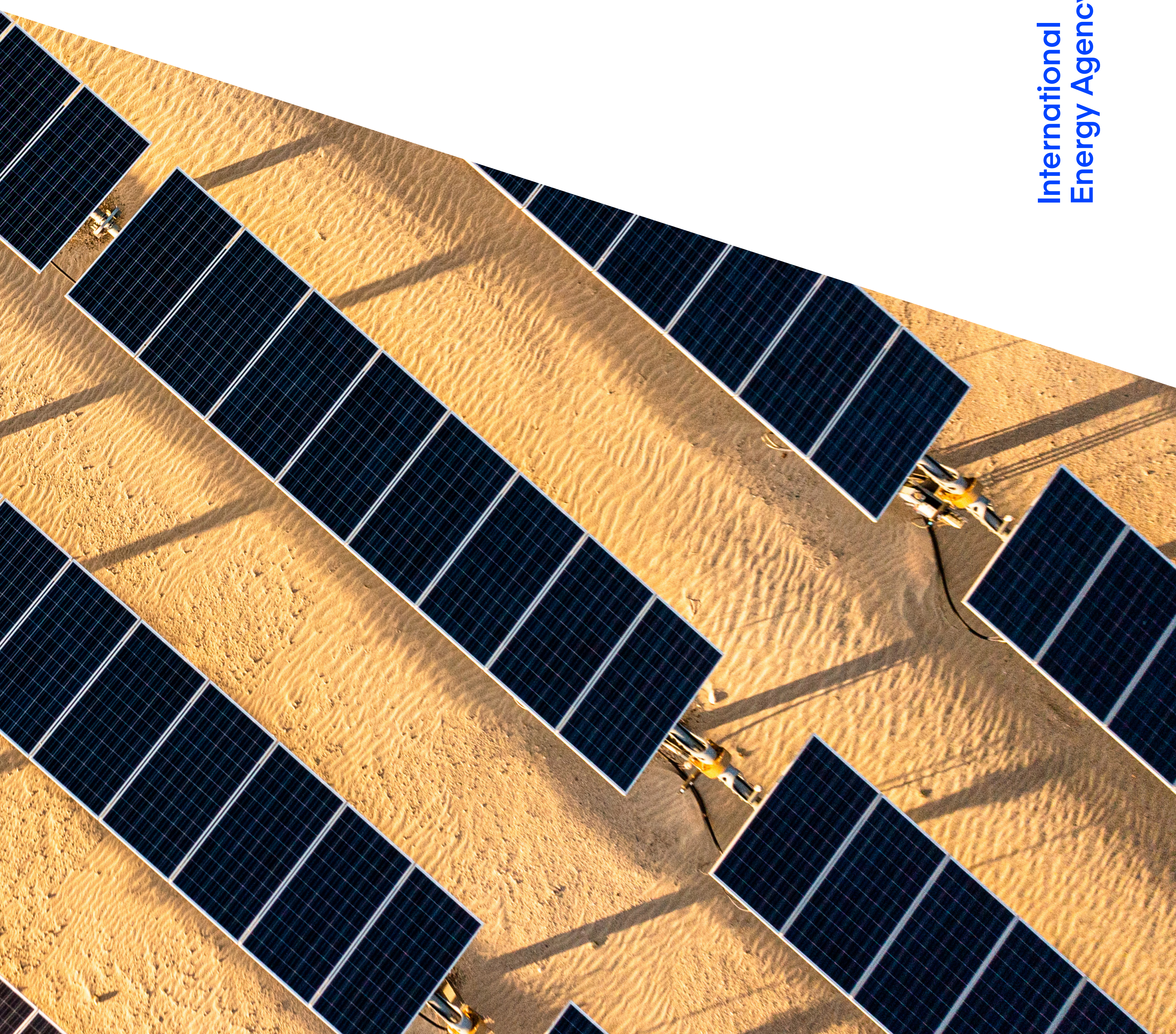
Renewable Energy Opportunities for Mauritania

International Energy Agency



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Abstract

Mauritania has high-quality wind and solar resources whose large-scale development could have catalytic effects in supporting the country to deliver universal electricity access to its citizens and achieve its vision for sustainable economic development.

Renewables deployment would benefit mining – the largest industry in the country – which is currently reliant on diesel and heavy fuel oil for its operations. A switch to renewable energy in the sector could lower costs, reduce emissions, increase efficiency and improve energy security in the country. There is also potential to further electrify energy uses in mining.

The government has announced various export-oriented projects to produce renewable hydrogen, ammonia and/or hydrogen-reduced iron. Anchoring demand on foreign offtakers would contribute significantly to de-risk these projects and generate the stable revenue stream needed to mobilise investors at the necessary scale. By attracting significant amounts of capital, such large-scale projects could enable a transformation of the power sector and spur sustainable economic development and growth, but robust and transparent policies and regulatory frameworks are needed.

This new IEA report – the first focusing on Mauritania – explores the potential benefits to Mauritania of developing its renewable energy options and includes an analysis of the water requirements of hydrogen and the potential for expanding potable water availability through seawater desalination.

Acknowledgements, contributors and credits

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Executive summary

Mauritania's tremendous renewable energy potential offers several possibilities for accelerated economic development in the country. Solar PV resources form the core of this potential, with Mauritania's lowest solar irradiation measurements on par with southern Europe's highest. Furthermore, its onshore wind resource in coastal areas enables offshore level performance but at a lower cost. Deploying these resources at scale to generate low-cost renewable electricity and hydrogen through electrolysis could therefore attract catalytic investments and accelerate Mauritania's energy system transformation by closing electricity access gaps, spurring clean and sustainable development and revamping the power sector.

Deploying renewable energy at scale could first help Mauritania deliver universal electricity access. With a young and fast-expanding population, half of which live in urban areas, the country has experienced economic growth in the past two decades. Although electricity access has more than doubled from 22% in 2001 to 48% in 2022, challenges remain (particularly to extend universal energy access to large swathes of nomadic rural populations), and attracting affordable capital to expand energy sector infrastructure will be critical for Mauritania to achieve its development goals. With a population of nearly 5 million, with roughly half lacking access to power, providing electricity connections for all remains a top government priority.

Renewables can also improve mining operations significantly. Mining already makes up a considerable portion of Mauritania's economy and is its largest industry subsector. In 2021, it accounted for 24% of the country's GDP and in 2022 it generated 71% of its total export income. Mauritania is the continent's second largest exporter of iron ore after South Africa, but it currently has little to no value-addition activities in the mineral supply chain.

As mining operations are energy-intensive and predominantly fossil fuel-based, raising efficiency in this area to curtail energy use could cut overall costs as well as CO_2 emissions. **Deploying solar PV and wind power plants can directly reduce the amount of imported diesel and heavy fuel oil** consumed by the generators that run electrically powered mining equipment, lowering costs and raising energy security in the mining sector.

However, the extent of such savings would be closely linked with the cost of capital for renewable energy projects, which in emerging economies can be two to three times higher than in advanced nations and can set the bankability bar for project development much higher. In the longer term, **moving towards higher value-addition activities in the mining supply chain could provide important**

opportunities for Mauritania and boost its economic growth more significantly, for instance by enabling the export of domestically produced hydrogen direct reduced iron.

Mauritania currently has the largest pipeline of renewable hydrogen projects in sub-Saharan Africa by 2030. The country's high-quality renewable resources and vast land area available for project development make it a potentially competitive producer of renewables-based hydrogen. In fact, it could be producing renewable hydrogen at a cost just over USD 2/kg by 2030.

Successful development of announced projects will rely on foreign offtakers to anchor demand and provide the stable revenue stream needed to mobilise investors at the necessary scale. But the real **transformational effect of such projects will depend on leveraging significant inflows of foreign currency and technological capacity to deliver domestic benefits and accelerate development**.

Mauritania has three major options to develop its renewable energy potential for exports. One pathway entails **shipping hydrogen to global markets in the form of ammonia**. Despite the high costs associated with converting hydrogen to ammonia, the overall seabound supply cost is lower for ammonia than for liquid hydrogen, making ammonia the likely choice for transporting hydrogen over long distances – at least during this decade.

The second pathway involves Mauritania **coupling its existing iron ore mining with renewable hydrogen to produce direct reduced iron** for export to Europe. The country currently export of iron ore was around 13 Mt in 2022 and generated around USD 1.3 billion of revenue. Direct reduced iron could enable the export of more refined product that further increases Mauritania's revenues, contributes to the creation of highly skilled jobs and stimulates the domestic economy.

The third option is to **transport hydrogen to Europe through a pipeline connecting Mauritania to Spain**. This would give Mauritania a competitive advantage over other potential renewable hydrogen exporters overseas, which would need to rely on shipping to reach European markets. However, its feasibility would hinge on mobilising significant upfront investment and co-ordinating all the various entities and stakeholders involved, and would require considerable time for implementation.

Deploying renewables for hydrogen production could be the starting point of wider power system transformation. While Mauritania's installed power generation capacity totalled less than 1 GW in 2022, up to 16 GW of renewable capacity could be required by 2030 to support the production of hydrogen, ammonia and/or direct reduced iron. Furthermore, oversizing power generation capacity needed for hydrogen production to provide also electricity for other purposes could be pivotal, especially if a fiscal framework were in place to allocate part of the revenues to expanding and "greening" the power sector.

However, **connecting locations with surplus generation capacity to distant demand centres would require the mobilisation of enough capital to expand and strengthen the grid in suburban areas and near mines and industries**, including to withstand increased variability of generation from solar and wind. Plus, to achieve the key policy and development objective of universal electricity access, significant investments in mini-grids and off-grid solutions will be needed to supply power to remote rural areas where grid expansion is not economically viable.

Renewable hydrogen production also requires significant volumes of purified water, which can be economically produced today by seawater desalination. Up to 13 million m^3 of purified water could be needed in 2030. Today's large-scale desalination plants can supply this quantity for around USD 1/m^3, representing just a small percentage of the production cost of hydrogen. Similar to power generation, desalination plants could also be oversized to supply excess water to the population for potable use, especially in water-stressed rural areas, and for agriculture to enhance food security.

While the cost of capital remains high in most of sub-Saharan Africa, **anchoring investments in foreign offtake can help de-risk large-scale projects and decrease currency risks**. Mobilising concessional capital would also likely be required to further de-risk such projects, particularly in their development phase, and to stimulate private sector appetite to attract the necessary capital. But ultimately, Mauritania's participation in low-emissions hydrogen trading will depend on global developments in certification standards, market demand and the number of off-takers willing to pay a premium for low-emissions feedstocks. Currently only 17% of export projects planned worldwide for 2030 have potential off-takers, so clearer signals by potential importers will be needed to enhance the bankability of such projects.

For Mauritania to pursue these pathways to accelerated sustainable development, **unprecedented co-ordinated action from the government, donors, private partners and development institutions is needed**. Although such large-scale projects are difficult to structure and implement, they offer Mauritania the opportunity to attract investment in the infrastructure that will underpin its economic development and growth. However, robust regulatory frameworks that encourage transparent resource management and good governance will be critical to unlock this potential.

Strong commitment from the donor and development community will be key to support these efforts, while private sector capital and expertise will be instrumental to move from concept to implementation. And while these pathways could be critical enablers for Mauritania to significantly advance the pursuit of its sustainable development goals such as universal access to electricity and economic growth, their true appeal lies in the opportunity to build a more prosperous and brighter future for the citizens of Mauritania and its future generations.

Chapter 1. Overview of Mauritania's energy system

Country overview

The Islamic Republic of Mauritania (hereafter Mauritania) in Northwest Africa spans a territory of 1 030 000 km^2, with a total population of around 5 million. Most citizens live in the south, as 90% of the country is desert or semi-desert. The country's population is young and growing quickly (2.6% annual growth in 2022), with more than half living in urban areas, which continue to grow rapidly, particularly on the coast and in the south.

Economic growth has lifted Mauritania into the ranks of lower-middle-income countries. In 2022, its GDP was USD 10.4 billion, twice as high as in 2008, and GDP per capita USD 2 191. The country's economy is dominated by services (44%), followed by the primary sector (20%) and industry (36%). The mining industry, which represented close to one-quarter of total GDP in 2021, is a key driver of the economy, followed by fisheries and agriculture. Mauritania's economic growth relies heavily on commodity exports (mainly iron ore, gold, copper and fish and crustaceans), which exposes it to global demand and price fluctuations for these commodities.

Mauritania's economy has been growing in real GDP terms thanks to increased household consumption and investments, while its fiscal deficit is expected to shrink and average inflation to fall to 5% by 2025. However, the country is exposed to downside risks resulting from sustained high oil and food prices, combined with low export commodity prices and constrained fiscal resources, regional political insecurity and extreme weather events.

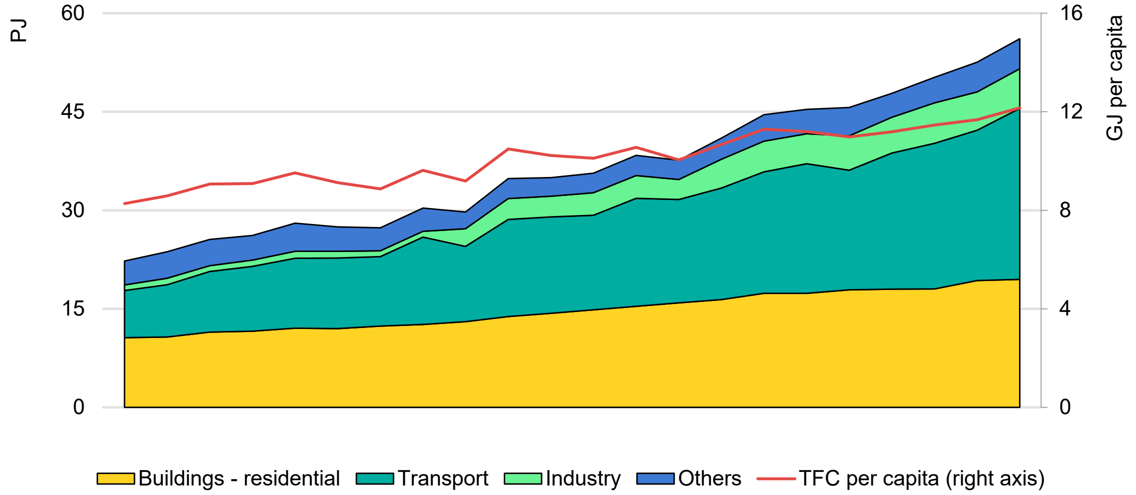
The government is increasingly under pressure to optimise public expenditures and alleviate the distorting impacts of an economy that relies heavily on export revenues from mining. To this end, the government has created an Agency for the Promotion of Investments in Mauritania, with the core mission of attracting and supporting investments in a range of sectors, including renewable energy. Nevertheless, several constraints continue to discourage private investment, including the high cost of capital linked to the elevated level of risk (both actual and perceived), limitations on the quantity and quality of information on investments, and low market competition.

Energy supply and demand

Data on energy supply and demand are fragmented and lacking in detail but are sufficient to identify the broad picture and general trends. In 2021, total energy supply (TES) amounted to 80 PJ, or roughly 17 GJ per capita. Mauritania's energy supply is generated almost entirely from imported oil and traditional local biomass (firewood and charcoal). The country's transport and mining operations rely on oil, which is also the main energy source for electricity generation.

Total final consumption (TFC) was 54 PJ, or close to 13 GJ per capita (Figure 1.1). Transport accounted for almost half of TFC, followed by residential buildings (35%) and industry (11%). Other uses such as agriculture, fishing and services represented 8%. Although TFC has increased roughly two-and-a-half times since 2000, per-capita consumption remains very low by international comparison, as global average TFC per capita (54 GJ) is four times higher than in Mauritania, and electricity use per capita (around 3 4500 kWh) is almost ten times higher. Nevertheless, TFC per capita remains aligned with the sub-Saharan Africa (SSA) average (excluding South Africa) (16 GJ).

Figure 1.1 Mauritania´s TFC by sector and per capita, 2000-2021



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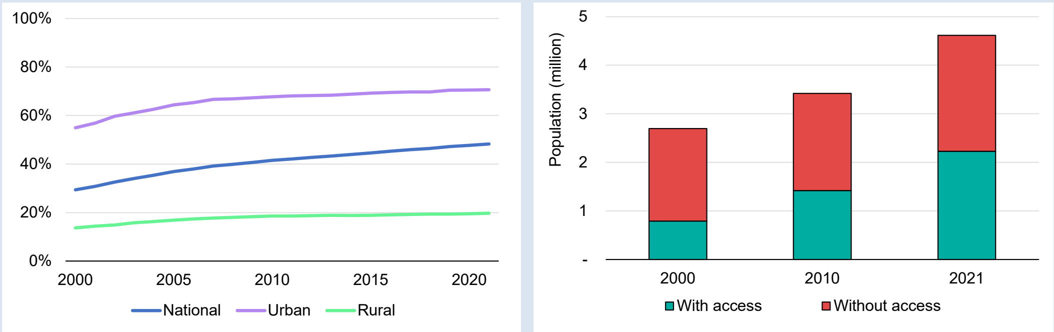
A large part of Mauritania's population, especially in rural areas, lives in poor conditions without full access to modern energy supplies. According to IEA 2022 data, less than half of the population has access to electricity and only 48% of citizens have access to clean cooking. Replacing the use of unsustainably harvested traditional biomass and increasing electricity access are therefore among the government's key development priorities.

Box. 1.1 Clean cooking

Today, nearly one-third of people around the world still use rudimentary methods to cook their meals. They burn coal, firewood and animal dung as fuel, breathing in hazardous fumes daily. Bringing clean cooking to households in developing economies is central to the provision of modern, secure and sustainable energy, and key to spur development, improve health and reduce gender disparities.

While in Asia and Latin America the number of people without access to clean cooking has been declining, in sub-Saharan Africa it continues to grow. Although access to modern energy has improved, this absolute growth results largely from population expansion outpacing gains. The share of population with access to clean cooking increased from 29% in 2000 to 48% in 2021, but the number of people without access rose from 1.9 million in 2000 to 2.4 million in 2021.

Clean cooking access in Mauritania by segment (left) and overall population (right), 2000-2021



Source: IEA (2023), A Vision for Clean Cooking Access for All.

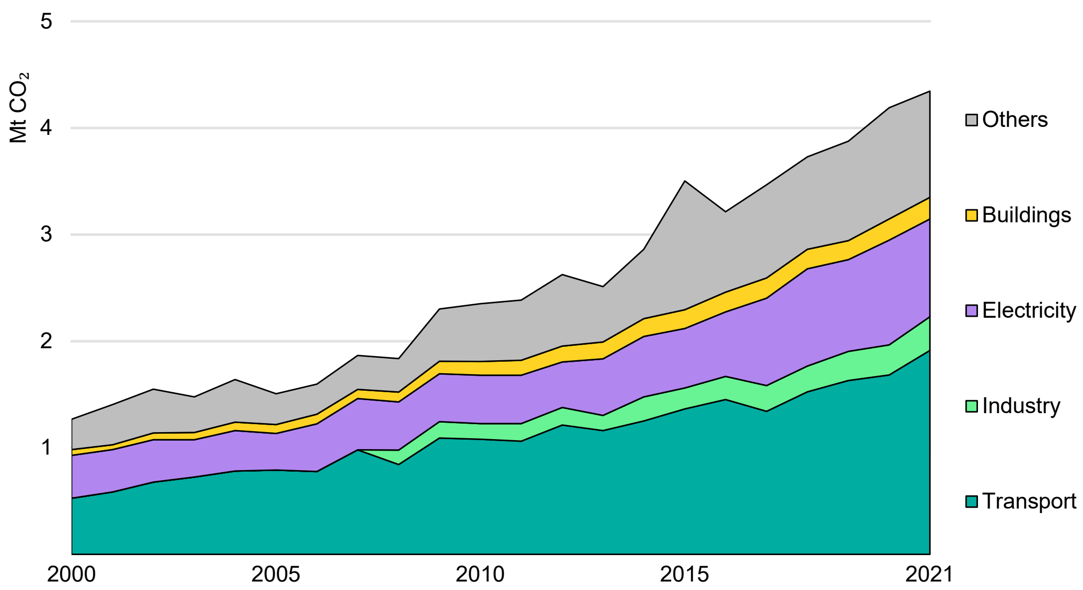
Major barriers to clean cooking for all continue to be affordability and financial support for households to cover upfront stove costs and, in some cases, ongoing fuel costs. A full scale-up of international capital injections and concessional financing would correct this rapidly, with just relatively modest funds required annually. According to IEA analysis, USD 8 billion would be needed each year to achieve universal access by 2030 globally; in SSA, around half of that amount would be required. Innovative financing solutions could make clean cooking a more attractive investment opportunity, as demonstrated by success stories in India, China and Indonesia, where the share of people without access was halved during the last decade. While cultural traditions linked to the preparation of dishes remain an important deterrent, governments can promote clean cooking through sensitisation campaigns.

CO_2 emissions from the energy sector

Energy-related CO_2 emissions come largely from oil use. In 2021, they amounted to 4.3 Mt (Figure 1.2), approximately 0.01% of total global CO_2 emissions. Per-capita emissions are almost 1 t, roughly equal to the African average (0.9 t), but only one-quarter of the world average. For instance, China's are seven times higher, and US per-capita emissions exceed Mauritania's by around thirteen times.

Transport accounted for almost half of Mauritania's total CO_2 emissions in 2021 and electricity generation for one-fifth, with emissions increasing 3.4 times from 2000 to 2021. In 2019, CO_2 emissions made up less than one-third of Mauritania's total GHG emissions (14 Mt). In fact, the country's main GHG sources (two-thirds of the total in 2018) are methane and nitrous oxide from its 20 million ruminants (sheep, goats and cattle).

Figure 1.2 Mauritania´s CO_2 emissions from fuel combustion by sector, 2000-2021



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Regarding its climate policy targets for 2030, Mauritania aims to reduce GHG emissions by 11% (unconditional) to as much as 92% (conditional on an estimated USD 30+ billion in international financing) from the business-as-usual level. These targets are included in Mauritania´s updated (October 2021) Nationally Determined Contributions under the UNFCCC Paris Agreement. The unconditional 2030 targets include attaining 13 GW of renewable power capacity (including the capacity to produce hydrogen for exports) and increasing the share of renewable energy in its electricity supply to 50%.

Mauritania's power sector

Electric system overview

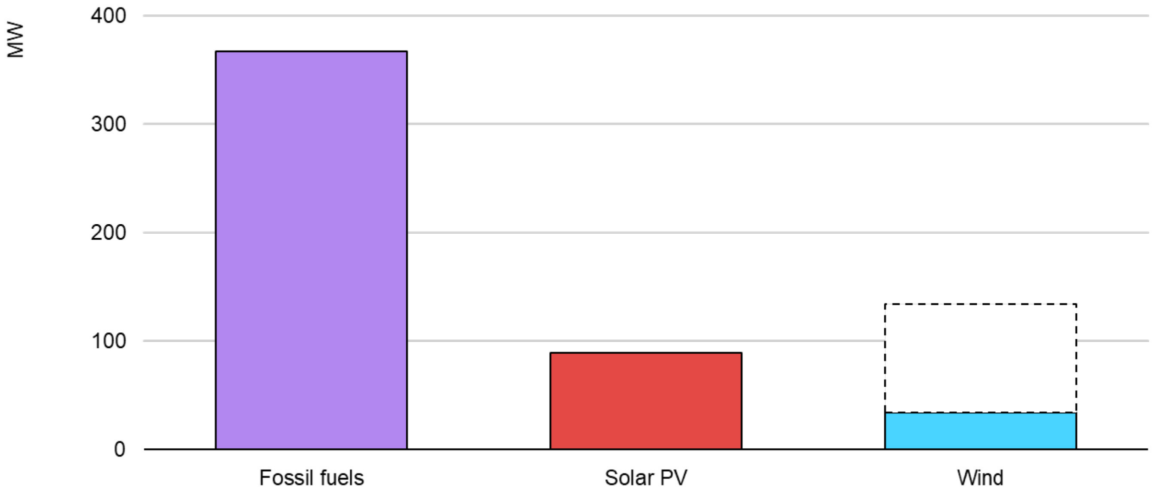
Mauritania's electricity grid is composed of one interconnected system; large, isolated grids (also considered on-grid systems); and diesel and hybrid mini-grids. The state-owned utility Société Mauritanienne d'Electricité (SOMELEC) generates and supplies electricity for most of the territory, except for the country's three large mining companies, which use their own generators to power their operations (see Chapter 3), and for a few mini-grid operators in isolated locations. According to IEA data, electricity generation in 2021 amounted to 1.7 TWh, primarily from oil (89%), followed by wind (6%) and solar PV (5%); installed capacity totalled 490 MW. Industrial and commercial consumers are responsible for nearly 65% of final electricity demand.

The country's electricity supply also includes hydropower imports from the Manantali, Felou and Gouina Hydro Power Plants (HPPs) on Mali's Senegal River, with imports totalling 188 GWh in 2021. These HPPs are overseen by the Organisation for the Development of the Senegal River (OMVS), whose member nations include Guinea, Mali, Mauritania and Senegal. Founded in 1972, the OMVS manages the Senegal River basin's agriculture, irrigation, energy, transportation and drinking water supply, and it safeguards the basin environment and continues to play a major role in the region's hydropower development.

In 2022, SOMELEC reported having 490 MW of generating capacity, mostly from thermal installations that run on heavy fuel oil (HFO). However, as Mauritania is set to begin producing natural gas in the first quarter of 2024, SOMELEC plans to add several hundred megawatts more capacity powered by nationally produced gas by 2030, and to switch from oil to gas at the 180-MW Nouakchott plant, the largest in its fleet. Switching to domestic gas from imported oil in electricity generation would bring Mauritania economic, environmental and energy security benefits.

SOMELEC is also increasing its focus on solar and wind power to generate clean and affordable electricity. Its fleet currently has 30 MW of wind and 83 MW of solar capacity (Figure 1.3), with the 100 MW Boulenouar wind power park awaiting connection. The government or SOMELEC own and operate the projects, with some rural installations being built by international companies. The wind capacity factor reached 44% in 2021, while the solar capacity factor is below 20%. The significant wind and solar power projects recently announced by international developers and the government in connection with the production of hydrogen via electrolysis (see Chapter 3) may also hasten and expandadoption of these technologies for domestic power production. SOMELEC therefore envisions roles for both domestic natural gas, and solar and wind power in the future as the country's electricity sector expands.

Figure 1.3 Mauritania's installed power generation by technology, 2022



Note: Included in wind power generation is the 102-MW Boulenouar Wind Farm, which is awaiting grid connection.
Source: IEA analysis based on data from SOMELEC and IRENA.

The 2022 Electricity Law

In December 2022, Mauritania adopted a new electricity law to improve the performance of the power sector and foster an enabling environment to attract private sector investment. The 2022 Electricity Law opens the electricity sector to independent producers and splits the state-owned electricity monopoly SOMELEC into four entities: a holding company, and separate subsidiaries for generation and transmission; distribution and marketing; and rural electrification.

However, SOMELEC remains responsible for electricity generation, transmission, distribution and marketing for customers served by the national grid. Independent power producers awarded generation licences must enter into agreements with a SOMELEC or other authorised user but receive priority dispatch in the system. In addition, industrial customers may also sign supply agreements for systems over 30 kW providing on-site power.

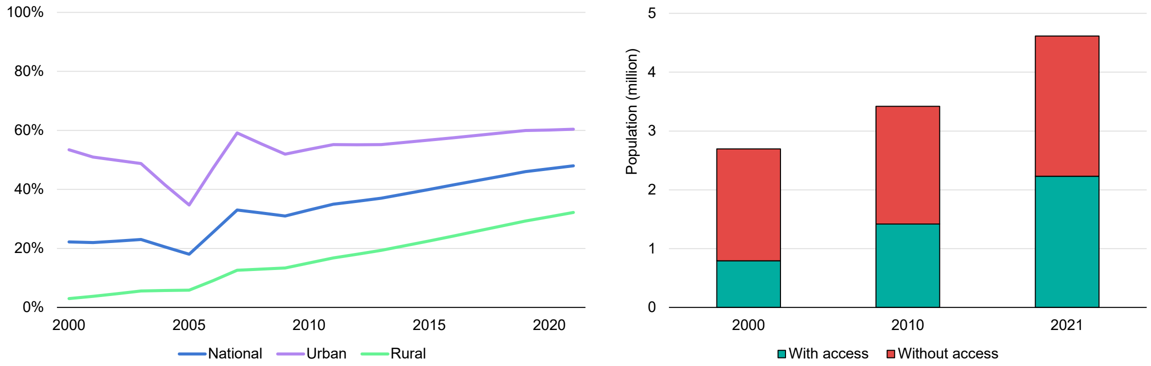
While the law aims to improve the electricity sector's financial health, it also contains provisions to accelerate rural electrification and gives connection and network preference to renewable energy and hybrid generating solutions to that end. It also states that mini-grids will be used instead of national grid expansion if the Energy Ministry's cost-benefit analysis supports it. The Energy Ministry will tender mini-grid projects and subsidise them as needed, with subsidies being paid out of a specific Rural Electrification Fund established under the law. The Fund will be financed from several sources, including the state budget, a levy on electricity generation, contributions from international development partners and carbon credits for GHG reductions.

Access to electricity

Although Mauritania's electricity supply has increased in percentage points since 2000, its insufficiency remains one of the main obstacles to the country's economic and social development. While the share of people with access to electricity rose from 22% in 2000 to 48% in 2021, the actual number of people without access increased slightly from 2.1 million in 2000 to 2.4 million in 2021 (Figure 1.4).

Perhaps counterintuitively, the number of people lacking electricity access increased from 2000 to 2021 in urban areas (from 0.5 million to 1 million) and declined in rural areas (from 1.6 million to 1.4 million). Nevertheless, in 2022 electricity access in urban areas was 60% and in rural areas 32%, which still represents a major difference. Expansion in rural areas surpassed the urban rate simply because urban population growth outpaced gains in electricity access. Since urban population growth exceeds rural values by around five times, electricity access is growing more slowly in urban areas.

Figure 1.4 Access by segment (left) and overall population (right), 2000-2021.



The government plans to meet its 2030 electricity access objective by [expanding the power grid](), increasing electricity generation capacity and implementing a [rural electrification programme](). Although the government's priority option to increase electricity supplies rapidly is to add gas-fired capacity, implementation depends crucially on the availability of gas from offshore gas projects and the development of infrastructure such as pipelines to transport the gas to shore.

The government also plans to provide electricity access to all localities of more than 500 inhabitants by both expanding transmission lines and offering decentralised mini-grid solutions to permanently isolated areas. It is especially challenging to supply power to rural communities of less than 500 inhabitants because they are dispersed nomadic populations in remote areas where road connections are poor, so connecting them through traditional grid infrastructure would not be cost-effective.

Transmission and grid expansion

Mauritania's electricity transmission system covers the south-east region of the country and is interconnected with the OMVS system. Nouakchott, the capital, is connected to the system by a 225 kV line extending to Dagana, Senegal. Large grid extension projects have been designed to connect main urban centres to the 180 MW Nouakchott power plant or to the Senegalese system OMVS covering the bordering south side of the country. Transmission expansion includes two main HV lines between Nouakchott and Nouadhibou completed in 2023 and an additional line between Nouakchott and Zouerate, which is under construction.

These plans stem from the 2012 Production and Transmission Master Plan, which focuses on expanding transmission and distribution lines to ultimately interconnect all existing systems. The 2012 Master Plan aimed to increase domestic electric production capacity, include more renewable resources in the energy mix, install additional off-grid power and develop transmission interconnections with bordering countries. Expansion plans announced in early 2023 include upgrading circuit capacity between the major cities of Nouakchott and Nouadhibou, while also increasing access for 12 000 additional customers surrounding the city. Planned expansions also include links with the neighbouring countries of Mali and Senegal, which would help supply southern Mauritania.

Box 1.2 Attracting investment to grid infrastructure

Scaling up renewable power generation capacity, particularly beyond captive systems, will require major investments in transmission and distribution infrastructure to improve system reliability, expand access and facilitate the integration of variable renewable energy sources. However, annual investments in Africa's grid systems grew only 5% between 2019 and 2022. Larger investments are needed not only to lay new lines and increase grid density to support greater generation, but to upgrade and enhance existing infrastructure.

Across most of the continent, state-owned utilities hold the monopoly on transmission and distribution, so much of the investments allotted to electricity system upgrades are expected to be done through public capital. This can be problematic as utilities' financial situations worsen due to poor payment collection rates, illegal connections, cost increases (including the cost of capital), operational problems and supply chain constraints that reduce cash flows and drive up debt. Furthermore, most African utilities report high system losses in the range of 10-19%, with an average of 15% across the continent in 2020 – more than double the global average of 7%.

Private sector financing could therefore be integral to develop transmission and distribution lines, although it is likely to be limited to countries that have relatively well-developed power systems and a stable regulatory environment. A variety of approaches for investments of this kind are used globally. Governments can prepare by reforming their country's tariff structure and authorising the use of concession agreements or other regulatory carveouts for private sector investment and ownership, as well as by introducing auctions and competitive tenders.

Source: IEA (2023), Financing Clean Energy in Africa.

Overview of energy policy

Mauritania has significant renewable energy potential, particularly solar and wind, as well as major offshore natural gas prospects. The government is encouraging the development of all types of energy resources for both export and the domestic market, and in the past couple of years has announced several projects worth more than USD 78 billion to produce renewable hydrogen (i.e., hydrogen made from renewable energy resources via electrolysis). The government is also pursuing natural gas development with the Government of Senegal through the Greater Tortue Ahmeyim (GTA) offshore LNG project, with gas production expected to commence in early 2024.

To take greater advantage of Mauritania's abundant but largely unexploited energy resources, the government has set three key energy policy objectives centred around achieving universal access to electricity by 2030. By developing gas, solar and wind resources, the government aims to enhance energy security, become a reliable supplier of gas and renewable energy, and use affordable and abundant domestic energy resources to stimulate economic and social development.

To meet these energy policy objectives, the government aims to increase energy supplies with a three-phase plan. The goal of the first phase, from 2022 to 2025, is to develop offshore natural gas resources in co-operation with major private sector partners. Phase two (2025-2030) involves expanding gas projects and introducing decarbonisation technologies – especially in iron ore and gold mining (currently fuelled by oil) – and building large-scale renewable energy projects, as switching away from oil in electricity generation would reduce costs and CO_2 emissions. In the third phase, from 2030 onwards, extensive production capacity for renewable hydrogen and ammonia are to be developed.

The Government of Mauritania is thus positioning the country as a potential producer of near-zero emissions steel, capitalising on its renewable hydrogen plans and extensive iron ore resources. The government also foresees opportunities for domestically produced renewable hydrogen to support the creation of new industry sectors, such as fertiliser production.

Together with Egypt, Kenya, Namibia and South Africa, Mauritania is a founding member of the Africa Green Hydrogen Alliance (AGHA). The purpose of AGHA is to intensify collaboration and supercharge development of green hydrogen projects on the African continent.

Box 1.3 Mauritania's natural gas developments

Mauritania is on the cusp of becoming a new gas producer and exporter following recent offshore discoveries of the GTA, developed jointly with Senegal and the BirAllah gas field, currently at the development stage. Like other African countries with large natural gas projects (e.g. Mozambique and Egypt), such developments could boost Mauritania's development significantly by increasing its national revenues and supporting industrialisation.

While gas currently meets around half of North Africa's energy needs, in sub-Saharan Africa the share of natural gas in the energy mix is a mere 5%. However, the considerable resource discoveries of the past decade provide an opportunity for natural gas to play a larger role in the region's energy systems. Around one-quarter of the 7 000 bcm of natural gas resources discovered in the past decade in Africa has been approved for development, including the GTA. If these projects are all completed on time, they will provide around 70 bcm of gas per year by 2030.

Cumulative CO_2 emissions from using these gas resources over the next 30 years would be around 10 Gt – equivalent to roughly four months of global energy sector emissions today. Africa's share of cumulative energy-related CO_2 emissions from 1890 to today is around 3%, and adding the cumulative lifetime emissions from burning this gas to Africa's current contribution would raise this share to just under 3.5%. However, there is a risk that new projects with long lead times could struggle to recover their upfront costs if the world successfully reduces gas demand to achieve net zero emissions by mid-century.

Note: For further information, see IEA (2022), Africa Energy Outlook 2022.

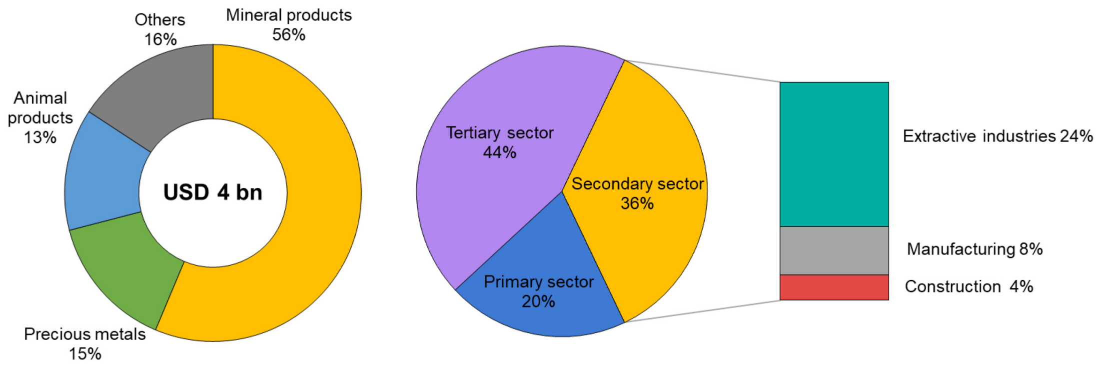
Source: IEA (2023), Financing Clean Energy in Africa.

Chapter 2. Renewables for mining

Extractive industries

Minerals are Mauritania's largest traded commodity, accounting for 56% of total export income in 2022. Precious metals are second-largest at 15%, represented entirely by gold ore mining and extraction. The remaining 29% is from the export of fish-derived products (fresh/frozen fish, fish oil and fish flour) and other products (textiles, machines, etc.).

Figure 2.1 Mauritania's exports by product, 2022 (left) and GDP shares by sector and activity, 2021 (right)



Sources: ANSADE (2023), Indice de la Producetion Industrielle (left-hand); ANSADE (2023), Mauritania data portal (right-hand).

Taken together, extractive industries represented 24% of the country's GDP in 2021. Iron ore is by far the largest primary mineral product by export value (90%), followed by copper (9%). Iron mines are all located in the northern part of the country, while copper ore and gold mines are in the central-western region. Mining is also Mauritania's largest industrial sector, with more than 60 national and international companies operating in extractive industries. The main companies are:

- The National Industrial and Mining Company (SNIM) – iron ore mining, exploiting deposits in the northern part of the country.
- Mauritania Copper Mines (MCM) – copper mining, operating in the western part of the country (in the Inchiri region) and also involved in iron and gold production. It is a subsidiary of First Quantum Minerals Ltd in Canada.

- Tasiast Mauritanie Limited S.A. – gold mining, operating a gold mine in the northwestern part of the country (in the Dakhlet-Nouadhibou region). The company is a subsidiary of Kinross Gold Corporation (Canada).

Table 2.1 Selected iron ore, copper ore and gold mining sites in Mauritania

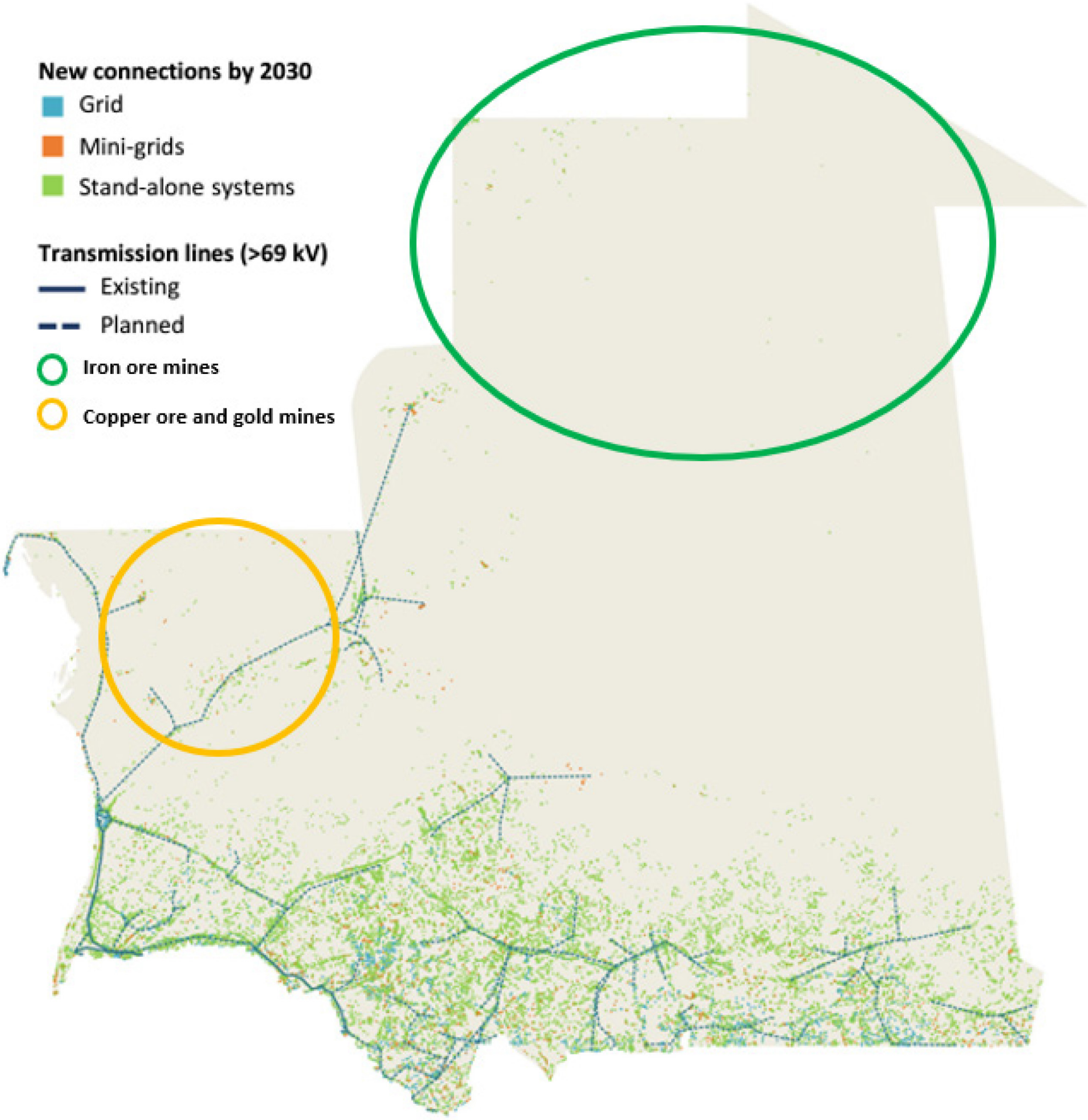
Site	Mine	Company	Type	Production/yr
Tiris-Zemmour District	Guelb El Rhein	SNIM	Iron ore (magnetite)	5 Mt
Zouerate System iron mine	M'Haoudat	SNIM	Iron ore (hematite)	8 Mt
Kedia d'Idjil mountain (part of the Zouerate System iron mine)	Tazadit	SNIM		
	Rouessa	SNIM		
	F'Derick	SNIM		
Inchiri region	Guelb Moghrein	First Quantum (Canada)	Copper ore	13 313 t in 2022
		First Quantum (Canada)	Gold	1 tonne in 2022
Northwest of Mauritania	Tasiast	Kinross Gold (Canada)	Gold	15 tonnes (2022, following expansion)
Northwest of Mauritania	Tijirit	Aya Gold and Silver	Gold	Feasibility study ongoing

Notes: M'Haoudat and Kedia d'Idjil are part of the Zouerate System iron mine. Tazadit, Rouessa and F'Derick are part of the Kedia d'Idjil mountain.

Mauritania is the second-largest exporter of iron ore on the African continent (just after South Africa) and the 11th largest exporter in the world. Mauritania's iron ore production and exports totalled 12.7 Mt in 2022 and generated around USD 1.3 billion of revenue. The excavated ore is transported to the coast by train, using a single-rail line of 700 km from the Zouerat region to the port city of Nouadhibou in the west. The trainline's annual capacity is about 17 Mt/yr.

Copper ore is Mauritania's second-largest exported mineral, with production of 13 313 tonnes in 2022 generating a total value of around USD 133 million. The country's main copper-gold open-pit mine is Guelb Moghrein, located in the Inchiri region, 250 km northeast of Nouakchott. In addition to copper, the mine also produced 570 000 tonnes of high-grade magnetite concentrate and almost 31 000 ounces of gold in 2022. The mine employs around 1 200 people.

Figure 2.2 Location of Mauritania's iron and copper ore mines relative to its electricity transmission network



Note: This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.
Source: IEA (2021), Clean Energy Transitions in the Sahel.

The country has a 704 km railway line linking the iron ore mining sites in the Tiris Zemmour region to the mining port of Nouadhibou. It also has a road network entirely dedicated to connecting the Inchiri, Dakhlet-Nouadhibou and Trarza mining basins to the seaports of the Atlantic coast.

Gold was discovered in Mauritania in the early 1990s, and gold mining has become a significant source of revenue: more than half a million ounces (15 tonnes) were produced in 2022 with a total value of USD 1 billion. Gold is excavated from two main sites, the Tasiast mine and Guelb Moghrein.

The Tasiast mine is an open-pit operation in northwestern Mauritania, operated by the Canadian company Kinross Gold. It is the largest mine in the country, representing over 90% of total gold production. Meanwhile, Guelb Moghrein is a copper-gold operation of the Canadian company First Quantum and located in northeastern Mauritania, near the town of Akjouit. In 2022, gold production totalled about 30 000 ounces (around 1 tonne).

Current energy use

Mining operations are energy-intensive and depend predominantly on fossil fuels. In 2021, the global mining sector produced 4-7% of global CO_2 emissions. Fuels are used mainly to operate mining equipment such as haul trucks, drills, excavators and loaders, while comminution (crushing and grinding) of the mined material is the main consumer of electricity. In remote locations – outside the reach of the electricity grid – power is usually provided by diesel generators, adding to fuel demand.

A mine's energy requirements depend on the material being extracted and the type of mine. All mines in Mauritania are open-pit, situated outside of populated areas and far from the electricity grid. Extraction relies on off-grid diesel and HFO generators, and diesel-fuelled machines and trucks for operations and transport. According to the Office of National Statistics of Mauritania, SNIM consumed 65 Mt of fuel oil in 2016 for mining.

Table 2.2. Estimated typical energy requirements per mining operation for copper, iron and gold

Mineral	Energy consumption	Distribution by end use		
		Mining diesel	Comminution (electricity-based)	Other processes (electricity-based)
Iron – hematite	0.15 GJ/t	90%	-	10%
Iron – magnetite	0.3 GJ/t	41%	43%	16%
Copper	26 GJ/t	57%	34%	9%
Gold	370 GJ/kg	60%	26%	14%

Source: Engeco (2021), Mining Energy Consumption 2021.

Magnetite and hematite mining requires 0.15-0.3 GJ of energy per tonne of iron ore, while copper mining uses much more energy, averaging 26 GJ per tonne of copper. Gold mining is very energy-intensive, requiring around 370 GJ per kilogramme of gold. In total, mining operations in Mauritania consumed around 5 500 TJ of diesel and 1 TWh of electricity in 2022.

Potential for renewables

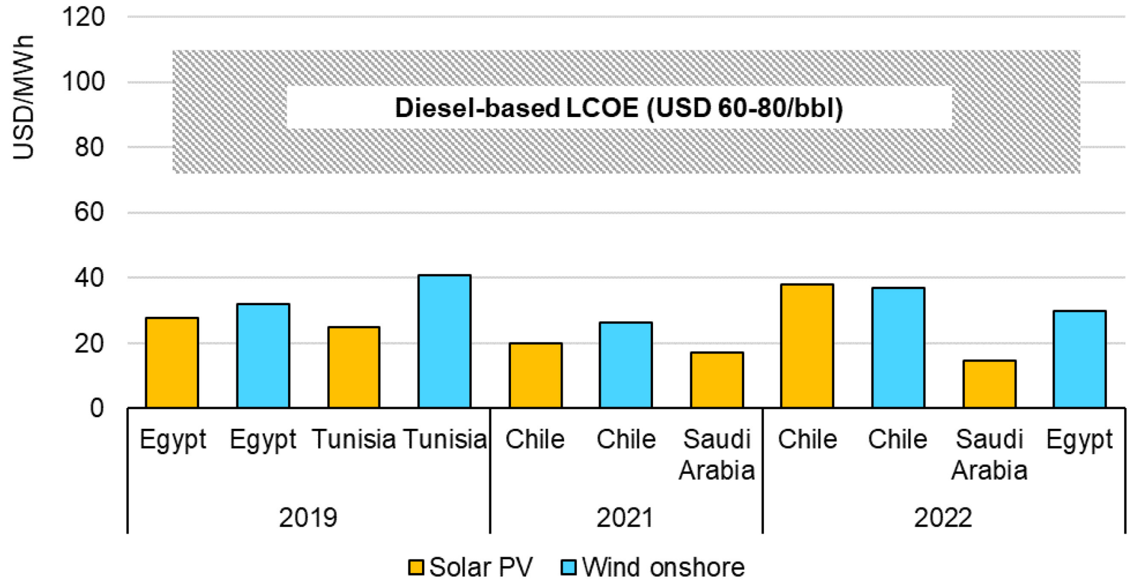
Renewables for mining

Increasing energy efficiency in mining operations can reduce energy use, overall costs and CO_2 emissions. Energy efficiency can be improved along the entire mining value chain, resulting from better management of electricity demand and utilisation of waste heat to improved data analysis. Some energy efficiency improvements have already been implemented at the Tasiast gold mine, where the redesign of mine roads has reduced the length of hauls, lowering diesel fuel use and reducing annual CO_2 emissions by 10 000 tonnes.

Further emission reductions can be achieved by switching to renewable energy sources. Approximately 40% of the fuel consumed by extractive industries in Mauritania is used to generate electricity for processes such as crushing, grinding, filtration and pumping. These uses can be directly powered from wind and solar PV plants instead of diesel generators.

Benchmark prices (Figure 2.3) of recently awarded renewable electricity projects – in locations with solar irradiation and wind speeds similar to Mauritania's – have been in the range of USD 15-38/MWh for utility-scale solar PV and USD 26-41/MWh for onshore wind. This suggests that the cost of renewable electricity in Mauritania is already well below the estimated cost of diesel-based electricity generation (USD 80-110/MWh) and would lead to significant savings in the mining sector. However, actual prices would depend on the specific characteristics of individual projects and could be influenced by the higher cost of capital for renewable energy projects developed in Mauritania compared with other parts of the world. The cost of capital for utility-scale energy projects in Africa can be two to three times greater than in advanced economies and is often higher for smaller projects that have fewer capital providers.

Figure 2.3 Awarded bid prices for solar PV and onshore wind in selected locations vs. estimated diesel-based LCOE in Mauritania



Note: LCOE = levelised cost of electricity.

As a variable electricity source, solar PV generation needs to be managed to avoid unexpected interruptions in mining operations. Initially, existing diesel generators can be used as a back-up electricity source at night or when weather conditions reduce generation from renewables. Depending on the site, a hybrid solar PV & wind power plant can increase the stability of electricity supply for industrial uses, and renewable electricity shares can be further enlarged by investments in battery energy storage systems.

The mining industry is already taking the first steps to introduce renewables into its operations. For instance, in 2022 Kinross began developing a solar PV power plant at Tasiast with power generation capacity of 34 MW and an 18 MW battery system. The project is part of Kinross's efforts to reduce its GHG emissions and is expected to provide approximately 20% of the site's power. Over the mine's lifetime, the Tasiast solar project is expected to reduce emissions by around 530 ktCO_2 and fuel use by approximately 180 million litres.

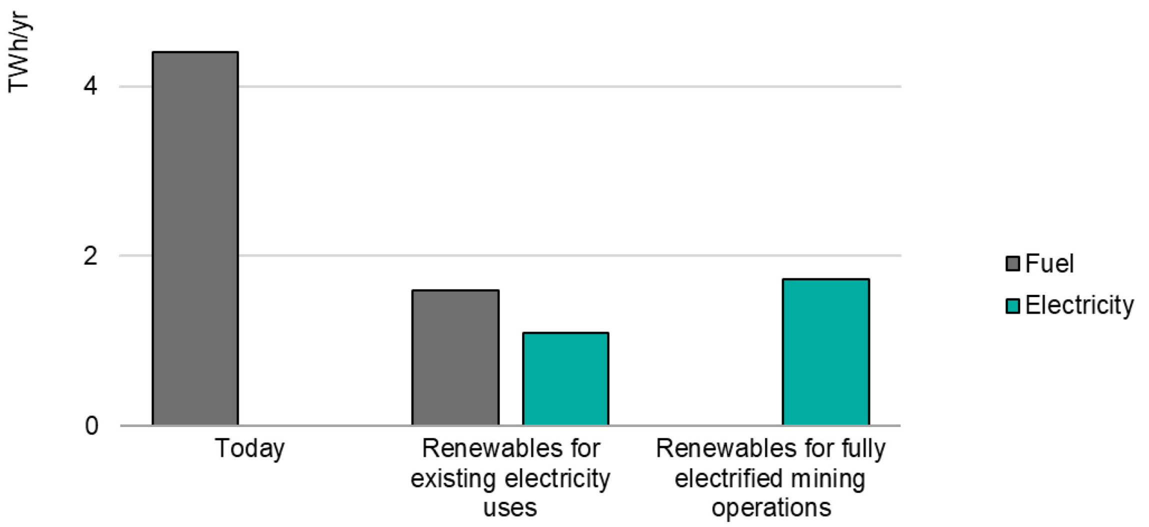
Another example is the Essakane gold mine in Burkina Faso, which sources its power from Africa's largest hybrid engine-solar PV power plant. By controlling and optimising the use of electricity from solar PV installations and engines, the gold mine was able to reduce its fuel consumption by approximately 6 million litres per year and its annual CO_2 emissions by 18 500 tonnes. A solar hybrid power plant is currently being developed also in South Africa at the Vametco gold mine.

Electrification of mining operations

In addition to electricity generation, diesel is used to run mobile equipment such as haul trucks, dozers and drills, as well as mining equipment such as hydraulic shovels and crushers. Electrification of mining equipment is already under way, and mining trucks with electric drive trains are commercially available today, offering higher payload capacity and greater energy efficiency than conventional diesel engines.

As an alternative to relying on stationary charging of batteries, haul trucks can be powered by overhead electric lines as they usually follow designated paths between mining areas and off-loading sites. The benefits of such catenary systems are highest when driving uphill, as this is when the most energy is required. During downhill travel, overhead lines could be used to recover braking energy as electricity.

Figure 2.4 Potential for renewable electricity to displace fuel use in mining operations



Note: Efficiency of diesel-based trucks 40%; efficiency of electric trucks 80%.

Equipment manufacturers are already offering and testing trucks with electric drive trains. A large battery electric mining truck was successfully demonstrated in 2022, completing a 7 km course fully loaded, achieving a top speed of 60 km/h, and successfully travelling for 1 km on a 10% grade both uphill and downhill. Key mining industry customers such as BHP (the world's largest mining company), Rio Tinto and Freeport-McMoRan (operator of the world's largest gold mine) supported the development of this prototype truck.

Battery electric trucks have higher efficiency and lower operating costs than diesel and hydrogen trucks thanks to their simplicity and smaller number of mechanical components. The time required for stationary charging of the batteries can be a challenge, although needs depend on the application. For example, on-board charging of batteries is possible from overhead lines on uphill climbs and by regenerating braking energy on the way down. In some cases, when the mine is higher than the offload location, during the downhill drive trucks can regenerate most of the energy needed to climb back up the hill empty.

Decarbonising all Mauritania's mining operations would require around 1.7 TWh of renewable electricity (Figure 2.4). As a first step, fossil fuel use can be reduced 60% by switching from diesel to solar PV and wind generators for electrically powered processes. Remaining fuel use could be displaced by electrifying all mobile equipment (trucks and drills), which would lead to an additional 0.6 TWh of demand for renewable power.

Box 2.1 Extractive Industries Transparency Initiative

The Extractive Industries Transparency Initiative (EITI) is a global standard for the good governance of oil, gas and mineral resources. The 57 countries committed to EITI aim to strengthen the transparency and accountability of extractive sector management by implementing the EITI Standard, which outlines requirements for EITI countries as well as the EITI Articles of Association. Validating the EITI Standard promotes dialogue and learning at the country level, providing opportunities to identify and address challenges related to improving extractive governance.

Among the conditions of the 2023 EITI Standard is a provision on the environmental impacts of the extractive industry (EITI Requirement 6), which sets a prerequisite for disclosing information on environmental impact assessments, certification schemes, licences and rights granted to oil, gas and mining companies, as well as details on the roles and responsibilities of relevant government agencies in implementing the rules and regulations. Included in this requirement are also transparency in environmental monitoring procedures and in government administrative and sanctioning processes, as well as environmental liabilities, environmental rehabilitation and remediation programmes.

Mauritania joined the initiative in 2007 to support economic growth and strengthen the contribution of extractive revenues to development projects and poverty reduction. Mauritania's priorities include improving the systematic disclosure, accessibility and use of extractive sector data, and facilitating multi-stakeholder dialogue on extractive sector governance. According to the EITI Mauritania Report

2020-2021, Mauritania has made some progress in becoming familiar with EITI requirements and standards.

For example, SNIM has established an environmental management system (EMS) in accordance with the ISO 14000 family of standards, placing environmental preservation and natural resource management at the heart of its business. Nevertheless, the report still highlights difficulties in accessing detailed information as well as insufficient consideration of social and environmental issues. This latter concern is exemplified by the extractive industry's payments to Mauritania's Environmental Commission in 2021, which amounted to just 5.61% of the sector's total revenue for that year.

Source: EITI (2023), Twenty Years of Extractives Transparency.

Chapter 3. Export opportunities from renewables

Mauritania's high-quality, abundant renewable resources and vast amount of land available for project development make it a potentially competitive producer of hydrogen from renewable energy sources. The country's solar PV potential is 2 000- 2 300 kWh/m^2/year, with its lowest irradiation measurements on par with southern Europe's highest solar resources. The country's wind energy potential is also significant around coastal areas in the Nouadhibou region, where capacity factors for onshore wind generation exceed 50%, offering similar performance to offshore wind but at a lower cost. The combination of these resources lays a solid foundation for low-cost production of hydrogen and hydrogen-based fuels from renewables.

Large-scale exports of hydrogen-based products can establish new low-emissions revenue streams and kick-start other positive developments such as economic diversification, improved energy access and increased energy security. By securing foreign offtake, these projects could provide the stable revenue stream needed to mobilise investors at the necessary scale and an opportunity for the Government of Mauritania to leverage inflows of hard currency to accelerate sustainable economic development.

For example, oversizing the power plants needed to run the electrolysers could provide surplus power to meet domestic needs, especially if a fraction of the revenues would be channelled – through fiscal policy – into expanding and enhancing the power system. However, a detailed analysis of how this could be implemented is beyond the scope of this report.

Table 3.1 Announced hydrogen and ammonia projects in Mauritania

Name of project	Status	Location	Project developer	Announced renewables capacity	Announced output	Export oriented
Aman project	Feasibility study	8 500 km^2 in the north of the country	CWP Global & Mauritanian government	18 GW wind and 12 GW solar	1.7 Mt H_2/ 10 Mt NH_3 of production output	Yes, partly
Nour project	Feasibility study	5 000 km^2 in the north of the country	Chariot with Total Eren	10 GW	1.2 Mt H_2 of production capacity	Yes – Port of Rotterdam

Name of project	Status	Location	Project developer	Announced renewables capacity	Announced output	Export oriented
Green ammonia project (Phase 1)	Concept	Near capital city Nouakchott	Conjuncta, Infinity Power, UAE's Masdar	400 MW	0.28 – 0.3 Mt NH_3 of production output	Yes (primarily to Germany)
Nassim project	Concept		bp	30 GW	10 Mt NH_3 of production output	

Source: IEA (2023), Hydrogen Projects Database.

Four major projects have been announced, which seek to leverage these opportunities. They are technically complex, require considerable infrastructure, significant investment and are still at early stages of development.

The Aman project, one of Africa's largest hydrogen projects, is located in northwestern Mauritania in the Dakhlet Nouadhibou and Inchiri regions. CWP signed a framework agreement in May 2022 to advance development of the project, which includes the construction of 30 GW of hybrid wind and solar capacity to produce 1.7 Mt/yr of renewable hydrogen once fully commissioned. The first stage of the project has a scale of around 5 GW of renewables and is to be online by 2029-2030.

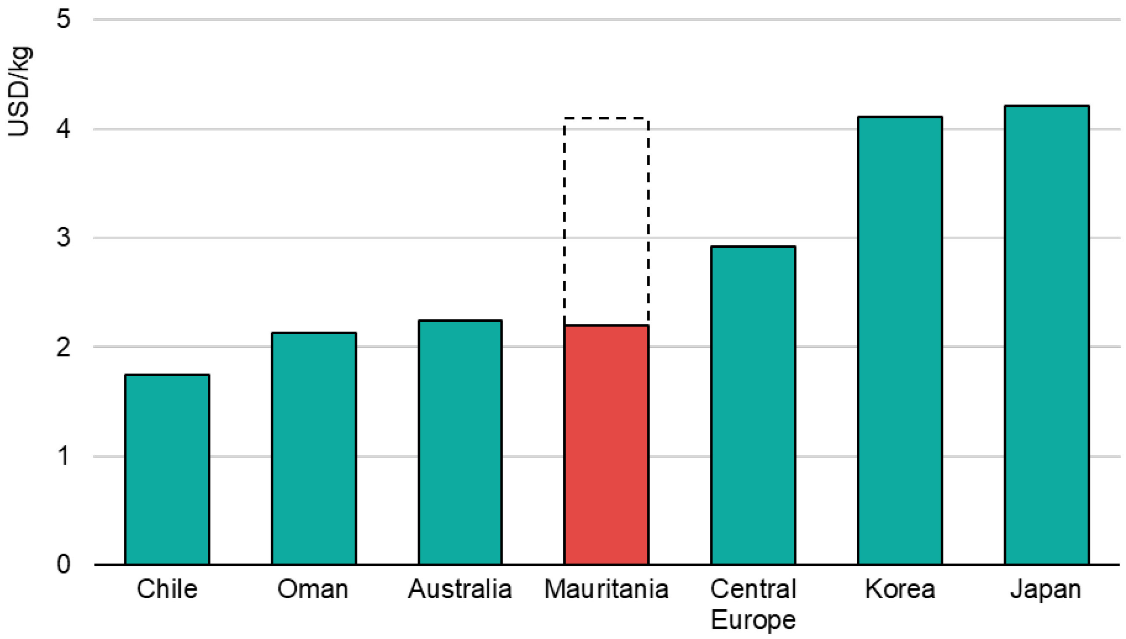
The Aman project has offered to boost electrification in Mauritania by investing in a dedicated grid-connected power plant, as well as by contributing USD 3 million to rural electrification programmes. Given its incorporation of a large desalination plant, the Aman project also has the potential to feed into national water supply infrastructure. Early volumes discussed with the government are in the neighbourhood of 50 Mm^3 of fresh water to supply local communities and increase agricultural production.

Meanwhile, the Nour Project is located in northern Mauritania close to the port of Nouadhibou, one of Mauritania's main export ports. The project is being co-developed by Chariot Energy and Total Eren and features 10 GW of renewable capacity to produce 1.2 Mt of hydrogen per year by 2030. In April 2022, Chariot Energy signed a memorandum of understanding with the Port of Rotterdam to export the plant's renewable hydrogen to Europe. The two parties agreed to establish the supply chains necessary for hydrogen trade, and to work together to connect with potential offtakers and secure contracts for specific volumes.

The Green Ammonia project, announced in March 2023, is being developed by Conjuncta (a German project developer), Infinity Power (Egypt's energy provider), the United Arab Emirates' Masdar and the Government of Mauritania. The project is located near Mauritania's capital city and will be developed in four phases. The first phase, which could start operating by 2028, aims to deploy 400 MW to produce around 0.3 Mt of renewable ammonia. Once all four phases are complete, land allocated to the project could accommodate around 10 GW of electrolyser capacity, with a final output of 8 Mt of renewable ammonia. Significant volumes are planned to be exported to Germany.

IEA analysis of the announced hydrogen projects in Africa shows that Mauritania could become sub-Saharan-Africa's largest exporter of low-emissions hydrogen by 2030, supplying 35% of the continent's total hydrogen exports.

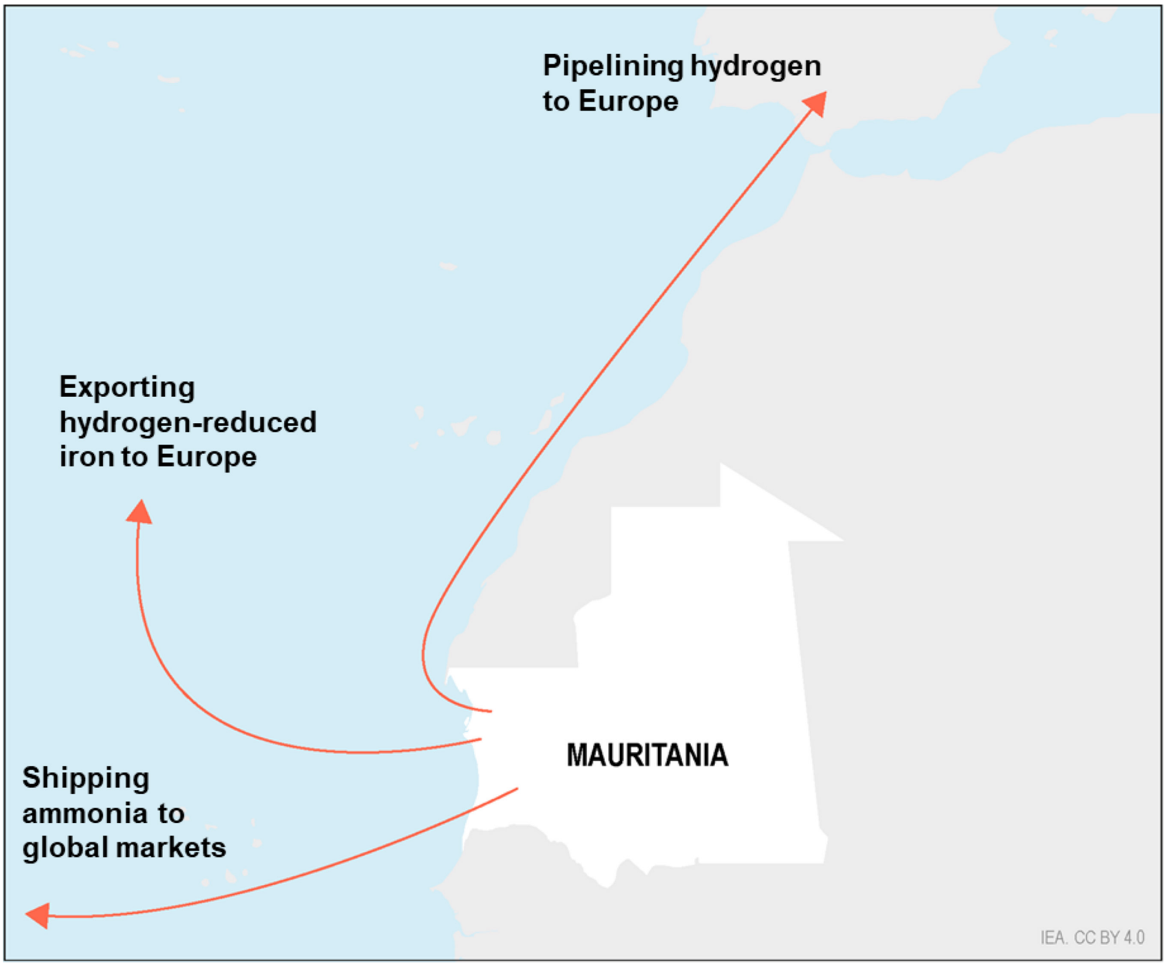
Figure 3.1 Levelised cost of renewable hydrogen in selected potential export countries and import markets in 2030



Notes: Technical lifetime 25 years. Electrolyser efficiency 69%. Electrolyser CAPEX USD 610/kWe. Annual OPEX 3% of CAPEX. WACC 6%. The dashed column represents the high-capital-cost case for Mauritania at 15% WACC.

With anticipated reductions in the price of electrolysers and of solar PV and wind, the levelised cost of renewable hydrogen will decline significantly from today's levels. By 2030, it could drop to USD 2.2/kg H_2 in Mauritania, USD 2.1/kg H_2 in Oman, USD 2.2/kg H_2 in Australia and USD 1.7/kg H_2 in Chile. In comparison, production costs near central Europe's major industrial hubs could still be around USD 3/kg in 2030 (Figure 3.1). Thus, for anticipated demand centres such as Europe and Japan, their higher production costs and more limited production potential due to high population densities means they will be more receptive to hydrogen imports from regions where production costs are lower. However, production costs are very sensitive to the cost of financing, which are typically higher in developing than advanced economies. For example, if the weighted average cost of capital for a hydrogen project in Mauritania were 15% instead of 6%, the levelised cost of hydrogen would jump to over USD 4/kg.

Figure 3.2 Three potential pathways to leverage Mauritania's renewable energy potential



Note: This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Of the several possible ways to develop Mauritania's renewable energy potential, we discuss three options:

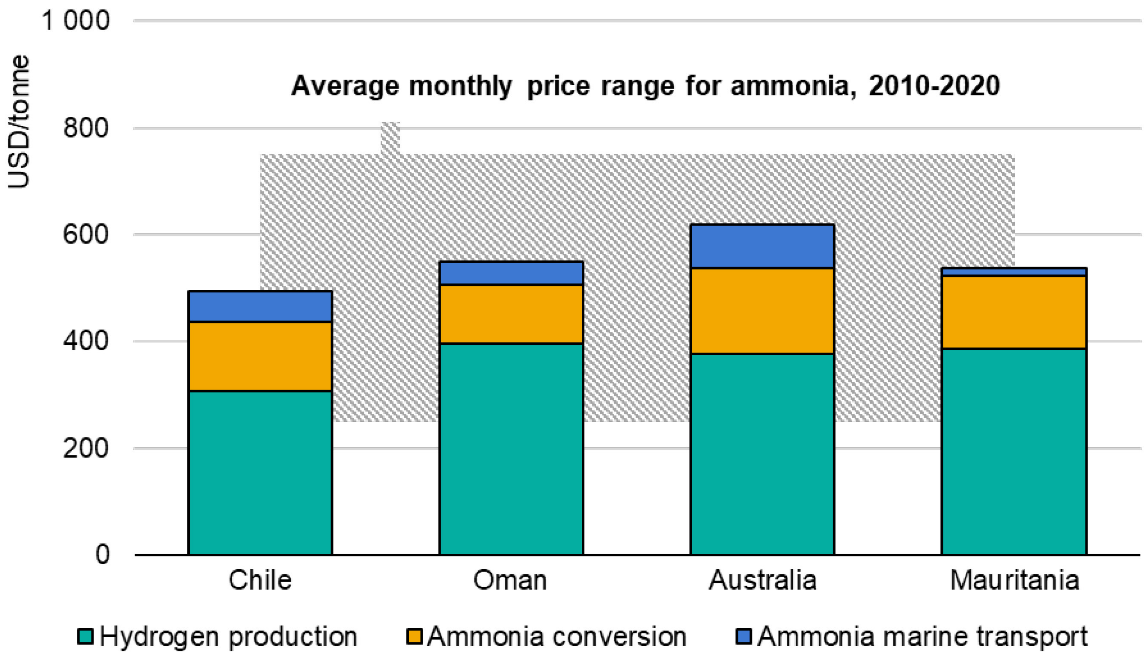
- **Shipping ammonia to global markets.** Mauritania could consider shipping its hydrogen to global markets in the form of ammonia.
- **Exporting hydrogen-reduced iron to Europe**. Mauritania could couple its existing iron ore mining industry with hydrogen reduction to produce hot briquetted iron for export to Europe.
- **Pipelining hydrogen to Europe**. Hydrogen could be exported to Europe through a hydrogen pipeline connecting Mauritania to Spain.

Shipping ammonia to global markets

In contrast to hydrogen, marine transport of ammonia is already well developed, relying on chemical and semi-refrigerated liquefied petroleum gas (LPG) tankers. Although it is expensive to convert hydrogen to ammonia, the overall supply cost by sea is lower for ammonia than for liquid hydrogen, making ammonia the likely form in which hydrogen will be transported over long distances, at least during this decade.

International trade of ammonia and the infrastructure required for its storage and transport are well established and technologically mature, although significant capacity expansions would be needed to facilitate growth in international hydrogen trade. Worldwide, approximately 150 terminals and ports can handle ammonia, as many countries with abundant natural gas resources export it, mainly for use as a fertiliser feedstock. However, Mauritania lacks both ammonia infrastructure and ammonia-related knowhow, so significant investments would be required, including for port infrastructure such as storage tanks, dedicated deepwater jetties, export terminals and pipelines. Building new infrastructure can often be the lengthiest part of the process, and port terminals can take nine years on average to build.

Figure 3.3 Estimated supply costs of renewable ammonia from selected potential export countries, 2030



Notes: Technical lifetime of 25 years. Haber-Bosch synthesis with ASU CAPEX USD 41/GJ per year. Annual OPEX 3% of CAPEX. Haber-Bosch synthesis efficiency 86% (LHV). Transport costs are adjusted depending on the transport distance to Europe. Between 2010 and 2020, average monthly ammonia prices in international markets were in the range of USD 250-750/t.

Mauritania's levelised production cost for renewable ammonia could reach 520/tonne by 2030, with the total supply cost rising to USD 540/tonne once the cost of shipping is considered. At this level, Mauritania could supply renewable ammonia at a cost that would be comparable to the higher end of ammonia market prices during 2010-2020, and well below the record levels of more than USD 1 000/tonne experienced globally in 2022 due to natural gas price hikes (Figure 3.3).

Exporting hydrogen-reduced iron to Europe

Mauritania's iron ore production and exports totalled 12.7 Mt in 2022, generating around USD 1.3 billion of revenue and having a decisive impact on Mauritania's economy. Nevertheless, it would be possible to combine existing mining operations and iron ore transport infrastructure with renewable energy to enable the export of a more refined product, such as direct reduced iron (DRI). This would generate more local value-added benefits than export of raw iron ore, which is Mauritania's current business.

DRI technology using low-emissions hydrogen is currently at the large prototype stage, with multiple projects announced in Europe. For instance, the HYBRIT (Hydrogen Breakthrough Ironmaking Technology) demonstration project produced the world's first "fossil-free steel" in 2020 and delivered its first shipment to Volvo in 2021. Another example is ArcelorMittal's new project in Hamburg, aimed at industrial-scale production and the use of hydrogen DRI with annual steel output of 100 000 tonnes.

In May 2022, ArcelorMittal announced that it had signed a non-binding memorandum of understanding with the iron ore mining company SNIM to evaluate the potential to jointly develop a pelletisation plant and DRI production plant in Mauritania. A prefeasibility study was to be completed in the first half of 2023.

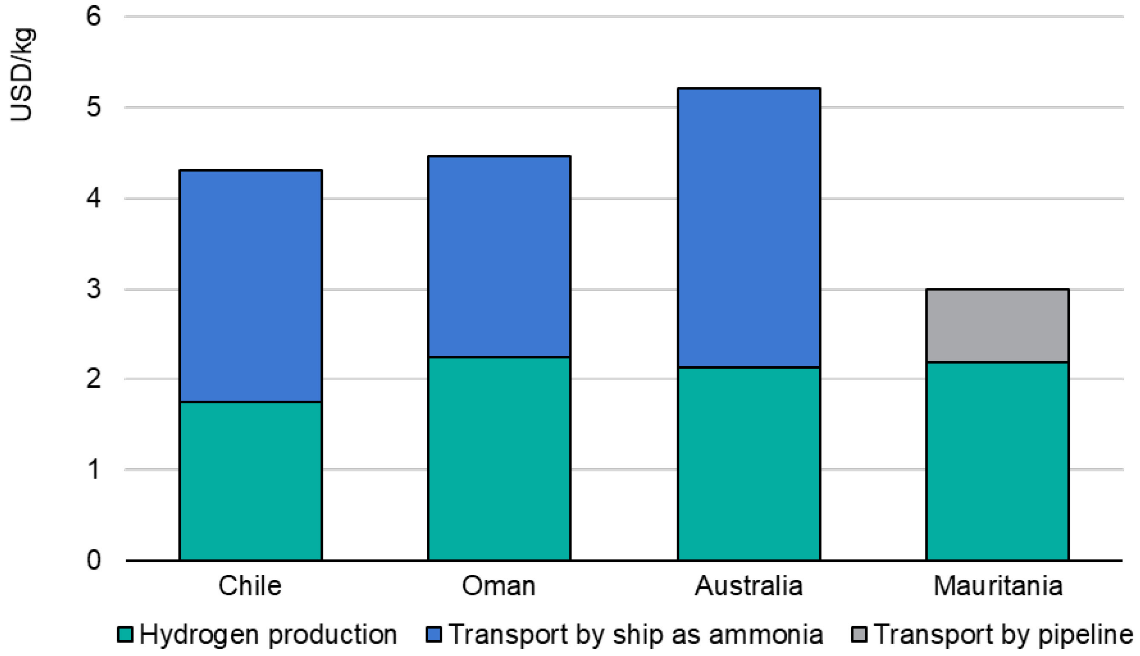
Due to the considerable amount of energy required to reduce iron ore, large steel importers such as the European Union and the United States are beginning to examine the possibility of importing sponge iron from regions that have abundant low-emissions energy resources and space for large-scale project development. As with ammonia, Mauritania could potentially become a cost competitive producer of DRI at a levelised cost of around USD 400/tonne by 2030.

Pipelining hydrogen to Europe

Due to its location, Mauritania could transport hydrogen to Europe via a direct pipeline connecting the two continents. This would give Mauritania a competitive advantage over other potential renewable hydrogen exporters such as Australia, Chile and Oman, which would all need to rely on shipping to reach European markets.

Hydrogen transmission by pipeline is a mature technology, with roughly 4 600 km of hydrogen pipelines currently in operation, over 90% of which are in Europe and the United States. These normally closed pipeline systems are owned by large merchant hydrogen producers and are concentrated near industrial consumer centres (such as petroleum refineries and chemical plants). The cost of transporting hydrogen by pipeline is generally around USD 0.2-0.4/kg for a distance of 1 000 km, assuming it is a large pipeline with several gigawatts of transport capacity. The distance from Mauritania to Spain is roughly 2 500 km, and it is another 2 500 km to central Europe's main demand centres.

Figure 3.4 Estimated supply costs of renewable hydrogen to Europe from selected potential export countries, 2030



Notes: Technical lifetime of 25 years. Electrolyser efficiency 69%. Electrolyser CAPEX USD 610/kWe. Annual OPEX 3% of CAPEX. WACC 6%. Transport costs by sea cover conversion to ammonia, shipping to Europe and reconversion back to hydrogen at the destination. For the pipeline estimate, a distance of 5 000 km is assumed (the distance between Mauritania and Central Europe).

Realisation of the pipeline would enable Mauritania to supply hydrogen to Europe at a cost of around USD 3/kg H_2, while the supply cost of shipping hydrogen as ammonia from Chile, Oman and Australia would be 30-70% higher after reconversion back to hydrogen (Figure 3.4).

A feasibility assessment by renewable energy developer Gaia Future Energy and the industrial consortium HyDeal for a subsea hydrogen pipeline from Mauritania and Morocco to Spain is ongoing. In June 2023, the two parties agreed to support a feasibility study for construction of the pipeline, which would capitalise on opportunities created by the H_2Med Pipeline connecting Spain to France and Germany by 2030. The first results of the pipeline feasibility study are to be presented this year during COP28 in Dubai, spearheaded by the Green Hydrogen Organization.

Evaluating different pathways

Mauritania's ample wind and solar resources position it as a potentially competitive exporter of renewables-based hydrogen, ammonia and direct reduced iron. However, success in scaling up these markets depends on several factors beyond just renewable resource quality. The potential pathways have widely divergent requirements, for instance for infrastructure development, market creation, stakeholder co-ordination, labour force training, etc, which need to be carefully considered in the weighing of options.

Table 3.2 Selected opportunities and challenges of the three possible development pathways

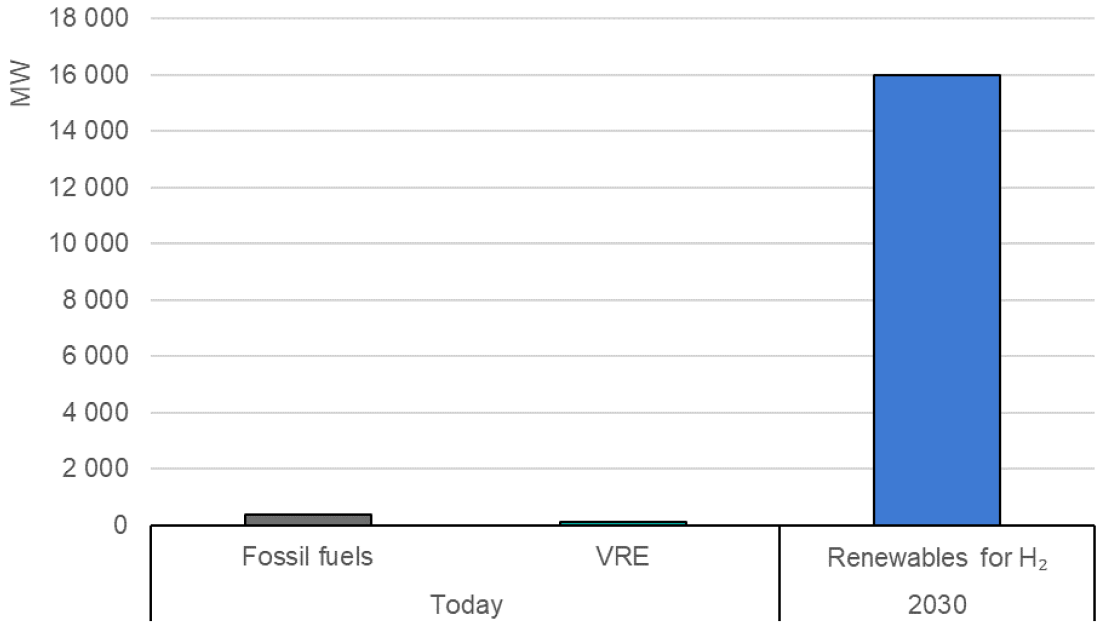
	Hydrogen pipeline	Ammonia exports	Iron ore reduction
Infrastructure development needs			
Stakeholder co-ordination			
Geopolitical issues			
Demand risk and market flexibility			
Labour force training needs			
Domestic retention of the value chain			
Job creation			
Technical standard readiness			
Technology readiness level			

Scaling up hydrogen direct reduced iron production would make good use of the country's multiple strengths. It could capitalise on existing mining and iron ore export infrastructure and expand to manufacturing of near-zero emissions iron, thereby producing a value-added export product. However, technology to produce hydrogen-based direct reduced iron is currently still at the large prototype stage and further technology development may be required for it reach commercial-scale production.

Meanwhile, the production and marine transport of ammonia are well developed but, unlike with iron ore, Mauritania does not have pre-existing expertise and knowhow for handling, processing and exporting fuels, including ammonia. Ammonia safety aspects especially needs to be carefully addressed in all parts of the supply chain. Substantial investments would be required to build new port infrastructure such as deepwater jetties and storage tanks to handle and store ammonia.

The pipeline to Europe would position Mauritania as a competitive supplier of renewable hydrogen, enabling it to have lower costs than other anticipated exporters that need to rely on marine transport. Although pipeline transport of hydrogen is well developed, experience in natural gas transport is not directly applicable to hydrogen without workforce training. Furthermore, developing a long pipeline that crosses national borders requires the overcoming of geopolitical barriers and careful co-ordination among the numerous stakeholders, including regulatory authorities and communities affected by the pipeline. The pipeline could be routed through the open ocean along the coast, but with added complexity. In any case, building a new pipeline may also be impeded by multiple hurdles related to construction management, standards requirements, environmental protection and regulatory models.

Figure 3.5 Mauritania's current installed capacity, and capacity required for hydrogen production by 2030



Sources: IEA analysis based on data from SOMELEC and IRENA (2023), Renewable Capacity Statistics 2023.

Despite representing very different approaches to developing Mauritania's renewable energy potential, all the pathways rely on massive deployment of wind and solar capacity. Indeed, up to 16 GW of renewable energy production could be needed by 2030 to support Mauritania's announced hydrogen projects, implying a massive increase from today's installed power generation capacity of less than 1 GW.

Chapter 4. Water requirements of renewable hydrogen

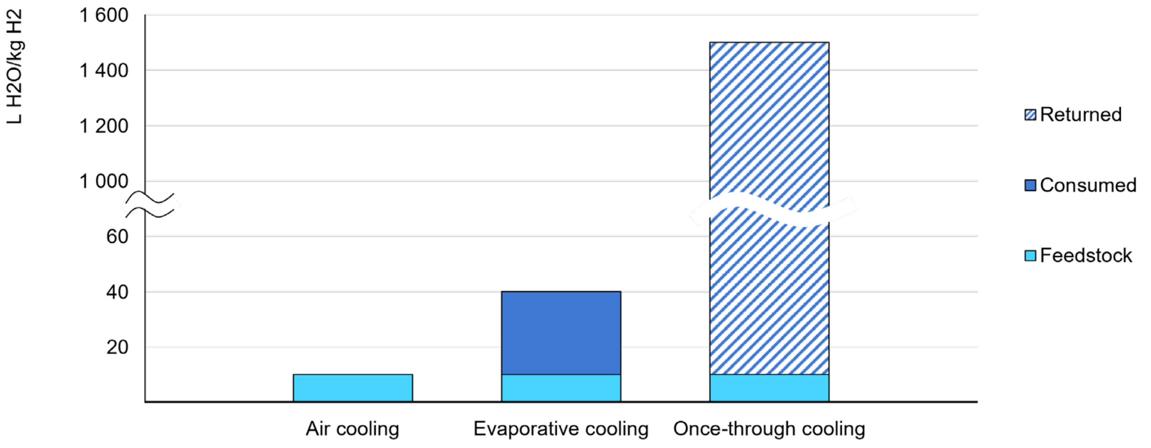
Around 10 litres of water is needed to produce 1 kg of hydrogen through electrolysis. In addition to serving as a feedstock, water might also be needed for cooling. Three main types of cooling systems can be applied, each associated with very different water requirements.

Air cooling does not consume any water, as byproduct heat from electrolysis is transferred to ambient air moved by fans. Air cooling offers flexibility in site selection, as plants are not dependent on a major body of water. However, a large surface area for heat exchangers and fans that move considerable amounts of air is required. Also, efficiency is low, especially in hot and arid climates, as cooling temperatures are limited by the ambient dry-bulb temperature.

Evaporative cooling systems discharge heat through controlled evaporation in a cooling tower. Given the high amount of energy required to evaporate water, relatively small volume is needed. However, water that is used for evaporative cooling cannot be returned to its source because it is lost as vapour in the process. Net water consumption can vary between 30 and 80 litres/kgH_2 depending on the design of the cooling system and climatic conditions.

Once-through cooling operates on liquid water that can be returned to its source after use. Heat from electrolysis is transferred to the water, increasing its temperature by about 10°C. Relatively large volume of water is needed – between 1 500 and 3 000 litres per kilogramme of hydrogen, which is possible only when electrolysers are located close to an abundant water source. Aside from filtering out foreign materials, no treatment of the raw water is needed for cooling purposes. However, regular maintenance is required to prevent corrosion, scaling and fouling in the cooling system.

Figure 4.1 Water requirements for electrolytic hydrogen production, by cooling method



If the produced hydrogen is not used on site, it is likely pressurised to reduce its volume for storage and transport. The pressurisation can be achieved using multi-stage compressors with intercooling, further increasing the water needs associated with large-scale hydrogen production.

In terms of water quality, electrolysers require ultrapure water, which needs additional deionisation to reach the conductivity range of 0.1 to 1 μSv/cm. Cooling water does not need to be as pure as electrolyser feedwater, but it must be treated for evaporative cooling purposes to minimise corrosion and prevent fouling in the system. In coastal areas, once-through cooling with seawater can be a good alternative to evaporative cooling, as it does not require desalinated water. Several large-scale power plants use this cooling method.

Innovative configurations can help decrease water requirements. Some companies are exploring the potential to use waste heat from electrolysers in membrane distillation desalination units to produce clean water, reducing the need for cooling water for electrolysis. Waste heat can also be used for district heating, as electrolysers produce around 45-65 MJ of byproduct heat per kilogramme of hydrogen, but this has rather limited potential in hot climates.

In an environment such as Mauritania's, evaporative cooling is the most suitable choice because it works better in hot and dry air while consuming relatively little water. However, dust and sand may get trapped inside the cooling tower and reduce the system's efficiency. Installing sand trap filters to remove heavy particles from the air can thus keep an evaporative cooling system clean and efficient. In fact, Oman recently commissioned 20 evaporative coolers with sand traps to air-condition an industrial warehouse. Similar configuration might be considered for electrolyser cooling as well.

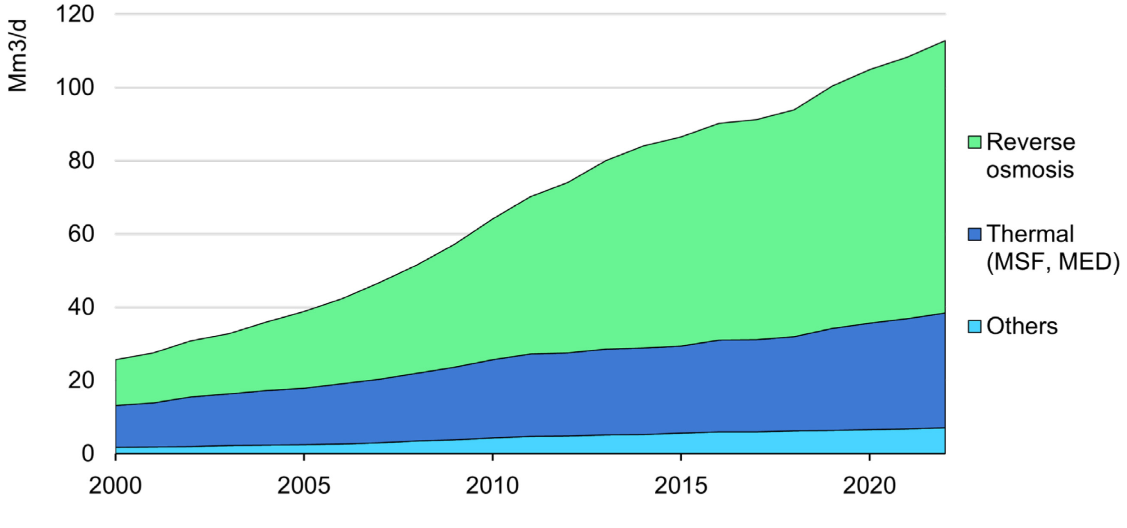
Seawater desalination as a solution

Water supply possibilities for electrolytic hydrogen production vary significantly depending on geographic and climatic conditions. Potential production sites with favourable solar resources are often in arid regions, meaning that limited surface and groundwater resources are likely to be claimed already, largely for agricultural and drinking water uses. Interest towards seawater desalination for hydrogen production in water-stressed areas has thus been increasing.

Thermal and membrane-based methods are the two main commercially available desalination technologies. Until the late 1990s, desalinated water was produced mostly through thermal evaporation. However, owing to improvements in membrane technology and associated cost reductions, membrane filtration now accounts for two-thirds of the world's desalination capacity.

Reverse osmosis is the most widely used membrane technology. It involves pushing saline water at high pressure through a semipermeable membrane that filters dissolved chemicals and biological species out of the water. Reverse osmosis plants typically produce about 40% desalinated water per litre of seawater, so the initial intake is higher than the amount of useable water produced, but since seawater is plentiful, the high-intake effect is insignificant. The most widely used thermal desalination technologies are multistage flash distillation (MSF) and multi-effect distillation (MED), wherein pure water is produced using multiple stages of thermal evaporation followed by condensation.

Figure 4.2 Global cumulative capacity by desalination technology



Note: IEA analysis based on data from DesalData.com, Media Analytics Ltd.

Seawater desalination capacity has expanded significantly in recent decades, especially in dry, high-income economies such as Middle Eastern oil exporting countries and small island nations such as Singapore. In fact, global desalination capacity has quadrupled over the past 20 years reaching over 100 Mm^3/d, with seawater reverse osmosis accounting for most of the growth. In terms of regional distribution, the Middle East and North Africa have the largest desalination plants with capacities of up to 500 000 m^3/d, followed by East Asia and North America. Regions that have limited desalination experience, such as Europe and Latin America, have also been gradually increasing their installed capacity in recent years.

With increasing capacity and technological learning, the cost of desalination has dropped significantly to around USD 1/m3. However, local costs vary according to numerous factors such as technology, plant size and feedwater salinity as well as energy prices and environmental regulations. Even so, the cost of desalinated water has only a small impact on hydrogen production costs. Given that roughly 40 litres of water are needed to produce one kilogramme of hydrogen, the cost impact of desalinated water is only around USD 0.04/kgH_2 or just few percent.

Current state-of-the-art desalination plants enable large-scale production of renewable hydrogen. An electrolyser plant that produces 1 Mt of H_2 per year consumes 40-90 Mm^3 of desalinated water, requiring a minimum desalination capacity of 110 000 m^3/d. This is still an average operating condition for desalination plants in countries such as Kuwait, Israel and South Korea, and well below the capacity of the Jebel Ali Desalination Plant in the United Arab Emirates, which is the world's largest seawater desalination plant at a capacity of 2 Mm^3 per day.

Environmental impact of desalination plants

Desalination is increasingly becoming a conventional method to produce fresh water to meet diverse needs of countries with limited water resources. However, large-scale implementation can also have important environmental impacts.

When desalination plants draw in the large amounts of seawater required for the purification process, marine organisms such as small fish, larvae and bacteria can get trapped in the plant's filtration systems. This phenomenon, known as impingement and entrainment, has raised concerns over the potential disruption of local marine populations. Addressing this issue necessitates the adoption of environmentally friendly intake methods that minimise the impact of desalination plants on marine life.

Another concern related to desalination is the disposal of reject brine, a highly concentrated byproduct containing salts and chemicals. When released back into the marine environment, this brine can disrupt the balance of local ecosystems due to its high salinity and altered chemical composition. Every day, desalination plants around the world produce 140 Mm^3 of reject brine, requiring proper brine management strategies to protect aquatic life and sensitive coastal habitats.

Brine disposal methods, such as surface water or sewer discharge, deep well injection, evaporation ponds, and halophyte irrigation, can have limited application depending on brine volume, composition, geographic location, and availability of disposal site. Considering that desalination plants will be scaled up to meet the water demands of large-scale hydrogen projects, brine disposal into oceans, rivers, or bays needs to be carefully planned, ensuring a disposal area wide enough for brine to spread and dissolve.

Water situation in Mauritania

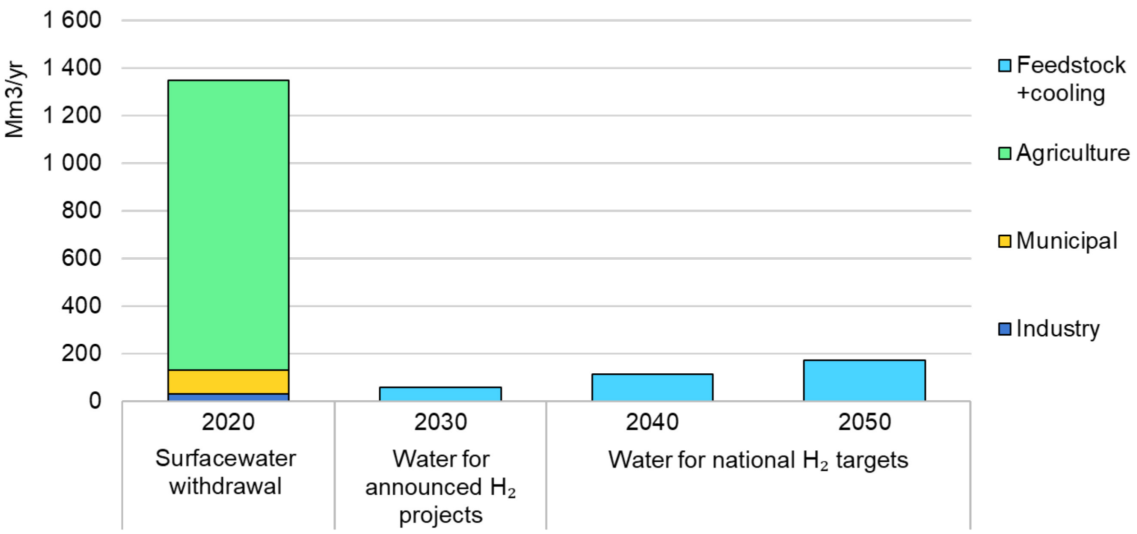
As Mauritania looks to embrace clean energy options, the close relationship between water and energy needs to be carefully considered, as it directly affects not only the feasibility and efficiency of hydrogen production but also the environment and people's lives.

Mauritania's primary water source is the Senegal River along its southern border. Since 2011, the city of Nouakchott has sourced most of its potable water from surface water due to the increasing salinity of Mauritania's groundwater, and many communities are struggling to secure sustainable water sources because they lack water treatment facilities. Furthermore, it is difficult to supply water to small towns that are not yet connected to water distribution networks. As a result, some rural areas in Mauritania are water-stressed. In urban areas, having access to water for basic services (drinking and sanitation) has improved significantly in recent years. However, periodic droughts coupled with water treatment disruptions still create water supply instability.

The country currently withdraws 1 350 Mm^3/yr in surface water. Agriculture accounts for the largest water withdrawal, while municipal services (100 Mm^3) and industry (30 Mm^3) together represent less than 10% of total withdrawals. Despite the large amount of water withdrawn, only half of Mauritania's potable water demand is being met, resulting in a deficit of 20 Mm^3 each year.

Mauritania could need around 60 Mm^3 of purified water for its hydrogen projects by 2030. This volume can be supplied from seawater desalination plants, gradually expanding to provide 110 Mm^3 by 2040 and 170 Mm^3 by 2050 to meet national H_2 production targets. Despite this increase, hydrogen-related water demand is likely to remain small compared with demand for other uses as population and industrial growth boost agricultural, industrial and municipal consumption in upcoming years.

Figure 4.3 Mauritania's water withdrawal by sector and water requirements for H_2 production



Notes: Water withdrawal data from FAO Aquastat. We assume at least 40 L of water is required to produce 1 kg of hydrogen.

To reduce stress on its scarce natural water resources, Mauritania can desalinate seawater also for agricultural and residential uses. Since desalination accounts for less than 5% of the cost of producing hydrogen, capacity additions are relatively inexpensive. In fact, a 50% oversizing of a desalination plant supplying water for a plant producing 1.5 Mt of H_2 per year would be sufficient to cover Mauritania's potable water shortage.

Project developers are considering oversizing desalination capacity given the economies of scale made possible by large hydrogen projects. The Aman Project aims to produce 50-150 Mm^3 of desalinated water, which is more than needed to cover its direct water requirements for hydrogen production by 2030. At the same time, the Nour Project aims to provide renewables-powered decentralised desalination systems that can be installed to supply potable water to remote rural areas.

Desalination practices can also contribute to infrastructure development, job creation and food security. Water pipelines and pumps need to be built to transport water from desalination plants to local communities, improving water access. Tanker trucks can be used to deliver water to small, scattered rural villages where pipelines are not economically viable, and constructing and operating desalination facilities and water networks can stimulate the economy by mobilising the local workforce. Furthermore, purified water from desalination plants can be used to irrigate farms and fields, leading to increased agricultural production and reduction in Mauritania's food imports.

Next steps

Our analysis identifies a strong potential for renewable energy deployment and renewable hydrogen production in Mauritania, which could have catalytic effects in supporting the country to achieve its vision for sustainable economic development. This potential could have implications in four major areas.

Deploying renewable energy at scale can first and foremost help Mauritania deliver universal electricity access to its citizens. Electricity is a key enabler for socio-economic development and with an access rate of 48% in 2022 and a population of nearly 5 million, the Government of Mauritania has set the target to achieve universal access by 2030.

Secondly, renewables can also improve mining operations significantly by lowering costs, improving efficiency, reducing emissions, and increasing security of supply by limiting the need to import diesel and heavy fuel oil. Given that mining accounted for nearly one quarter of Mauritania's GDP in 2022, switching to renewables in mining can have a large impact on national scale.

With the largest pipeline of renewable hydrogen projects in sub-Saharan Africa by 2030, high-quality renewable resources and vast land area available for project development, Mauritania is well placed to become a competitive exporter of renewables-based hydrogen. Anchoring demand on foreign offtakers can contribute to de-risking the projects and generate a stable revenue stream needed to mobilise investors at the necessary scale. Such projects could have a transformative impact in Mauritania through a combination of significant inflows of foreign currency and technological capacity to deliver domestic benefits and accelerate development.

However, in order to reap all these benefits, strong policy interventions would be needed, with the establishment of robust and transparent regulatory frameworks in Mauritania and beyond, including strong coordinated action and agreements between stakeholders across the entire value chain, innovative financial models and public-private partnerships, as well as certification standards for renewable hydrogen trade. A detailed analysis of which policy interventions and regulatory frameworks could be critical to enable these positive catalytic effects is outside the scope of this report, but could be part of a future study.

We hope that our analysis will further raise interest in this field and contribute to broader support on policy action from the international community, academia, multilateral and bilateral development institutions, donors and other partners to continue pursuing this debate and deliver the strong commitment and unprecedented action needed for Mauritania to pursue its vision and pathways for accelerated sustainable development.

Annex

Explanatory notes

Terminology for hydrogen production

In this report, “low-emissions hydrogen” means hydrogen produced through electrolysis, with the electricity generated from a low-emissions source (renewable or nuclear resources), biomass, or fossil fuels with CCUS. Meanwhile, “renewable hydrogen” is hydrogen produced via electrolysis, with the electricity generated from renewables. The same principle applies to low-emissions feedstocks and fuels made using low-emissions hydrogen, such as ammonia.

The IEA does not use colours to refer to the various hydrogen production routes. However, when referring to specific policy announcements, programmes, regulations and projects in which an authority has used a colour to define a hydrogen production route (e.g. green hydrogen), we use that terminology to report developments in this review.

Abbreviations and acronyms

ASU	air separation unit
CAPEX	capital expenditure
CCUS	carbon capture, use and storage
CO	carbon monoxide
CO_2	carbon dioxide
DRI	direct reduced iron
GDP	gross domestic product
GTA	Greater Tortue Ahmeyim
H_2	hydrogen
LCOE	levelised cost of electricity
LHV	lower heating value
LNG	liquefied natural gas
MCM	Mauritania Copper Mines
NH_3	ammonia
OMVS	Organisation for the Development of the Senegal River
OPEX	operational expenditure
PV	photovoltaic
SNIM	Société Nationale Industrielle et Minière
SOMELEC	Société Mauritanienne d’Électricité
SSA	Sub-Saharan Africa
TFC	Total Final Consumption

TES	Total Energy Supply
USD	United States dollar

Units of measurement

bcm	billion cubic metres
bcm/yr	billion cubic metres per year
gCO_2	gramme of carbon dioxide
gCO_2/kWh	grammes of carbon dioxide per kilowatt hour
GJ	gigajoule
Gt/yr	gigatonnes per year
$GtCO_2$	gigatonne of carbon dioxide
$GtCO_2$/yr	gigatonnes of carbon dioxide per year
GW	gigawatt
GWh	gigawatt hour
kg	kilogramme
km^2	square kilometres
kW_e	kilowatt electrical capacity
Mm^3	million cubic metres
Mt	million tonnes
MW	megawatt
MWh	megawatt hour
PJ	petajoule
TWh	terawatt hour

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