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Green hydrogen in Africa: opportunities and limitations

Abstract

Green hydrogen is globally seen as a universal fuel, feedstock or energy carrier and storage. The study aims to examine the role of the emerging green hydrogen market in developing countries in Africa. The goal is to indentify key factors that may either positively or negatively affect the development of green hydrogen energy in Africa. Several developing countries have been identified as potential key players in green hydrogen production: South Africa, Egypt, Morocco, and Namibia. These countries are expected to play a vital part in the development of hydrogen technologies due to favourable climatic conditions for the production of low-cost renewable energy, the possibility of exporting hydrogen to EU countries, and the presence of various national policy initiatives (national hydrogen strategies) and international partnerships (the Africa Green Hydrogen Alliance). The results showed that green hydrogen will boost economic development in African countries, stimulate investment and create new jobs. The study also identifies several barriers that could affect the development of green hydrogen in Africa: high investment costs for hydrogen infrastructure, financing, weak institutions, water scarcity and the imbalance between hydrogen for local use and for export.

Keywords: green hydrogen, renewable energy, energy transition, economic development
JEL Classification: Q42

Introduction

Population growth, burning fossil fuels, deforestation, industrialization, and farming in the past 200 years have resulted in global pollution of our environment. Climate change has both direct and indirect impacts on water scarcity, drought, flooding, land degradation, and a number of health issues. Approximately 2 billion people around the world do not have safely managed drinking water services, 3.6 billion people do not have safely managed sanitation services, and 2.3 billion lack basic handwashing facilities [UNICEF, WHO, 2019].

African countries are particularly highly vulnerable to climate change, and its impacts are occurring in all economic sectors. During COP27 seven out of ten countries were defined as being most at risk due to environmental problems resulting from climate change: Chad, Somalia, the DRC, South Sudan, the CAR, Nigeria, and Ethiopia [Iberdrola, 2023]. The biggest issues in these countries are their high economic dependence on climate-related activities, low economic growth rates, increased population, and their low adaptive capacity. This study proposes green hydrogen as one of the factors that could address these challenges.

With the continent's abundant hydro, solar, wind and geothermal sources and low-cost renewable electricity, many countries in Africa (especially in the north and south) are ideally positioned to produce green hydrogen and become significant players in the green hydrogen market. Green hydrogen would allow African countries to build their own energy independence, create economic growth, promote zero-carbon industrialization, and meet the continent's rising demand for energy.

The aim of the article is to illustrate the importance of the green hydrogen and renewable energy market in Africa's energy transition. The paper identifies both challenges and opportunities in the energy transition process facing the green hydrogen market in Africa. The study also focuses on identifying future major importers and exporters of green hydrogen in the global market. Northern and southern countries in Africa are well positioned to become competitive exporters of green hydrogen. In contrast, most likely importers of renewable energy are countries with limited access to renewable energy and high demand (European Union, South Korea, and Japan).

The authors' participation in the discussion on this topic arises from the belief that green hydrogen will contribute to the economic development of countries and address the urgent challenge of climate change.

Methodology and literature review

The methodology for reviewing the potential of green hydrogen in Africa includes a review of the existing literature, reports, market analyses, research papers, policy documents related to green hydrogen, energy policies and strategies. The analysis is based on the availability

of data related to natural renewable energy endowments, announced international trade partnerships, the existing or upcoming critical infrastructure and current progress on green hydrogen technology in key countries across Africa.

The starting point for the literature review was several studies conducted by the Green Hydrogen Organisation (GH2), IRENA, Abu Dhabi Sustainability Week, Mo Ibrahim Foundation, Hydrogen Europe, and Intersolar Europe. In all the research, the southern and northern African contexts are considered to be the most relevant in order to better embed the efforts of these regions for green hydrogen development, focusing on the Africa Green Hydrogen Alliance (AGHA) countries as a case study.

The GH2 analysis provided the first comprehensive study on the position of the AGHA members in the green hydrogen market in Africa. The authors indicated that the countries participating in the Africa Green Hydrogen Alliance (Egypt, Kenya, Mauritania, Morocco, Namibia, South Africa) could become a credible supplier in the global hydrogen economy. However, achieving this ambition will require strong leadership, creative partnerships, and significant capital. In another report on the renewable energy market in Africa, IRENA states that the transition to a renewable energy system in Africa promises significant growth in GDP, employment, and human welfare in every region of the continent. As in the GH2 study, IRENA argues that any policy initiative must be supported by strong institutions and adequate financial resources, international cooperation, and local communities.

The joint Abu Dhabi Sustainability Week (ADSW) and Masdar report outlines the 'symbiotic' relationship between green hydrogen and renewable energy deployment on the African continent. It was found that green hydrogen initiatives would create a renewable energy ecosystem and infrastructure that would enable faster deployment of renewable energy sources. The ADSW also points out that the development of renewable energy sources for hydrogen production on the African continent will support the creation of a qualified local workforce. To realise the full potential of hydrogen in Africa, all governments, domestic and international stakeholders, and the private sector must act together.

Some scientists perceived the energy efficiency and renewable energy technologies as the core elements of energy transition [Gielen et al., 2019]. In particular, the continuing fall in the cost of wind and photovoltaic energy and rapid innovation in the sector facilitate the ongoing transition. Similarly, as in the mentioned reports, the authors claim that leveraging synergies between RES and climate policy can result in overall GDP growth and have a positive impact on net employment.

Africa's potential for producing renewable hydrogen lies in its abundant human resources, available land, and diverse renewable energy resources [Adow et al., 2022]. According to Swilling et al. [2022], for the first time RES are growing faster (as a unit of GDP) in the Global South than in the Global North. In the article, the authors examine the linkages between the energy transition and economic development, using South Africa as a case study. The actual outcomes of the energy transition depend on the complex integration of local materials, highly globalized value chains, and institutional conditions.

The positive relationship between local economic development and the urgent challenge of climate change development was also discussed by Augier et al. [2023]. The article is based on an 'achieved commitments scenario', meaning that the described capital expenditures would meet both Africa's energy demand and the GHG reduction targets. This scenario assumes that technological advancement will continue at a rapid pace and that policy measures will support the transition. In the long term, projects that support the development of RES and green hydrogen, as well as harnessing the potential of local natural resources, will help to achieve the goals of the 'achieved commitments scenario'.

Pee et al. [2022] identify 4 areas that need be addressed to scale green hydrogen market: scaling competitive supply of green hydrogen in the long term, stimulating local demand, developing transportation technology, and facilitating corporations across value chains, customers, and countries. Strategies for developing green hydrogen in Africa should also be based on the ethos of transparent and accountable governance structures, local participation, multi-stakeholder involvement, and anti-corruption standards [Adow et al., 2022]. However, policies and visions for energy decarbonization differ from country to country. Adow et al. [2022] distinguish 4 elements that any hydrogen strategy must include in order to provide broader socio-economic benefits to local African communities: ending energy poverty and creating energy access, accelerating RE deployment, powering key industries and sectors for Africa's socio-economic transformation, and maximising energy efficiency.

Renewable energy market: a cornerstone of green hydrogen market development

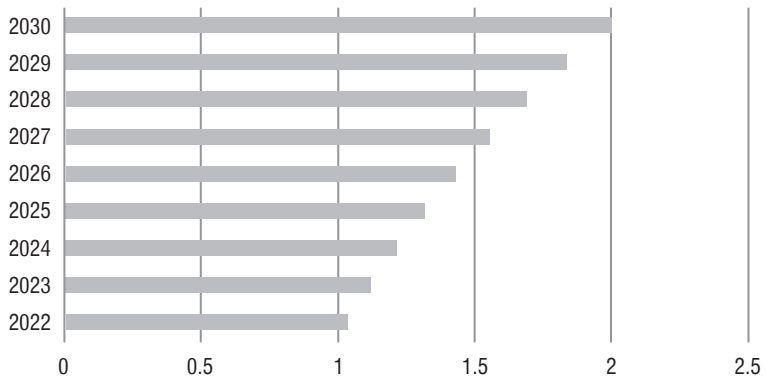
The volatility and intermittency of renewable energy sources leads to a mismatch between demand and supply. Hydrogen as energy storage helps optimize the use of surplus renewable energy during off-peak hours. Green hydrogen is produced by splitting water molecules into hydrogen and oxygen using renewable generated electricity. The electricity used for the electrolysis process is derived from renewable sources like solar, wind, and hydroelectric power. Using abundant and low-cost renewable energy, electrolysis produces hydrogen with minimal carbon emissions.

There is a clear link between the renewable energy market and the green hydrogen market. The growing size of the renewable energy market, declining costs of production, and improved efficiency are driving the growth of the green hydrogen market. In 2022 the global renewable energy market size was valued at $ 1,030.95 billion, and is projected to reach over $ 1,998.03 billion by 2030, growing at a CAGR of 8.6% from 2022 to 2030 (Figure 1).

Over the past decade, the use of clean renewable energy has surged in response to climate policies. Between 2000 and 2020, renewable power generation capacity worldwide increased 3.7-fold, from 754 gigawatts (GW) to 2,799 GW [IRENA, 2021, p. 21]. Yet, above all, the growth in the renewable energy market has been driven mainly by the falling cost of renewable

energy technologies. For instance, the cost of electricity from utility photovoltaics (PV) fell by 85% between 2010 and 2020 [IRENA, 2021, p. 26]. These costs have fallen sharply thanks to ever-improving technologies, competitive supply chains, economies of scale, improving developer experience, and favourable policies. As Gielen et al. [2019, p. 47] state in their article: "Rapid innovation is taking place that facilitates the ongoing transition through falling costs of renewable technologies and also enabling technologies such as batteries. Along with the new policy imperatives, innovation strengthens the momentum of energy transition… The progress for solar and wind technology is a prime example that the future can be steered in a certain direction through technology policy".

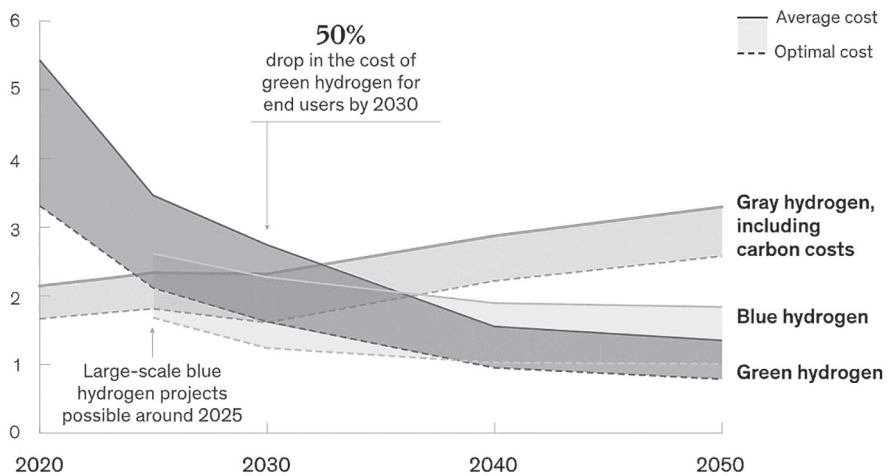
Figure 1. Renewable energy market size, 2022–2030 (USD billion)



Source: own elaboration based on Renewable Energy Market [2023].

As the cost of renewable electricity falls and electrolyzer production scales, the global cost of producing green hydrogen is also predicted to fall by roughly 50 percent by 2030 (Figure 2).

Figure 2. Projected global production cost of hydrogen, $/kilogram

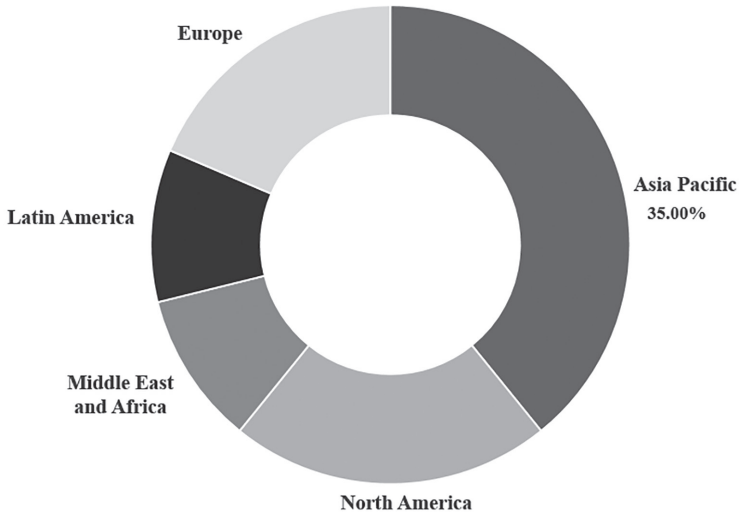


Source: own elaboration based on Pee et al. [2022, p. 4].

Currently, hydrogen produced from natural gas (grey hydrogen) is the cheapest, costing around $2 per kilogram. In contrast, hydrogen produced by electrolysis (green hydrogen) costs about $3.5 to $5.5 per kilogram. By 2030, green hydrogen will reach a cost range of $1.5 to $3 per kilogram, bringing it closer to being competitive with blue and grey hydrogen.

There are two criteria for dividing the renewable energy market: the end-user and the region. If we look at the *end user*, the global renewable energy market was dominated by the residential segment in 2021. The industrial segment was second, and the commercial segment was third [Precedence Research, 2023]. Whereas in the Middle East and Africa, the industrial segment accounted for the highest market share [BlueWeave Consulting, 2023]. In terms of the *region* as a criterion of division, Asia Pacific was the largest and fastest growing renewable energy market with a market share of more than 35% in 2021. Globally, more than half of renewable energy is consumed in this region (Figure 3).

Figure 3. Renewable energy market share, by region, 2021 (%)



Source: Renewable Energy Market [2023].

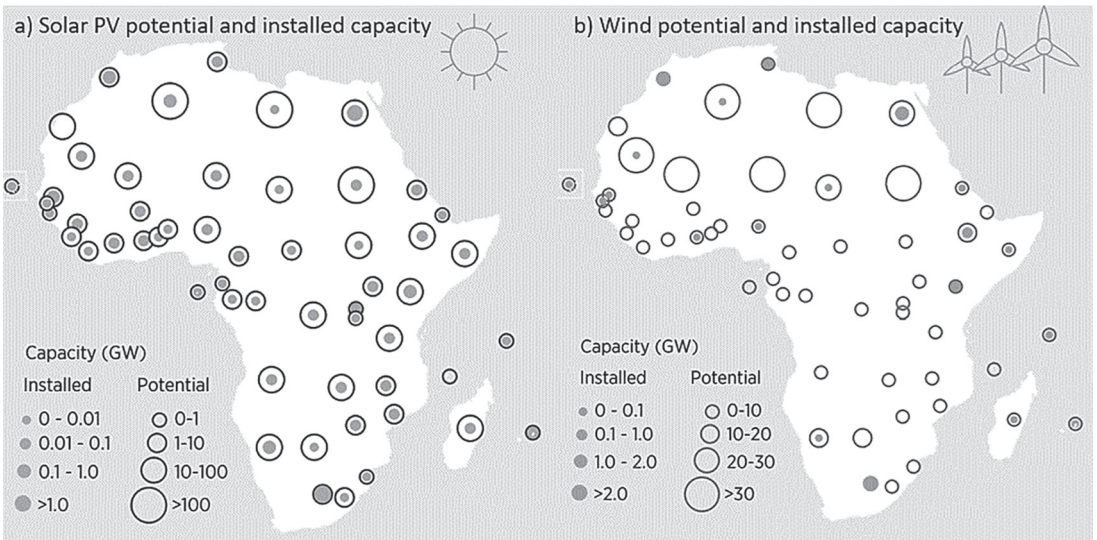
For the first time, renewable energy is growing faster in developing countries than in developed countries. In the Global South we can observe accelerated large-scale deployment of solar and wind energy [Swilling et al., 2022, pp. 1, 10]. Within the Asia Pacific region, emerging economies such as India and China are observing rapid growth in the renewable energy market, due to the increasing industrialization and urbanization. China has been leading in renewable energy production figures for years and is the key producer of the wind energy, hydropower, and solar photovoltaic. China accounts for 696 gigawatts of renewable energy, while India accounts for nearly 118 gigawatts [Expert Market Research, 2023]. For India, solar and wind energy also dominated generation capacity growth. Together, solar and wind added 15.7 GW of new generating capacity in 2022, 17% more than in 2021 [Ember-climate, 2023]. In general, China and India account for three-fourths of the region's renewable energy capacity [Expert

Market Research, 2023]. As for the Middle East and Africa regions, Saudi Arabia is expected to grow at the fastest rate, followed by the UAE, Qatar, Kuwait, South Africa, Nigeria, and Algeria between 2023 and 2029 [BlueWeave Consulting, 2023].

Africa's renewable energy potential for green hydrogen production

The African continent is rich in renewable energy sources. Countries in the north and south of the continent are particularly well suited for the production of hydrogen, both from the sun and the wind (Figure 4). However, many of these sources remain heavily underutilized. There are many remote or stranded locations across the continent with very high renewable endowments that could be used for large-scale renewable energy deployment.

Figure 4. Solar (a) and wind (b) power potential in Africa



Source: IRENA [2022, pp. 42, 44].

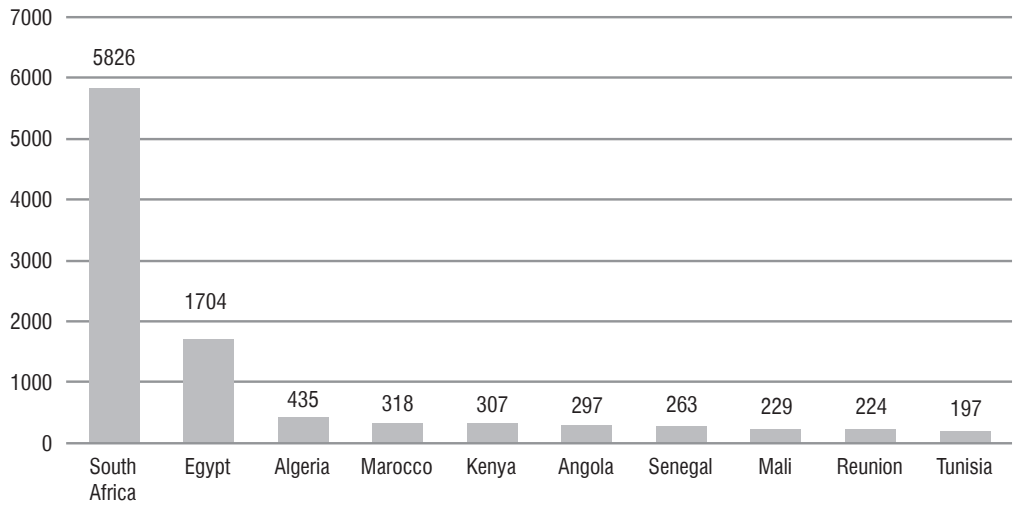
Although Africa represents 40% of the world's total solar potential, only 1% of the world's panels are located there. In 2019 less than 2% of Africa's electricity was generated by solar technologies. Five of ten countries in the world with the highest capacity to generate energy per solar panel are located in Africa: Namibia (1st), Egypt (4th), Lesotho (8th), Libya (9th), Botswana (10th). The Sahara Desert is one of the world's most promising places for solar power generation. In Namibia, one-fifth of electricity (19.1%) is generated by solar power (the fourth highest share in the world). Morocco is also home to the world's largest concentrated solar power plant: the Noor-Ouarzazate Solax Coplex [MIF, 2022]. In addition, the Desert to Power (DtP) initiative will add up to 10,000 MW of grid-connected solar power generation capacity

in the Sahel region. This will not only make the Sahel the world's largest solar production zone, but also bring electricity to 250 million people. Eleven countries are beneficiaries of the initiative: Burkina Faso, Chad, Mali, Ethiopia, Eritrea, Djibouti, Mali, Mauritania, Niger, Nigeria, Senegal, and Sudan [AfDB, 2021].

Coastal and mountainous areas in the north and south of the continent are the best locations for wind farms. In particular, North Africa, the Sahel region, the Horn of Africa and the west coast of Africa are the most suitable areas for the development of wind power. The Seychelles are already among the top ten countries in the world with the highest offshore wind capacity per capita. The AfDB estimates that in the Sahel region, the full mobilisation of the technical capacity of wind power would increase the electricity supply in Chad, Mauritania, Niger, and Mali by more than 30 times. Senegal is also an ideal hub for wind energy due to its strategic location on the Atlantic coast and the prevalence of the harmattan wind [MIF, 2022].

As stated by McKinsey & Company, at present hydropower is the largest source of renewable electricity in Africa and represents 45 GW of capacity on the continent (mainly across Subsaharan Africa). However, installed capacity is expected to grow only 4 times by 2050 [Augier et al., 2023, p. 7]. Currently, the largest hydropower producers in Africa are Ethiopia, Angola, South Africa, Egypt, the DRC, Zambia, Mozambique, Nigeria, the Sudan, Morocco, and Ghana [IRENA, 2022]. Compared to hydropower, solar and wind power have much greater growth prospects. Wind power potential is currently 12 gigawatts (GW), and is predicted to grow 35 times by 2050. In comparison, solar power capacity currently stands at 15 GW and is on track to grow 100-fold by 2050 [Augier et al., 2023, p. 7]. South Africa (5.8 GW), Egypt (1.7 GW), and Algeria (0.4 GW) account for the largest share, as shown in Figure 5.

Figure 5. African nations by installed solar capacity in MW, 2022



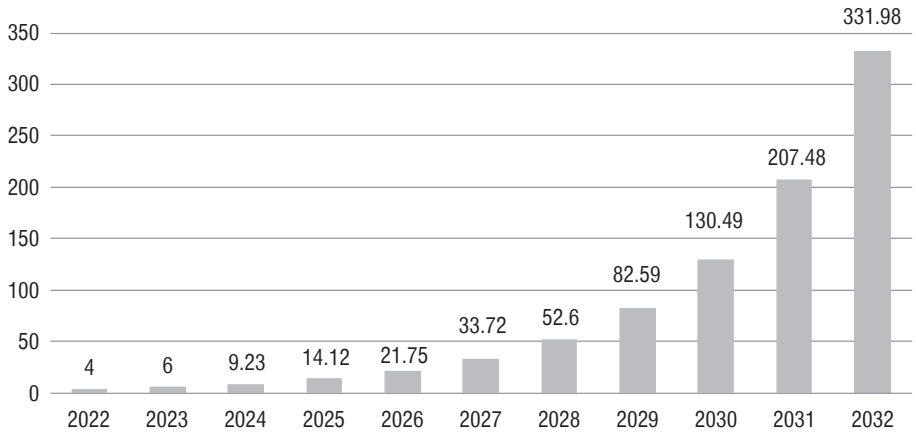
Source: own elaboration based on Intersolar Europe [2023, p. 10].

The country with the largest cumulative PV capacity on the continent is South Africa. PV installations in the country reached almost 6 GW in 2022. South Africa's Integrated Resource Plan (IRP) sets an ambitious target of installing 17,800 MW of renewable energy by 2030, including 8 288 MW from solar PV and 600 MW from CSP. In Egypt, installed photovoltaic capacity reached more than 1.7 GW in 2022, thanks mainly to the Benban Solar Park. Nevertheless, Algeria is considered to have one of the highest solar irradiance levels in the world, as 75% of its territory is covered by the Sahara Desert. The total PV capacity in Algeria amounted to 435 MW in 2022 [Intersolar Europe, 2023].

Green hydrogen market in the world and in Africa

The global green hydrogen market size was estimated at $ 4.02 billion in 2022. It is projected to reach $ 331.98 billion by 2032 (Figure 6). From 2023 to 2032, the market is likely to witness a compound growth at a CAGR of 54.98% [Precedence Research, 2023].

Figure 6. Green hydrogen market size, 2022–2032 (USD billion)

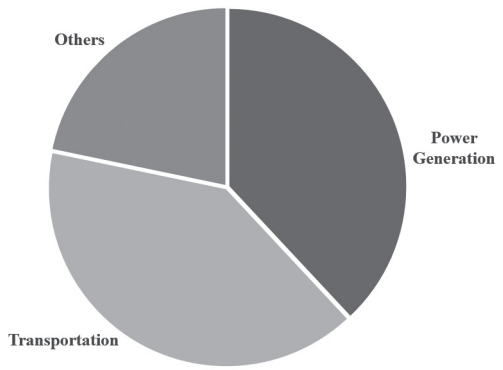


Source: Green Hydrogen Market [2023].

According to a report published jointly by Masdar and Abu Dhabi Sustainability Week, Africa would account for around 5 to 10 per cent of global demand for green hydrogen by 2050. By that year, 30 to 60 million tonnes per annum (mtpa) of green hydrogen will be produced using abundant solar and wind resources, and 20 to 40 million tonnes of green hydrogen will be exported as pure hydrogen, ammonia, and synthetic fuel (the rest will be used for domestic purposes) [ADSW, Masdar, 2022]. European Investment Bank calculates that by 2035, more than 50 million tonnes of low-cost green hydrogen produced annually by solar power will be enough to meet local demand, develop African national economies, support local communities and export to major international off-takers [EIB, 2022].

Hydrogen has many promising applications in the industrial, energy, transportation, and construction sectors [Komorowski, 2016, pp. 193–204]. Based on the end-use industry, the green hydrogen market is divided into 3 segments: mobility, power generation, and others, as shown in Figure 7.

Figure 7. Global green hydrogen market share, by application, 2021 (%)



Source: Report Overview [2023].

Globally, by application, the transport segment accounted for the largest revenue share of over 41.5% in 2022 [Precedence Research, 2023]. Here, hydrogen is useful as a fuel due to its high energy density, especially in those sectors where electrification is difficult (maritime, air, truck, and rail transport). In shipping and aviation in particular, the availability of low-carbon fuel solutions is limited, so hydrogen is an attractive option here. The second *power generation* segment is likely to grow with the second highest CAGR in both value and volume and, consequently, can become the most lucrative segment. The expansion of power generation is expected to boost demand for green hydrogen, spurring growth in the global market. Another application of green hydrogen includes the household sector, in which green hydrogen can be used to replace the natural gas grid with a green hydrogen network to provide electricity and heat to households. In 2022, approximately 600 million people (40 percent of its population) in Africa lacked access to electricity. Green ammonia generators would help provide energy for lighting and cooking in homes [Hydrogen Europe, 2022].

There are many other ways to segment the green hydrogen market, for example by distribution channel or technology. When it comes to the *distribution channel*, the pipeline segment has accounted for 62.4% revenue share in 2022 [Precedence Research, 2023]. Pipelines are currently the most economically viable method for transporting large quantities of hydrogen over long distances. For example, by supplying Europe via existing or new pipelines, North Africa is able to export 12–30 Mt of hydrogen equivalent [GH2, 2022].

If we take *technology* into account, globally, the alkaline electrolyzer held the largest green hydrogen market share. This is due to its high time efficiency and low cost compared to the PEM electrolyzer. In general, the alkaline electrolyzer has generated revenue share of more than

66.8% [Grand View Research, 2023]. As for the PEM electrolyzer, the segment is growing at a higher CAGR over the forecast period [Precedence Research, 2023]. Rystad Energy Africa's estimates that the total announced electrolyser pipeline capacity in Africa has reached 114 GW, spread across 52 projects. East, South, West, and Central Africa account for more than 60% of the announced capacity of green hydrogen pipelines on the continent [Prime Progress, 2023].

Out of 25 announced pipeline projects in Africa, 21 are being developed by Egypt. With a unique geographic location at a crossroads of Africa, Europe, and Asia and control of the Suez Canal, Egypt is positioned to become a leader in green hydrogen production in Africa. A number of European companies (e.g. Equinor, Siemens, Maersk, Eni) are already involved in green hydrogen export initiatives around the Suez Canal Economic Zone [Prime Progress,2023]. Apart from Egypt, major green hydrogen projects are also underway in South Africa, Algeria, Namibia, and Morocco (Figure 8).

Figure 8. Distribution of energy segments around Africa by green hydrogen

Source: Augier et al. [2023, p. 7].

South Africa aims to produce 500,000 tonnes of green hydrogen per year by 2030 and install 10 GW of electrolysis capacity in the Northern Cape region by 2030 and 15 GW by 2040. South Africa is expected to produce green hydrogen at a cost of $ 1.60 per kilogram by 2030, which is one of the lowest costs in the world. Similarly, Namibia's abundant solar and wind energy resources offer low-cost green hydrogen production. Namibia's hydrogen strategy aims to make the country a leading exporter of green hydrogen and unlock its potential to meet the global demand of 10 million tonnes by 2030 [GH2, 2023]. In 2023, Namibia and the EU signed a strategic partnership on renewable hydrogen, with the aim of putting those countries at the forefront of clean energy innovation [European Commission, 2023].

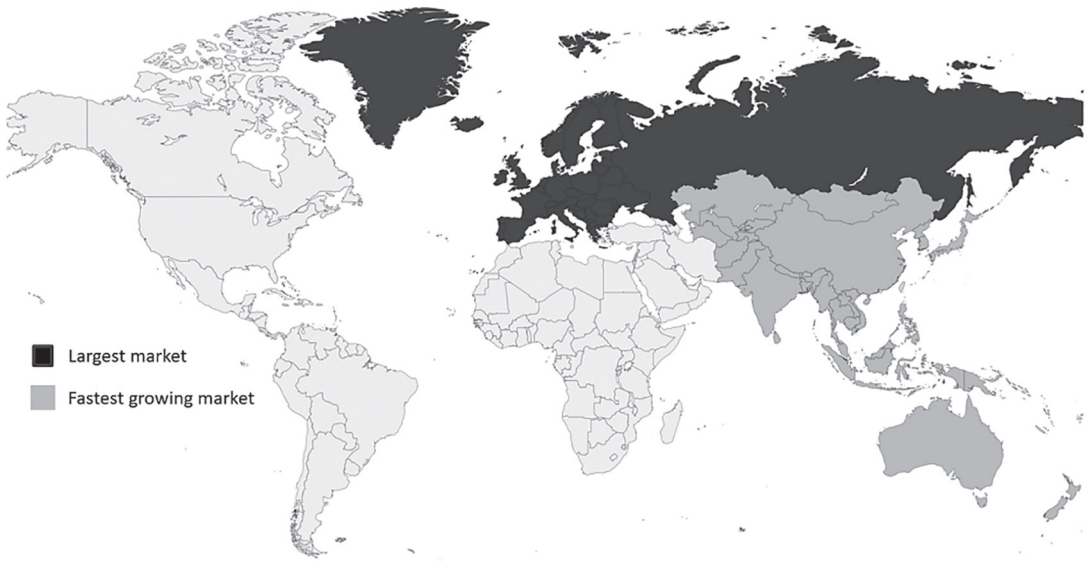
Morocco has also an exceptional wind and solar energy resources. Morocco's national green hydrogen strategy commits to 78 GW of electrolysis capacity by 2050 [GH2, 2022]. French

energy company Eren Group launched a $ 10.6 billion green-hydrogen and green-ammonia production plant in Morocco's southern region Guelmim-Oued Nour [Augier et al. 2023, p. 8].

Importers and exporters of green hydrogen

The global green hydrogen market is dominated by Europe. The region accounted for a significant revenue share of more than 50% in 2021 (Figure 9). This is due to the massive investments made by European economies that are pursuing an energy transition to a clean hydrogen economy. Moreover, governments in European countries are offering subsidies to the business sector to promote sustainability and environmental protection. Some key players operating in the European green hydrogen market include Siemens Energy AG (Germany), Air Liquide S.A. (France), Nel ASA (Norway), and Linde plc (Ireland).

Figure 9. Green hydrogen market share by region



Source: Report Overview [2023].

One of the leaders in the green hydrogen market is Germany. This country has a higher share of green hydrogen installation around the world due to the presence of supportive policies, regulations, and funds for green hydrogen in the country. The value chains for both green hydrogen and ammonia are the heart of Germany's National Hydrogen Strategy. In 2019, the German government approved 11 green hydrogen projects for demonstration scale in the country [Grand View Research, 2023]. Germany has also declared to fulfil all its electricity needs with supplies from renewable sources by 2035 [Gordon, Tatarenko, 2023].

Although Europe is the largest segment for green hydrogen market in terms of region, Asia Pacific hit the highest CAGR in the global green hydrogen market. Therefore, Asia Pacific

is the fastest growing region in the green hydrogen market. China, Australia, and Japan, in particular, account for the largest share of regional growth. However, with a 20-million-ton output, China leads the global green hydrogen market, accounting for one third of global production [Precedence Research, 2023]. North America is also expected to achieve a significant CAGR, with the United States and Canada gradually strengthening the green hydrogen industry through the implementation of clean energy policies. The US is one of the earliest adopters of clean energy solutions in the world, especially in the energy and transportation sectors. As in the case of Germany, this is due to the increased importance given to clean energy solutions under The Energy Policy Act (EPAct) introduced by the U.S. government. "The Roadmap to a U.S. Hydrogen Economy report forecasts that hydrogen from low-carbon sources will supply roughly 14 percent of the country's energy needs by 2050, including hard-to-electrify sectors now dependent on natural gas such as high-heat industrial processes and manufacturing fertilizer" [Grand View Research, 2023].

The quality and cost of producing hydrogen from renewable sources vary considerably from region to region. Hydrogen exports are mainly aimed at countries with high potential for renewable energy sources, i.e. Australia, Chile, North Africa, Uruguay, Morocco, Canada, and Portugal. They offer attractive conditions for low-cost hydrogen production, such as high solar irradiance, high wind speeds, and available land area. On the other hand, hydrogen imports are particularly important for densely populated and developed countries that cannot meet their energy transition goals with domestic hydrogen production. This is due to insufficient renewable resources in these regions. Germany, Japan, South Korea, the Netherlands, and Belgium are among the largest future importers. Only a few regions of the world (including China and the United States) have favourable conditions to become major centres of both hydrogen demand and supply, with sufficient renewable energy sources to meet their own green hydrogen needs in a cost-effective manner [GH2, 2022].

A critical factor that will determine the viability of hydrogen trade will be whether the scale, technologies, and other improvements can offset the costs of transporting hydrogen from areas with low production costs to areas with high demand. Thus, for trade to be profitable, the cost of producing green hydrogen must be sufficiently lower in the export region than in the import region. Table 1 presents the official agreements of selected countries on international green hydrogen trade.

Many of the green hydrogen exporters to developed countries are economies in North and South West Africa (e.g. Morocco, Namibia, South Africa). These partnerships present a major opportunity for those countries as they create local value chains and local demand, as well as contribute to improving exporting countries' trade balances and technology transfer [OECD, 2022, p. 26]. For example, the European Union is considered to be one of Africa's most important partners in the green hydrogen market. The European Union's Strategy for Africa identifies Africa, with its renewable potential and proximity to the EU, as an ideal partner to support the European Union's energy transformation through the supply of green hydrogen. According to the strategy, North Africa is to be the main supplier of this gas to the EU by 2030

[European Commission, 2020]. Germany, for instance, is setting up strategic partnerships with several African nations, including South Africa, Angola, Morocco, Namibia, and Nigeria, to increase their potential to produce and export green hydrogen [Adow et al., 2022, p. 2].

Table 1. Examples of bilateral green hydrogen trade agreements

Prospective importer	Belgium	Germany	Japan	Netherlands	Republic of Korea	Belgium
Prospective exporter	Namibia	Namibia	UAE	Namibia	Australia	Namibia
	Chile	Chile	Brunei	Chile	Saudi Arabia	Chile
	Oman	Denmark	Australia	South Africa		Oman
		Russia	Saudi Arabia	Canada		
		Tunisia		Uruguay		
		DRC		Oman		
		Australia		Morocco		
				Iceland		
				Portugal		
				Australia		

Source: own elaboration based on IRENA [2022, p. 77].

Opportunities and risks of the development of the green hydrogen market in Africa

Falling costs of renewable technologies worldwide are affecting the cost of green hydrogen. The biggest decline has been in solar energy: solar power prices have dropped by over 89% in the last 10 years [*How Does Solar Energy*…, 2023]. This is due to advances in technology and production, raw material costs, and higher product efficiency. This is a huge opportunity for Africa, as solar power capacity on the continent is expected to increase 100 times by 2050 [Augier et al., 2023, p. 7]. Another factor affecting the final cost of green hydrogen is the reduction in the cost of electrolyzers. Indeed, the cost of electrolyzers dropped to nearly half its value five years ago [Green hydrogen market by technology, 2023], and the decline is predicted to continue in the current decade. The main driver of the drop in the cost of electrolyzers are the investment put into research and development of the technology to make it more efficient.

With Africa being positioned as a future global exporter of green hydrogen, this sector appears to become a major contributor to the continent's gross domestic product. Proceeds from the export of green hydrogen could fund Africa's needs for infrastructure, education, and healthcare. The hydrogen economy also strengthens local economic actors and builds new skills among the local community through the transfer of technological knowledge. As Abu Dhabi Sustainability Week and Masdar state in their report, Africa will meet 10% of the world's demand for green hydrogen by 2050. Investments in green hydrogen production will

range from £680 billion to £1,300 billion and create 1.9 to 3.7 million jobs. Overall, the total impact on GDP in 2050 would be in the range of $ 60 to $ 120 billion [ADSW, Masdar, 2022].

National strategies and global partnerships are key elements that accelerate the development of the green hydrogen market. In Africa five countries have already published their national hydrogen strategies (South Africa, Morocco, Algeria, Egypt, and Namibia) and 18 more African countries are now developing one [UN, 2023]. In November 2022 at COP27, South Africa also launched its Just Energy Transition Investment Plan, pledged by the EU, the UK, and the US. Green hydrogen is one of the tree priority areas of the Just Energy Transition Investment Plan [JET IP, 2022]. Africa also has many opportunities for the development of strategic and long-term partnerships in the form of regional economic associations, such as the Africa Green Hydrogen Alliance. The AGHA was established to strengthen joint initiatives and advance green hydrogen development among its members: Egypt, Kenya, Mauritania, Morocco, Namibia, and South Africa. The AGHA's green hydrogen market is estimated to reach 22% of the expected international cross-border hydrogen trade by 2050. Approximately two-thirds of the AGHA's market potential will be for export. However, this new market will also require massive investment of $ 450 billion to $ 900 billion by 2050. Renewable energy capacity would range from 510 to 975 GW, and that of electrolyzers from 290 to 560 GW. Overall, by 2050, the AGHA's green hydrogen ambitions would create about 4.2 million jobs and add between $ 66 billion to $ 126 billion to the current GDP of AGHA member countries [GH2, 2022].

The green hydrogen market is also the place where many challenges await governments, companies, and investors alike. The major challenge is that the green hydrogen market is still widely underdeveloped. Demand for green hydrogen is currently limited to developed countries that have committed to a net-zero emissions target by 2050, such as Sweden, the UK, France, Denmark, New Zealand, and Hungary. There is a considerable risk, particularly for poorer Sub-Saharan countries, that green hydrogen will be produced mainly for export to countries in the Global North, without meeting local demand for green hydrogen and renewable energy. This scenario would worsen injustice and energy poverty in African countries. Without transparent rules and regulations for hydrogen production, and with weak institutions, corruption, and exclusion of local stakeholders, most of the benefits in the value chain of green hydrogen production might remain in the Global North.

The second factor is that electrolysis currently requires clean, pure water. It should be noted that the regions with abundant renewable energy sources and space for green hydrogen plants are also areas where 'water stress' is a growing problem. In 2020, approximately 187 million people in Sub-Saharan Africa did not have access to basic drinking water [World Bank, 2023]. Water availability in African countries will become even more scarce due to climate change. Unless energy and water policies are better integrated, it is likely that demand for green hydrogen will compete with the water sector. This in turn could exacerbate poverty and conflicts over water resources in these countries. The development of new technologies, such as additional desalination plants in the vicinity of electrolysis plants, may prove helpful.

Another reason for the underdeveloped hydrogen market are the high initial investment costs required to set up hydrogen infrastructure. To build a hydrogen economy in Africa, most countries have to invest in the new hydrogen and renewable energy infrastructure, the production of electrolyzers and distribution channels to transport the gas (pipelines). The cost of such investment will be very difficult for African countries to bear. Therefore, it is necessary to improve access to low-cost financing at the national and private level.

Summary

African countries are the most vulnerable to loss and damage from climate change. However, the energy transition brings some opportunities for these countries as well. The results showed that green hydrogen has a potential to play a key role in achieving an orderly transition to a green and low-carbon economy, while contributing to energy demand and economic growth in African countries. The article draws the following conclusions on the opportunities for development of green hydrogen market in conditions of climate change:

- Africa is rich in renewable energy sources and has the potential to produce large amounts of efficient electricity at low cost. Therefore, it is a suitable place to produce green hydrogen, which can then be exported to other regions with scarce renewable energy resources.
- The falling costs of RES (wind and solar power) and electrolysis technologies are one of the key factors in Africa's successful energy transition. Therefore, policies that encourage companies to implement innovations and contribute to reducing the costs of energy technologies play an important role in the energy transition.
- The countries with the greatest potential to produce and export green hydrogen are mainly those located in the north and south of the continent: South Africa, Egypt, Morocco, and Namibia. These are all the Africa Green Hydrogen Alliance members. These countries should take advantage of these export opportunities as well as the domestic benefits that green hydrogen might bring. It will help promote economic growth and meet global targets for CO_2 reduction in Africa.
- Some of the significant future importers of green hydrogen from Africa are Germany, the Netherlands, Belgium, Russia, Japan, and South Korea. Only China and the US are able to meet their hydrogen demand with domestic production.
- National hydrogen strategies, a stable legal system, international partnerships, investment in R&D, and policies that support the partnerships with other countries (AGHA) have a significant impact on green hydrogen market development.

African countries have a huge opportunity to become clean energy exporters thanks to the abundance of solar and wind power, but other factors play an equally important role in the development of the green hydrogen market. The paper distinguishes 3 main threats related to climate change for economic development of the green hydrogen market in Africa:

- The green hydrogen economy would threaten water security in African countries.
- Achieving the energy transition takes huge amounts of investment in improving or building new critical infrastructure, such as pipelines.
- The highest-income countries in the Global North (EU, US) will mainly benefit from investment in newly built renewable capacity in Africa, if domestic policy does not give priority to local use. This requires building strong and incorruptible institutions.

The assessment of opportunities and risks clearly shows that each possible benefit of a green hydrogen production can turn into a major risk if comprehensive policies and strict social and environmental safeguards do not guide its implementation.

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