brandfinance.com/insights/brand-spotlight-maaden-2022

Photo above: A Saudi Aramco hydrogen engine stands on display in the Saudi Arabia pavilion on day four of the COP28 Climate Conference at Expo City Dubai on Dec. 03, 2023, in Dubai, United Arab Emirates. Photo by Sean Gallup/Getty Images.

itself is committed to achieve carbon neutrality by 2050.[288] Riyadh aims to utilize steeply rising global demand for minerals to advance Saudi Arabia's national industrial transformation and enhance its role in green energy value chains.[289] Speaking in 2023, Saudi Arabia's vice minister of industry and mineral resources for mining affairs, who oversaw the creation of the kingdom's mining and mineral industries strategy as part of the Vision 2030 plan, affirmed that the strategy reflects Saudi Arabia's Vision 2030 commitments to green energy transition.[290] With Saudi Arabia's ample mineral deposits and Ma'aden's focus on the production of copper, aluminum, and phosphates,[291] the company has already experienced increased demand for its products driven by the global growth in renewable energy infrastructure construction, EV manufacturing, and fertilizer production.[292]

Saudi Arabia is positioning itself to become a significant supplier of mineral and metal products necessary for global energy transition on an even wider scale than the UAE. When powered by renewable energy, the Saudi Arabia's metals processing will place the kingdom at the heart of circular green energy production. Saudi Arabia also holds the potential to play a broader role in manufacturing the infrastructure for renewable energy. In particular, the kingdom is eyeing the solar PV manufacturing supply chain with the production of polysilicon, a highly purified form of silicon that serves as the input for the production of

288. https://www.maaden.com.sa/en/news/details/563

289. https://www.spa.gov.sa/en/N1977761

290. https://www.spa.gov.sa/en/N1977761

291. https://www.maaden.com.sa/en/business/business

292. https://brandfinance.com/insights/brand-spotlight-maaden-2022

silicon wafers that form the base of solar cells. China's GCL Technology Holdings, the world's second largest polysilicon producer, is in advanced negotiations with Riyadh to open its first overseas factory in Saudi Arabia.[293] With an annual production capacity of 120,000 tons, GCL's Saudi plant could be operational in early 2025.[294]

In 2022, Riyadh began the development of steel and EV battery metals manufacturing plants to supply a domestic EV manufacturing sector.[295] In September 2023, the PIF-majority owned EV maker Lucid Group opened its first Saudi factory at the Red Sea port of Jeddah.[296] With an initial capacity to assemble 5,000 vehicles a year from semi-knock down kits manufactured by the company in the United States, Lucid plans to transition its Jeddah plant to complete build unit production to manufacture a total of 155,000 EVs annually.[297] EV manufacturing in Saudi Arabia with both component manufacturing and assembly powered by renewable energy could possibly become an important driver of green circular production.

As with the UAE, electricity exports via inter-regional undersea interconnectors represents a further possible mechanism to reach offtake markets for renewable energy produced in Saudi Arabia. Through its 3 GW interconnection with Egypt, Saudi Arabia could utilize Egypt's interconnections with Sudan to export power to those countries as well as electricity-poor African nations like Chad.[298] In February 2024, Saudi Arabia and Greece established a special purpose company to explore the commercial viability of establishing a power interconnection between the two countries with the explicit aim of supplying Europe with cheaper green energy.[299] The route could utilize the Egypt-based Euro-Africa Interconnector once completed or the Israel-based Great Sea Interconnector (formerly known as the Euro-Asia interconnector) depending on the status of Saudi-Israeli relations.

Exports from the UAE as well as those from other GCC states could be incorporated into either route. However, at the moment, direct electricity exports via interconnectors are not playing an analogous role in the development of Arab Gulf states' renewable energy sectors that crude oil and LNG exports played in the development of the region's hydrocarbon sector. When it comes to green energy ecosystems in the Arab Gulf states, hydrogen is currently playing a more prominent role in the development of renewable energy supply chains.

Qatar, Oman, Kuwait, and Bahrain: Opportunities for Expansion and Diversification

Although the UAE and Saudi Arabia are at the leading edge of the development of green energy ecosystems and renewable energy supply chains, Qatar and Oman are in the earlier stages of developing their own green energy ecosystems while Kuwait has restarted its renewable energy development and Bahrain, a relatively late adopter, has issued a tender for its first utility-scale solar power plant in 2024.[300]

293. https://www.straitstimes.com/business/companies-markets/chinese-solar-firm-eyes-saudi-arabia-for-first-foreign-plant

294. https://www.bloomberg.com/news/articles/2023-09-05/chinese-solar-firm-gcl-technology-eyes-saudi-arabia-for-first-overseas-plant

295. https://www.reuters.com/business/saudi-arabia-announces-6-bln-investments-steel-complex-ev-metals-plant-2022-05-06/

296. https://www.reuters.com/business/autos-transportation/lucid-opens-first-international-ev-factory-saudi-arabia-2023-09-27/

297. https://lucidmotors.com/media-room/lucid-makes-history-saudi-arabia-first-car-manufacturing-facility

298. https://www.ispionline.it/en/publication/egypts-prospects-energy-export-hub-across-three-continents-27408

299. https://www.offshore-energy.biz/special-purpose-company-established-for-potential-greek-saudi-electricity-interconnector/; https://www.reuters.com/business/energy/greece-saudi-arabia-look-linking-their-power-grids-2023-09-27/

300. https://www.pv-magazine.com/2024/02/13/bahrain-launches-100-mw-pv-tender-2/#:~:text=Bahrain%20wants%20

Grounded in its own Qatar National Vision Plan 2030,[301] Doha's renewable energy strategy revolves around reaching an original intermediate 2030 target of 20% of the country's power to be generated from renewable energy sources on the way to achieving net zero by 2050. On track to reach its original 2030 target, Doha is now seeking to achieve an increased intermediate target of 30% of the country's power mix to be produced from solar power.[302]

In October 2022, Qatar inaugurated al-Kharsaah Solar PV Power Plant, its first large-scale solar power facility. The plant cost $462 million and has an installed capacity of 800 MW, equivalent to about 10% of the country's peak demand.[303] Qatar is presently engaged in the construction of two additional solar power plants with a combined installed capacity of 880 MW.[304] Additionally, it is exploring developing utility-scale wind power as well as waste-to-energy power generation options.

As the world's third largest exporter of LNG,[305] Qatar is looking to use renewable energy to reduce the carbon footprint of its LNG production to enhance LNG's status as a bridge fuel in energy transition.[306] Like the UAE and Saudi Arabia, Qatar is seeking to capture a share of the global hydrogen market through production of blue ammonia. In August 2022, Qatar announced it was constructing the world's largest blue ammonia production plant. Expected to be operational in 2026, the $1.06 billion facility will have an initial production capacity of 1.2 million tons of blue ammonia per year.[307] Through establishing its market share and distribution channels via the export of blue ammonia, Qatar could develop a green ammonia sector in the future, but so far, in contrast to the UAE and Saudi Arabia, Doha has not made any significant investments in green hydrogen.

In contrast, Oman is planning to develop a hydrogen-centric economy built on both blue and green hydrogen. Focused on developing large-scale green hydrogen projects, Muscat plans over $45 billion of green hydrogen and green ammonia projects, including a 14 GW green hydrogen facility to be powered by 25 GW of solar and wind energy resources.[308] In 2023, Oman had 625 MW of installed capacity from solar power and 49.9 MW from wind power.[309] Between 2025 and 2029, Oman has an additional 4.04 GW of renewable energy projects scheduled to become operational — 3 GW from solar power, 0.9 GW from wind power, and 140 MW from waste-to-energy.[310] If the projects are completed on time, renewable energy could account for over 10% of Oman's power production in 2025 and about 30% by 2029.[311] Muscat has already identified 7,830 sq km of land for new renewable energy infrastructure development in addition to the 50,000 sq km already specified for green hydrogen production.[312]

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to%20bring%20255,waste%20generation%20capacity%20by%202030

301. https://www.psa.gov.qa/en/qnv1/Documents/QNV2030_English_v2.pdf#page=17

302. https://thepeninsulaqatar.com/article/02/09/2023/solar-power-to-produce-30-of-total-electricity-by-2030

303. https://www.qatarenergy.qa/en/MediaCenter/Pages/newsdetails.aspx?ItemId=3730

304. https://www.zawya.com/en/business/energy/qatar-to-build-two-more-880mw-solar-power-plants-dpqjj8y1

305. https://www.statista.com/statistics/1262074/global-lng-export-capacity-by-country/#:~:text=The%20United%20States%20has%20the,country%2C%20behind%20Qatar%20and%20Australia

306. https://www.zawya.com/en/business/energy/qatar-to-build-two-more-880mw-solar-power-plants-dpqjj8y1

307. https://www.reuters.com/business/energy/qatar-build-worlds-largest-blue-ammonia-plant-qatarenergy-ceo-2022-08-31/

308. https://www.trade.gov/country-commercial-guides/oman-renewable-energy

309. https://www.power-technology.com/marketdata/amin-solar-pv-park-oman/

310. https://renewablesnow.com/news/oman-plans-to-add-some-4-gw-of-renewables-by-2029-831717/

311. https://taiyangnews.info/oman-unveils-7-year-electricity-outlook/

312. https://solarquarter.com/2023/10/20/oman-identifies-vast-land-areas-for-renewable-energy-development/#google_vignette

Photo above: Solar panels are installed on the roof of a school in Bahrain's capital Manama on Aug. 25, 2022. Photo by MAZEN MAHDI/AFP via Getty Images.

The development of Oman's renewable energy sector is part of a larger restructuring of the economy under the Oman 2040 Vision plan promulgated in 2020.[313] Under the plan, Muscat established the company Energy Development Oman (EDO) to facilitate investments to create a local sustainable energy sector.[314] In 2022, EDO established Hydrogen Oman (Hydrom), regulated by Ministry of Energy and Minerals, to implement the country's ambitious green hydrogen program.[315] In a June 2023 report, the International Energy Agency published a program outlining how Oman can produce over 1 million tons of green hydrogen by 2030 and 3.75 million tons by 2040 on the way to reaching output of 8.5 million tons by 2050.[316] The 2050 target is modest when considering that the 50,000 sq km of land designated by the Omani government for green hydrogen production — a territory the size of Slovakia — is sufficient to produce 25 million tons of green hydrogen. If Oman succeeds in achieving these targets, it would become the largest producer of green hydrogen in the Middle East as early as 2030.

The implementation of Oman's green hydrogen program faces two principal problems: obtaining sufficient investment and developing offtake infrastructure and mechanisms. To achieve the 2030 goals, Oman would require an aggregate investment of at least $33 billion, with $20 billion for the construction of renewable power generation dedicated to green hydrogen production and $13 billion for green hydrogen production and its

313. https://www.oman2040.om/?lang=en

314. https://edoman.om/about-us/

315. https://hydrom.om/

316. https://www.iea.org/reports/renewable-hydrogen-from-oman

conversion to green ammonia.[317] Oman's ports are well situated for green ammonia to reach both Asian and European markets. However, unlike its GCC neighbors, Oman does not have a large conventional ammonia industry to leverage in the transition to green ammonia. Despite its natural gas production, Oman exports only 0.2 million tons of gray ammonia per year.[318] To export a significant portion of its slated 2030 green hydrogen output, Oman would need to increase the capacity of its ammonia export infrastructure by at least a factor of 20.[319]

Given Oman's need for foreign investment to develop infrastructure and offtake distribution, Muscat may be able to exploit synergies with the UAE, Saudi Arabia, and Qatar to forge win-win partnerships. Investment may also come from European and Asian partners, particularly if Oman focuses on integrating into the green ammonia supply chains of its GCC neighbors as well as developing a more green energy ecosystem of its own.

Despite investing in the development of renewable energy abroad, Kuwait has no utility-scale infrastructure to generate power from renewable energy resources. To address this lacuna, Kuwait is reviving the recently moribund al-Shagaya project to create 2 GW of installed capacity from renewable power by 2030.[320] The first development phase of the project was inaugurated in 2019 and slated to construct 70 MW of renewable capacity — 50 MW of CSP, 10 MW of PV solar power, and 10 MW of wind power — but little construction occurred. In early January 2024, Kuwait issued a new tender for the construction of a 1.1 GW PV solar power plant designated as Phase III of the al-Shagaya project.[321] Parallel to Algeria and Qatar, Kuwait's path to developing renewable energy infrastructure and a green energy ecosystem will likely come from using renewable energy to reduce the carbon footprint of its upstream oil production. Without a clear option for entering the hydrogen economy, Kuwait's longer-term role in renewable energy supply chains remains obscure and may in large part depend on smart investments in the green energy ecosystems emerging among other countries in the MENA region.

Bahrain similarly does not have a clear path to participating in renewable energy supply chains. In 2022, the country possessed only 12 MW of installed capacity for PV solar power production.[322] Bahrain has focused on increasing energy efficiency and seeks to achieve 700 MW of installed capacity power generation capacity for solar, wind, and waste-to-energy resources to meet its Vision 2030 sustainable development goals.[323] In 2024, Bahrain issued a tender for the construction a 100 MW PV solar plant, which would be the country's first utility-scale solar power plant.[324] Bahrain is focused on rooftop solar and wind power projects.[325] Installed on major industrial

317. https://www.iea.org/reports/renewable-hydrogen-from-oman

318. https://www.iea.org/reports/renewable-hydrogen-from-oman

319. https://www.iea.org/reports/renewable-hydrogen-from-oman

320. https://www.kisr.edu.kw/en/gi/5/details/; https://www.agbi.com/renewable-energy/2023/10/kuwait-to-resurrect-renewable-energy-mega-project/

321. https://solarquarter.com/2024/01/03/kuwait-launches-tender-for-1100-mw-solar-power-plant-advancing-renewable-energy-goals/

322. https://www.pv-magazine.com/2024/02/13/bahrain-launches-100-mw-pv-tender-2/#:~:text=Bahrain%20wants%20to%20bring%20255,waste%20generation%20capacity%20by%202030

323. https://www.sdgs.gov.bh/Goal/?ID=hSirOimZ58WUkA7gF7p9Rw==

324. https://www.pv-magazine.com/2024/02/13/bahrain-launches-100-mw-pv-tender-2/#:~:text=Bahrain%20wants%20to%20bring%20255,waste%20generation%20capacity%20by%202030

325. https://bahrain.bh/wps/portal/en/!ut/p/z0/dc5PTwIxEAXwr1IPe25ZYIGjSMJqwh89GOyFTNlJGelOlzKgfHsXDsaI3t5LJm9-2uqVtgwn8iAUGULb32yx7jz2TTl8MKacLyemWJTDQT4Yd3vTXD9p-_NgOenl5vl19FKMZx0zm3YvC_S-39t7bTeRBT9Frxw3a0iZARePomSLakfsq1hnxsE2ATGpgJ4O4eo4ZCZhG7FSEhvatB3rJsRzjSwKuFIJhRJe6m_Qrfg_EPKfIOQTpcjfrxjkmPBWlJDxA1xA1Ybkz7rZWdcP_u4L6Wodyg!!/; https://www.pv-magazine.com/2024/02/13/bahrain-launches-100-mw-pv-tender-2/#:~:text=Bahrain%20

and commercial enterprises, like the initiative to run Bahrain's Khalifa Bin Salman Port on PV solar power, such projects serve as useful exemplars for other parts of the MENA region, especially the Levant, that face significant limitations when it comes to land availability.[326]

The Levant

The lack of sufficient available land for distributed systems required for utility-scale solar and wind power generation is a unique distinguishing feature of the Levant among the sub-regions of MENA. The notable exceptions to this limitation are the Negev Desert and especially the Jordanian desert, whose solar energy resources approach Sahara Desert levels. The Jordanian desert comprises approximately 75% of Jordan's territory, with its 67,000 sq km being five times larger than Israel's Negev Desert.[327] The lack of available land across the region means that cross-border cooperation plays a vital role in the development of utility-scale renewable energy supply chains. The Palestinian-Israeli conflict, the Syrian Civil War, and other geopolitical cleavages in the Levant have imposed impediments to such cooperation. Jordan is the anchor for any configuration of cross-border cooperation, while Israel's advanced green energy technologies and its Mediterranean commercial ports could make it a key player in the development of regional and inter-regional renewable energy supply chains.

Jordan and Israel: Renewable Energy Supply Chains Will Be Shaped by the Patterns of Geopolitical Cooperation

Jordan and Israel are the most dynamic countries in terms of developing renewable energy in the Levant sub-region. In the previously cited Renewable Energy Country Attractiveness Index, Jordan ranked as the 5th the most attractive renewable energy market for investment and Israel ranked as 16th, when normalized for GDP.[328] Israel is a global leader in the development of solar technology and in 2022 ranked seventh in the world for the use of solar power, with 11% of its electricity generated from solar resources.[329] In 2022, Israel led the Middle East with an installed capacity of 4.41 GW for PV solar power while Jordan had 1.91 GW of installed capacity, placing it third behind the UAE. With regard to wind power the situation was reversed,[330] with Jordan leading the Arab Middle East with 614 MW of installed capacity.[331] Israel began operating its first significant utility-scale wind power plant in 2023, with a final installed capacity of 207 MW.[332]

In 2023, Jordan's accelerating renewable energy development program catapulted the country into being a regional energy transition leader as the Middle Eastern country with the highest proportion of power production from solar and wind sources.[333] By the end of 2023, Jordan's power generation capacity from renewable energy sources amounted to 2.6 GW, accounting for 27% of the country's installed capacity and prompting Jordan to raise its 2030 target for renewable power generation from 30% to 50% of installed capacity.[334]

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wants%20to%20bring%20255,waste%20generation%20capacity%20by%202030

326. https://www.pv-magazine.com/2023/05/31/bahrains-port-to-host-10-million-solar-project/

327. https://jordan.unfpa.org/en/about-jordan#:~:text=The%20country%20has%20an%20area,a%20land%20steeped%20in%20history

328. https://assets.ey.com/content/dam/ey-sites/ey-com/en_us/topics/energy-resources/ey-recai-60-report-november-2022.pdf

329. https://www.energymonitor.ai/tech/renewables/the-worlds-top-ten-solar-power-superpowers

330. https://www.energyinst.org/statistical-review

331. https://www.energyinst.org/statistical-review

332. https://www.power-technology.com/news/enlight-genesis-wind-israel

333. https://jordantimes.com/news/local/jordan-secures-top-spot-renewable-energy-capacity-potential-grow-%E2%80%94-kharabsheh

334. https://jordantimes.com/news/local/jordan-aims-lead-region-green-hydrogen-exports-%E2%80%94-govt; https://kalam.chathamhouse.org/articles/how-to-unlock-the-potential-of-jordans-renewable-energy-sector

Jordan's remarkable success in transforming its power system is occurring within the framework of the Jordan Energy Strategy 2020-2030.[335] To fulfill its ambition to become the renewable energy production hub of the Levant, Amman needs to restructure its energy sector to create a business-friendly regulatory and legal framework for renewable energy development. Additionally, Jordan needs to develop sufficient capacity for energy storage and transportation. Investment in the infrastructure required for the latter will be facilitated by the adoption of the former. In early 2024, the Jordanian cabinet presented a new renewable energy law for parliamentary approval that seeks to rationalize the regulatory framework to encourage the scale of investment needed for Jordan to reach its revised 2030 target.[336]

While the upgrade and expansion of Jordan's national electricity grid is required for the transmission of additional power from renewable sources, particularly for offtake via international electricity interconnection, the further acceleration of the kingdom's transition to renewable energy will likely occur through the development of its green hydrogen sector as an alternative offtake mechanism. In October 2023, Jordan's minister of energy announced that the kingdom anticipates producing 500,000-600,000 tons of green hydrogen during the present decade and is devising further targets for 2040 and 2050.[337] As seen in Morocco and elsewhere in the MENA region, green hydrogen's use in fertilizer production is likely to be the key to Jordan's development of a green energy ecosystem. Jordan is the world's seventh largest producer of potash, which forms the basis of the country's fertilizer industry.[338] The industry has a potential capacity to use 6,800 tons per year of hydrogen, which can be supplied by green ammonia.[339] Beyond fertilizer production, green hydrogen would be well suited for various Jordanian heavy industries, such as cement production and steel processing, as well as food processing. The current annual utilization capacity of hydrogen in Jordanian industries is 8,900 tons and the estimated potential capacity is 57,000 tons per year.[340] Jordan could replace its entire consumption of gray hydrogen with green hydrogen by meeting its minimum intermediate green hydrogen target, with almost 10 times the amount left over for domestic power consumption or export.

Based on the 13 MoUs Jordan signed in 2023, the kingdom could produce up to 2.35 million tons of green hydrogen or its green ammonia equivalent, upon the completion of the intended projects.[341] With Jordan's main foreign partners being firms and entities from Poland, Germany, South Korea, the UAE, and Saudi Arabia, Amman is positioned to become major green ammonia exporter to major European and Asian markets, potentially utilizing the export networks being developed by the UAE and Saudi Arabia.[342] The Korea Electric Power Corporation, which is involved in developing Saudi Arabia's blue ammonia sector, has partnered with the Saudi conglomerate Xenel to develop a green ammonia production facility in Jordan with a 1 million ton annual capacity.[343] The Emirati green hydrogen firm Ocior is similarly looking to construct a 1 million ton green ammonia plant in Jordan, while Masdar, ACWA Power, Germany's renewable firm Enertag, and Poland's hydrogen producer Hynfra are each exploring smaller green ammonia projects.

335. https://www.memr.gov.jo/EBV4.0/Root_Storage/EN/EB_Info_Page/StrategyEN2020.pdf

336. https://www.zawya.com/en/projects/utilities/jordan-to-have-new-renewable-energy-law-rf0lf527

337. https://www.reuters.com/business/energy/jordan-plans-raise-renewable-targets-by-year-end-or-early-2024-2023-10-03/

338. https://www.statista.com/statistics/1376220/worldwide-largest-potash-producing-nations/

339. https://www.mdpi.com/1996-1073/17/1/213

340. https://www.mdpi.com/1996-1073/17/1/213

341. https://renewablesnow.com/news/jordan-strengthens-green-hydrogen-commitment-with-five-new-pacts-842584/

342. https://renewablesnow.com/news/hynfra-fidelity-to-assess-feasibility-of-green-h2-project-in-jordan-836890/; https://www.energy-jordan-germany.org/home/221017-hydrogen-roadmap/

343. https://renewablesnow.com/news/jordan-strengthens-green-hydrogen-commitment-with-five-new-pacts-842584/

Additionally, the Amman-headquartered Iraqi firm MGH has signed an MoU with Jordan to develop an annual production capacity of 180,000 tons of green ammonia.[344] MGH already operates Jordan's 100 MW al-Tafilah wind farm and Jordanian produced green ammonia could supply MGH's cement production plants in Sudan and Iraq as well as its Iraqi steel operations — indicating the potential markets for green ammonia within the Middle East itself and Africa.[345]

Many of the sites for green hydrogen projects under exploration in Jordan are located at or near Jordan's Red Sea port of Aqaba for reasons of export and water use. As discussed earlier, green hydrogen production in the Middle East is highly dependent on water desalination as a source of freshwater input. The green ammonia plant to be built in the Aqaba Special Economic Zone by Hynfra and Jordan's Fidelity Group is slated to produce 100,000-200,000 tons of ammonia annually, powered by a dedicated 530 MW PV solar plant.[346] Jordan suffers from the world's second most severe level of water scarcity, with annual access to water of about 61 cubic meters per person — dangerously below the United Nations threshold of "absolute water scarcity" of 500 cubic meters per person per year.[347] To address the kingdom's water crisis, Jordan is building the Aqaba-Amman Water Desalination and Conveyance Project. The $2.5 billion project will consist of a water desalination plant in Aqaba that will produce 300 mcm of freshwater from the Red Sea and a transport system to deliver the water 450 km to the greater Amman region.[348] The Aqaba desalination plant is slated to be powered by dedicated solar power infrastructure.[349]

Desalination of water also formed the cornerstone of a new phase of Jordanian-Israeli green energy cooperation with the 2021 UAE-brokered water-for-energy deal in which an Emirati-funded 600 MW solar power plant in Jordan would supply electricity to Israel in exchange for Israel supplying 200 mcm of water to Jordan.[350] The original framework of the agreement, known as the "Green Blue Deal for the Middle East," proposed by the Israeli-Palestinian-Jordanian organization EcoPeace, included extensive Palestinian participation.[351] However, Palestinian participation in the project was derailed by hostility between the Palestinian Authority and the UAE leadership. The formal agreement between Jordan and Israel was intended to be signed in November 2023 at the COP28 conference hosted by the UAE in Dubai, but Jordan backed out of the agreement two weeks prior to the start of the international climate conference over Israel's conduct in the Gaza war that broke out on Oct. 7, 2023.[352]

The Jordan-Israel water-for-energy deal was part of a wider movement of green energy cooperation that emerged following the Sept. 15, 2020 accords that normalized relations between the UAE and Israel. The UAE began making significant investments in Israel's renewable energy sector, including Masdar's landmark 2021 agreement to become the strategic partner of EDF Renewables Israel, the Israeli subsidiary of France's EDF, which operates 18 solar power facilities in Israel.[353]

344. https://renewablesnow.com/news/jordans-mass-group-inks-pact-for-major-green-ammonia-project-841655/

345. http://www.massgroupholding.com/English/

346. https://solarquarter.com/2023/07/04/jordans-aqaba-special-economic-zone-embarks-on-green-ammonia-and-solar-energy-endeavor/

347. https://archive.unescwa.org/absolute-water-scarcity; https://jordantimes.com/news/local/jordans-national-water-carrier-project-track-alleviate-water-scarcity

348. https://www.eib.org/en/stories/aqaba-amman-water-desalination-jordan

349. https://jordantimes.com/news/local/water-energy-experts-stress-sovereignty-resource-management

350.https://www.aljazeera.com/news/2023/9/26/israel-advances-water-for-energy-deal-with-jordan-uae

351. https://ecopeaceme.org/wp-content/uploads/2021/03/A-Green-Blue-Deal-for-the-Middle-East-EcoPeace.pdf

352. https://www.timesofisrael.com/liveblog_entry/amman-says-it-is-pulling-out-of-jordan-uae-israel-energy-and-water-deal/

353. https://en.globes.co.il/en/article-uae-fund-to-invest-100m-in-clean-energy-in-israel-1001357897

Photo above: At a water desalination plant on the sea near the northern Israeli town of Hadera, water pumped in from the Mediterranean goes through a process called reverse osmosis. Photo by Quique Kierszenbaum/MCT via Getty Images.

After the 2023 UAE-Israel Comprehensive Economic Partnership Agreement, Emirati-Israeli green energy technology cooperation became even more robust and involved trilateral cooperation with India, forming the basis for the India-Middle East-Europe Economic Corridor (IMEC).[354] The September 2023 signing of the IMEC MoU at the G20 summit by host India, the UAE, Saudi Arabia, France, Germany, the EU, and the US — and which was preceded by the warming of Saudi-Israeli relations — raised the prospect of renewable energy supply chains stretching from India to the Arabian Peninsula and the Levant and then onto Europe. While the economic and political logic for such renewable energy supply chains remains, the current Middle East war demonstrates that such cooperation will require a new form of Palestinian-Israeli accommodation that involves a sufficient level of equity and dignity for the Palestinian side.

Leveraging its central position in the region, Jordan has also been looking at alternative geographies for renewable energy supply chains. As with green hydrogen, Iraq has emerged as a partner for renewable power offtake via electricity interconnection. In February 2024, Jordan and Iraq amended their electrical sales contract, paving the way for transmission to Iraq along a 40 MW interconnection from a Jordanian substation near the border across 330 km of Iraqi territory to the al-Qaim substation, which was established in July 2021.[355] The two countries are working on a 150-200 MW

354. https://www.mei.edu/sites/default/files/2022-07/Tanchum%20-%20India-Middle%20East%20Food%20Corridor.pdf; https://www.isas.nus.edu.sg/papers/indias-arab-mediterranean-corridor-a-paradigm-shift-in-strategic-connectivity-to-europe/

355. https://solarquarter.com/2024/02/13/amendment-to-energy-contract-jordan-to-supply-iraq-with-132kv-electrical-

interconnection as an intermediate goal toward a 500 MW interconnection.[356] Similarly, Jordan signed a January 2022 agreement with Lebanon and Syria to transmit power to electricity-starved Lebanon via its interconnection with Syria, providing transmission along a 150 MW interconnection from midnight to 6 am and then 250 MW during the day, covering about 10% of Lebanon's electricity demand.[357] Financed by the World Bank, the activation of the energy supply agreement was contingent on Lebanon meeting the World Bank's requirements to implement reforms to curb corruption in the country.[358] Transmission was not implemented, however, for fear of secondary sanctions from the United States under the Caesar Syria Civilian Protection Act of 2019 (the Caesar Act).[359]

The development of utility-scale renewable energy infrastructure in Lebanon has been rather meager, hampered by the country's fractured political system and the severe economic crisis that began in 2019. By the end of 2020, Lebanon had an installed capacity of PV solar power of 89.84 MW, failing to reach its target of 100 MW due to its economic woes. Lebanon illustrates an important alternate trend beyond the main scope of this study: the widespread use of rooftop PV solar power. With Lebanon's grid able to provide only 1-3 hours of power per day,[360] the country's citizens have long turned to private power generation and, in the face of growing difficulties obtaining fuel oil, they have increasingly relied on rooftop solar power. In contrast to 2020 when people in the country added only 14 MW of rooftop solar power, Lebanon saw 663 MW installed on rooftops in 2022, with the cumulative capacity exceeding 1 GW in mid-2023.[361]

Similarly, rooftop solar combined with mini-grids and micro-grids could provide a more resilient and affordable supply of electricity for Palestinian residential use in Gaza and the West Bank, where there is insufficient land to develop of utility-scale solar power. In the absence of renewable energy cooperation involving Israel, Gaza and the West Bank could receive power produced from renewable energy via interconnection with Egypt and Jordan respectively.

Regional cooperation in the Levant is essential for the establishment of renewable energy supply chains to the European electricity market, particularly given the recent progress in advancing an Israel-based electricity interconnector to Europe. In 2023, Greece's Independent Power Transmission Operator (IPTO) assumed the role of project promoter for the 2 GW Great Sea Interconnector between Israel, Cyprus, Crete, and mainland Greece. While the EU has funded one-third of the project's €1.9 billion price tag, IPTO's role as project promoter will facilitate foreign investment and international financing for the rest of the project, already prompting the UAE's TAQA to sign a 2023 MoU to explore becoming a shareholder.[362] Similarly, the US government's Development Finance Corporation has expressed interest in becoming a 10% stakeholder as well.[363] As the pace of construction on the segments of the interconnector accelerates in 2024 thanks to IPTO's oversight, the Greek transmission systems operator is also concurrently working to triple its interconnection capacity with Italy and expand its

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356. https://solarquarter.com/2024/02/13/amendment-to-energy-contract-jordan-to-supply-iraq-with-132kv-electrical-power/#google_vignette

357. https://www.reuters.com/world/middle-east/lebanon-jordan-agree-bring-electricity-through-syria-2022-01-26/

358. https://www.thenationalnews.com/mena/2023/03/28/jordan-says-dormant-electricity-deal-starts-with-lebanon/

359. https://today.lorientlejour.com/article/1424392/cesar-law-partly-blamed-for-edl-blackout-says-walid-fayad.html; https://www.washingtoninstitute.org/policy-analysis/how-caesar-act-restricts-normalisation-syria

360. https://www.wilsoncenter.org/article/theres-still-time-back-solar-power-lebanon

361. https://www.pv-magazine.com/2023/06/08/lebanese-households-fight-economic-crisis-with-record-rooftop-pv-additions/#:~:text=In%20May%2C%20the%20Lebanese%20Center,installed%20capacity%20of%20663%20MW

362. https://www.offshore-energy.biz/taqa-eyes-joining-900-kilometer-european-interconnector/

363. https://energypress.eu/us-state-fund-dfc-entry-into-great-sea-interconnector-a-catalyst/

interconnection with countries in the Balkans. With the Great Sea Interconnector on track to be completed by 2029, the Israel-based interconnection is becoming the leading offtake mechanism for Jordanian, Emirati, and potentially Saudi renewable energy exports to reach the wider EU electricity market.

Conclusions

MENA will emerge as one of the world's largest renewable energy-producing regions over the next 25 years. During the rest of the 2020s, the region will increasingly become an engine of global energy transition and the center of renewable energy supply chains. Morocco, Egypt, the UAE, Saudi Arabia, Jordan, and Israel are spearheading the trend by developing green energy ecosystems, in which the development of utility-scale renewable energy infrastructure is anchored in the deliberate development of diverse offtake markets and the storage and transportation mechanisms to service those markets. Other MENA nations that have recently demonstrated some positive trends will need to develop their own diverse green energy ecosystems and/or integrate into those of their neighbors.

Cross-border electricity interconnections form an export offtake mechanism for renewable energy exports but are insufficient by themselves to create robust renewable energy supply chains. Transporting renewable energy on demand as seaborne green ammonia exports greatly expands the scope of opportunities for developing a diverse array of renewable energy supply chains. The value of the global clean hydrogen market is forecast to surpass that of the global LNG trade by 2030 and continue to grow to $1.4 trillion by 2050. By 2050, MENA is expected to earn $130 billion annually from clean hydrogen exports, with blue hydrogen playing an important role in market development and paving the way for an expanded green hydrogen trade.

Moving MENA Forward: Green Energy Ecosystems and Renewable Energy Supply Chains

The overall outlook for MENA-based renewable energy supply chains is promising. Morocco, the UAE, Saudi Arabia, and Jordan are the main regional players on track to drive the growth of the region — along with Egypt and Israel, providing the former can tackle its current debt crisis and the latter can put regional normalization back on track following the Gaza war. Promising trends in Tunisia and Oman could add further momentum for the region to become the international center of renewable energy supply chains to Europe, Africa, and Asia.

The map of MENA-centered supply chains is unlikely to be determined primarily by the pattern of cross-border electricity interconnections. Barring paradigm-shifting new technologies in energy storage and transport, the versatility of green hydrogen exports in the form of seaborne green ammonia will play a prominent role over the next five years in shaping MENA's renewable energy supply chains. With exceptions such as the Xlinks project, hydrogen exports are proving themselves more amenable to deliberate coupling of renewable energy infrastructure development with international offtake markets. With global hydrogen trade forecast to overtake LNG by 2030, MENA-produced green hydrogen will be the main means by which renewable energy in the MENA region will service fertilizer production, sustainable fuels production for air travel and power plants, minerals and metals processing, and industrial manufacturing in Europe and Asia. The Arab Gulf states, particularly the UAE and Saudi Arabia, are likely to play a formative role in organizing the seaborne flows of MENA-produced green ammonia to European and Asian markets with Morocco forming a regional distribution hub to Europe and Egypt or Oman possibly playing a similar role for both European and Asian markets.

The map of MENA-centered renewable energy supply chains will be shaped by the diversity and robustness of green energy ecosystems within the MENA nations themselves. Beyond ammonia as an energy carrier, MENA nations, through the development of renewable energy-

powered manufacturing, will be shipping renewable energy in the form of higher-value-added products. Fertilizer will be one of the first products and could serve as a bridge for the development of green energy ecosystems. Morocco, Egypt, the UAE, and Saudi Arabia are likely to be the primary exporters, while Algeria, Tunisia, Jordan, and Israel could carve out significant international market share.
The development of minerals and metals processing with renewable energy will increasingly shape the map of regional renewable energy supply chains over the next five years. The UAE has already pioneered the production and export of green aluminum. Saudi Arabia is likely to emerge as the region's main metals processor with significant contributions in specific metals processing by Morocco. Egypt, Algeria, Tunisia, Jordan, and Sudan could also become green metals exporters of varying scales.

Green mobility is shaping up as the premier sector in the MENA for the use of renewable energy in industrial manufacturing. Morocco is the region's undisputed leader in overall EV manufacturing with the UAE and Saudi Arabia recently launching their first embryonic ventures. All three will leverage their comparative advantages in green metals processing of aluminum, steel, and EV battery metals to expand market share. The manufacture and export of products from cement to home appliances could establish new renewable energy supply chains for MENA countries such as Egypt, Jordan, and Oman.

The most sustainable MENA-based renewable energy supply chains will be those based on the export of "green" goods from agri-food products to EVs made in MENA countries with locally produced renewable power. The region's most robust green energy ecosystems will be those in which the intermediate inputs ranging from fertilizers and aluminum are also produced using renewable power, creating a vertical integration of renewable power usage. The full map of MENA's renewable energy supply chains moving forward into the 21st century will be the map of the region's manufacturing and agri-food production powered by its own renewable energy resources.

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