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D1.2 "Assessment of African Green H2 SotA context"

WP1 "Scenario definition also thanks to stakeholders' elicitation and valorisation of existing policies"

WP leader: UNIGE

T1.1 "Assessment of Existing African Hydrogen Strategies and Roadmaps to identify project outcomes thanks to local stakeholders elicitation"
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0.1	09-10-2023	UNIGE	Table of Content and template
0.2	October to December 2023	UNIGE, NWU, JULICH, STRATH, AHP, TEKI, IRESEN	Preparation of different inputs along the report sections
0.3	26-01-2024	UNIGE	Integration of all inputs in a final draft
0.4	02-02-2024	IRESEN	Final draft ready for submission
0.5	11-03-2024	UNIGE	Final submission including inputs from Nairobi events and other most recent updates
1	15-03-2024	UNIGE	Submission

Partners

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EXECUTIVE SUMMARY

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Clean Hydrogen Partnership

This document is the Deliverable “D1.2 Assessment of African Green H2 SotA context”, developed within WP1 of the JUST GREEN-AFRH2ICA project.

The document provides a quite detailed overview of the Green Hydrogen potential in the African continent according to:

- An analysis of the green hydrogen potential of the continent via a multi-aspects assessment realized by UNIGE in accordance with available literature, datasets etc with the current and future (2040) time horizon (Chapter 2)
- Complementing D1.1 results (where policies of EU-AU countries were deeply analysed) an analysis of the currently on-going projects in Africa country and a helicopter view of most relevant African green hydrogen initiatives currently on going is presented in Chapter 3 by AHP/TEKI
- In Chapter 4, a deep assessment (also via SWOT analysis and assessment of local driver and barriers) of green hydrogen potential and on-going activities in the four African continental sub-zones are presented by project “local area responsibles” namely IRESEN (North Africa), STRATH (Central – Eastern Africa), JULICH (West Africa), NWU (South Africa). These analyses are presented in a detailed way often with “country per country” assessments.

The overall report contents will be wrapped up in Conclusions chapter: the outcomes of this deliverable (together with D1.3 ones) will be the guidelines for WP2 and WP3 project activities.

1. INTRODUCTION

Due to its great RES potential (large open arid spaces along windy coastlines) many regions in Africa offer a great potential for producing low-cost, price competitive green electricity with a minimal impact on bio habitat and biodiversity. Many African countries, when water is also available could leapfrog to the new age of hydrogen technologies. Developing hydrogen economies in Africa would have indeed an impact on import/export African economy: reducing the economic burden of importing costly refined fossil fuels, also making African energy intensive industries (e.g. fertilizer, chemicals, mining) more attracting and generating revenue streams from exporting green H2, while creating employment, skills, and wealth domestically as well as opportunity for African Countries to meet their own decarbonization goals. Thanks to a low-RES energy cost, African hydrogen produced by electrolysis could be both, “renewable” or “low carbon” and competitive with Diesel and Petrol withing 2030. As such it could materially assist the World to decarbonize. African low carbon hydrogen could also become a major enabler of EU hydrogen accelerator recently mentioned in “RePowerEU” program, which is foreseeing 10 Mt/yr of hydrogen import, by EU.

To do so, it’s important that European and African hydrogen plans will dialogue, and this is one of the missions of JUST GREEN AFRH2ICA project.

In order to form the strongest possible international alliance for utilizing Africa’s hydrogen potential and creating markets and green wealth in Africa, EU and AU hydrogen stakeholders must indeed work together facilitate the collaboration between governments, industry, technology and financial institutions and large end consumers of hydrogen across continents. JUST GREEN AFRH2ICA aims therefore to create awareness and to make compelling propositions at 360° (technological – financing – regulatory/policy) for the benefit of AU/EU of developing green hydrogen economies.

Since early 2020s (thus before the promotion of “RePoweEU” plan) low carbon hydrogen is one of the central discussion topics between EU and AU as highlighted during the 2022 European Union-African Union summit. Since its 2020 Hydrogen Strategy, EU has made its ambitions to import hydrogen from the African continent clear: in its 2020 Hydrogen Strategy, the European Commission foresaw 40 GW of renewable hydrogen electrolyzers in the EU neighbourhood, a large proportion of which are expected to be in North Africa, by 2030.

Alongside EU plans to import renewable hydrogen from the neighbourhood, member states are setting up bilateral hydrogen initiatives with countries across the African continent. Germany is a frontrunner in this sense, having set up a global hydrogen import scheme and bilateral initiatives with African countries (foreseeing investment and R&D initiatives), including Morocco, Namibia, and South Africa.

EU interest in importing low carbon hydrogen from Africa is driven by the assumption that member states will require significant quantities of renewable hydrogen to decarbonize certain economic sectors (for example, the chemicals industry, steel industry and heavy transport sectors such as maritime and aviation) that exceeds cost-effective domestic potential.

One of the goals of WP1 is therefore to understand (as much as possible from a quantitative point of view) how EU and AU can cooperate and support each other in this sense, understanding how much hydrogen EU could realistically needs and how much hydrogen AU could realistically produce and export.

The present document constitutes the Deliverable D1.2 "Assessment of African Green H_2 SotA context", developed within WP1 of the JUST GREEN-AFRH2ICA project and, together with D1.3, it sets the basis of different in-depth activities to be performed in WP2 and WP3 for modelling and roadmap development.

The report aims to analyse current State of the Art of Low Carbon Hydrogen initiatives in Africa at 360° according to:

- An analysis of the green hydrogen potential of the continent via a multi-aspects assessment realized by UNIGE in accordance with available literature, datasets etc with the current and future (2040) time horizon (Chapter 2)
- Complementing D1.1 results (where policies of EU-AU countries were deeply analysed) an analysis of the currently on-going projects in Africa country and a helicopter view of most relevant African green hydrogen initiatives currently on going is presented in Chapter 3 by AHP/TEKI
- In Chapter 4, a deep assessment (also via SWOT analysis and assessment of local driver and barriers) of green hydrogen potential and on-going activities in the four African continental sub-zones are presented by project "local area responsibles" namely IRESEN (North Africa), STRATH (Central – Eastern Africa), JULICH (West Africa), NWU (South Africa)

The overall report contents will be wrapped up in Conclusions chapter: the outcomes of this deliverable (together with D1.3 ones) will be the guidelines for WP2 and WP3 project activities.

Structure of the Deliverable

To comprehensively cover all the topics previously introduced, the following structure was chosen for the document:

- Section 2 presents a renewable hydrogen potential assessment prepared by UNIGE in accordance with available literature data of African countries renewable production, their energy policies targets (From D1.1) and future hydrogen production. This assessment has been prepared with two-time horizons (current and 2040) also to make a first assessment of the state of the art of renewable hydrogen production potential.

- Section 3 describes ongoing commercial and implementation market initiatives starting from AHP database of on-going African electrolysis installation projects and potential low carbon hydrogen/derivatives export activities between AU and EU, mainly carried by industrial consortia, for hydrogen production and usage/export.
- Section 4 presents an analysis (coming from T1.1 sub-tasks outcomes) of Northern (IRESEN), Western (JULICH), Central-Eastern (STRATH), Southern (NWU) Africa areas low carbon hydrogen potential via SWOT/PESTLE analysis tools and presenting local drivers/barriers/opportunities to facilitate local green hydrogen projects promotion.
- Section 5 presents deliverable's conclusions and next steps.

Relation to Other Tasks and Deliverables

This Deliverable D1.2 is based on Task 1.1 and Task 1.3, and it provides relevant inputs to T1.4, towards the final goal of WP1: setup the scene for WP2 and WP3 modelling and road mapping activities.

The goal of T1.1 is indeed to set the basis of the overall project: to do so the state of the art of existing AU Hydrogen experiences will be assessed from a policy, expertise, technological and previous assessment point of view.

T1.1 activities, already reported in D1.1, have been complemented in this report also integrating T1.3-T1.4 outcomes in order to present a detailed and honest overview of barriers/drivers for low carbon hydrogen project promotion in Africa.

Such assessment will drive next activities in WP2-WP3 and the focus on specific use cases as presented in D1.3.

2. AFRICAN LOW CARBON HYDROGEN POTENTIAL ASSESSMENT

In the framework of Work Package 1 of JUST GREEN AFRH2ICA and in order to "setup the scene" together with D1.1 activities, UNIGE realized the following study aiming to identify which could be, via a multi-sector assessment, the most relevant countries who could develop their own renewable hydrogen potential looking at current and 2040-time horizon. Starting from available literature and databases (Chapter 2.1), the study developed a countries scoring and ranking method (Chapter 2.2) that enabled to identify most strategic countries where to develop renewable hydrogen projects, particularly looking at local renewable energy, infrastructural, socio-economic and commercial potential. This approach has been implemented to assess green hydrogen potential in 2023 and 2040 (Chapter 2.3) also comparing the results collected by AHP related to most relevant and strategic African countries as presented in D1.1 (Chapter 2.4 – 2.5).

2.1 Data Collection

In this chapter all the data collected by UNIGE team for the analysis and used for the final scoring and ranking methodology used in the study are presented and described, as well as the ranking related to each type of category data.
It is important to highlight that several countries (i.e. Cape Verde, Mauritius, Seychelles, S.T. &Principe, eSwatini, Comoros) have been excluded right from the beginning of the data collection, even if they were ranked particularly high on socio-economic parameters, due to their very small geographical extension, as well as their limited hydrogen market relevance. It is relevant to specify that all the data and rankings discussed in this chapter, exception for the "Energy Data" section and "LNG terminals", have been considered valid for both the periods of analysis (2023 and 2040).

Analysed data can be categorized via four macro-categories:

- Energy data (mostly related to renewable energy production, local energy demand, local energy inter-exchange with surrounding countries, access to electricity…)
- Socio-economic
- Energy Infrastructure
- Civil and transport Infrastructure

Differently from some already released studies and available literature which focus mainly on evaluating the renewable hydrogen potential assessing the potential renewable energy available in the African continent, e.g. wind and solar maps, (thus confirming the significant role of this area of the world for what concerns the future transition to green hydrogen), in this analysis green hydrogen production has been calculated starting from current and forecast future energy data collection (meaning energy demand at country level, renewable production at country level etc.).

Furthermore, as socio-economic aspects as well as, civil, energy and transport infrastructure relevance could determine the possibility to unlock Africa renewable potential, or set new pathways for Africa and Europe growth through targeted policies and investments, these aspects have been analysed in this study. This data gives a deeper analysis of the topic, however some further expansions of this study may regard in the future the following topics, which have not been considered:

- Water availability
- Soil consumption
- Hydrogen local demand
- Quantified energy transfer between countries

In particular, data about water availability have still not been collected or are still uncertain, as well data about local hydrogen demand, (mostly depending on local industries' production processes) and about quantified electrical energy exchange and trade within cross border countries in common power pools.

2.1.1 Energy Data

To estimate the potential green hydrogen production both in 2023 and 2040, a deep research about energy data was needed, including the Total Capacity Installed in every country with the relative Renewable Share, the Total Electricity Production and the relative Renewable Share, the Operative Equivalent Hours, highly depending on the main source of power on which every country relies on. Moreover, to have an estimated value of the Net Energy Surplus of every country, data about electricity consumption were needed.

The data about the current energy production were collected directly from the IRENA Energy Profiles, available on the official website; these profiles provide, other than several key indicators such as GDP per capita or Access to electricity, a state-of-the-art overview about the Electricity Capacity, including Installed Capacity [GW] with the relative Renewable Share, as well as Electricity Generation [GWh], with specific information about the main power sources.

The Electricity Capacity multiplied by the relative renewable share gives the Renewable Capacity currently installed; as shown in the latter §2.4, these data have been ranked to classify the countries relatively to their energy related values, since they are strictly correlated to the hydrogen production assessment.

It is important to underline that in this analysis any renewable energy potential estimation (theoretical, according to wind/solar atlas) has been considered, but countries' renewable energy assessment has been realized mostly looking at nowadays and future (according to clean energy policies declared by the different countries) renewable energy production.

2.1.1.1 Access to electricity

Across the whole African continent, access to electricity represents still an important barrier to economic growth, as this parameter affects human activities, such as education, communication, health, nutrition, trade, transport, tourism, and women's empowerment. For instance, Sub-Saharan Africa electrification rate at 45% is significantly lower compared with other developing regions. Extreme disparities can be found not only between single African nations, but furthermore between urban and rural areas.

A high access to electricity ratio is generally positive for the purpose of this research, since the more the electrical grid of a country is well developed and widespread, the lesser investment in those facilities will be required, as the electrical energy to power hydrogen-related means is already available.

Although, even if low access to electricity signifies low and bad maintained energy infrastructure, it could represent an opportunity for those countries to develop green hydrogen economy in order to provide electrical energy through mini-grids to isolated and rural areas where people are not connected to the main grid and rely mainly on diesel generators.

As presented by some R&D studies, mini-grids are expected to be the least cost option to electrify more than half a billion people living predominantly in isolated communities in sub-Saharan Africa, however ,Power-to-hydrogen-to-power technology is still at its early stages and might be hardly competitive in areas where low-cost diesel is available.

For these reasons, two specific parameters were considered by consulting IRENA's available data: Total Access to Electricity (%) and Rural Access to Electricity (%), which have been ranked both from higher to lower and lower to higher.

Tab. 1 – Total Access to Electricity (Min to Max)

RANK	COUNTRY	ACCESS TO ELECTRICITY 2020 (TOTAL – MIN TO MAX)
1	CENTRAL AFRICAN REP.	5%
2	SOUTH SUDAN	7%
3	CHAD	8%
4	D.R. CONGO	9%
5	BURUNDI	10%
6	MALAWI	11%
7	NIGER	14%
8	BURKINA FASO	21%
9	SIERRA LEONE	22%
10	UGANDA	26%

Tab. 2 – Total Access to Electricity (Max to Min)

RANK	COUNTRY	ACCESS TO ELECTRICITY 2020 (TOTAL – MAX TO MIN)
1	ALGERIA	>99%
2	EGYPT	>99%
3	LIBYA	>99%
4	MOROCCO	>99%
5	TUNISIA	>99%
6	SOUTH AFRICA	97%
7	GABON	91%
8	GHANA	85%
9	KENYA	78%
10	IVORY COAST	78%

Tab. 3 – Rural Access to Electricity (Min to Max)

RANK	COUNTRY	ACCESS TO ELECTRICITY 2020 (RURAL – MIN TO MAX)
1	CHAD	<1%
2	D.R. CONGO	<1%
3	BURUNDI	<1%
4	DJIBOUTI	<1%
5	MAURITANIA	<1%
6	BURKINA FASO	<1%
7	SIERRA LEONE	<1%
8	CENTRAL AFRICAN REP.	2%
9	ZAMBIA	2%
10	NIGER	2%

Tab. 4 – Rural Access to Electricity (Max to Min)

RANK	COUNTRY	ACCESS TO ELECTRICITY 2020 (RURAL – MAX TO MIN)
1	EGYPT	>99%
2	LIBYA	>99%
3	MOROCCO	>99%
4	TUNISIA	>99%
5	ALGERIA	97%
6	SOUTH AFRICA	93%
7	GHANA	74%

8	KENYA	69%
9	IVORY COAST	55%
10	RWANDA	51%

2.1.1.2 Shared hydropower plants

Hydropower is the most available renewable energy source in Africa and provides 70% of the total renewable energy production globally. This importance is expected to grow in the next years, as projections indicate that hydro power will remain the most important contributor of low-carbon electricity in 2040.

Moreover, several African countries (e.g. Ethiopia, Congo, Rwanda, Cameroon, Zambia, Zimbabwe) rely totally on hydro power, which constitutes up to 99% of the electricity sources. Also, the vast majority of African power station which are under development or under construction are hydropower dams, including the Grand Ethiopian Renaissance Dam (GERD), which will have a design capacity of more than 6 GW.

An important stage of this research concerned the localization of both operating and developing shared hydropower plants across the African continent. Other than transboundary dams, several countries showed interest in a forecast purchase of the power generated by the largest under-development dams, such as the Grand Renaissance Dam in Ethiopia and the Grand Inga in the Democratic Republic of Congo. At the state-of-the-art, the Kariba Dam represents the most important transboundary power station, sharing 1626 MW between the countries of Zambia and Zimbabwe.

The following hydropower projects in *Tab. 5* are under development or announced to be built and are expected to be operating within 2040.

Tab. 5 – Shared Power Plants (2040)

Hydropower Plant	Design Capacity [MW]	Countries Involved
Rusumo	80	Rwanda, Burundi, Tanzania
Songwe	180	Tanzania, Malawi
Ruzizi III	206	DRC, Rwanda, Burundi
Ruzizi IV	287	DRC, Rwanda, Burundi
Chollet	600	Cameroon, Congo
Baynes	600	Angola, Namibia

Other than the above mentioned, several developing projects have been found where countries are involved in forecast agreements in order to purchase the renewable energy from the producer country. Among those, the most relevant project is the Grand Inga: upon full completion, it would be the biggest hydropower dam in the world and could generate enough power to supply one-third of the current electricity demand in Africa. Its final installed capacity is comparable to the current capacity in Sub-Saharan Africa (excluding South Africa), which is approximately 42 GW. The building of this enormous power transmission facility certainly requires big capital investment and strong international cooperation not only to develop the power station, but also to enhance a power grid that ensures electrical interconnection between countries, covering a very large area that is currently lacking any electrical infrastructure. There is no doubt that a greater grid integration to facilitate trade can serve to unlock considerable volumes of cost-competitive power from renewable energy sources. The website *Africa Electricity Grid Explorer* provides an interactive map in which are showed both operational and programmed electrical grids across the continent; this data highlights a good mutual interconnection in different areas, in particular between South African area and West Africa area. On the other hand, North African countries, despite having the greatest access to electricity rate in the continent, are not connected among themselves, with the grid that interrupts just before the foreign border.

2.1.1.3 Electrical Interconnection

As a part of the whole infrastructure facilities, electrical interconnections and transboundary grids are one of the most important features to create an energy market, linking cities and regions efficiently to the production sites, such as hydropower dams, solar power plants or wind farms. A well interconnected country allows energy export and import from the bordering countries, guarantees higher accesses to electricity and an improved network stability; furthermore, electrical renewable energy could be exported from the countries with higher renewable surplus and converted into green hydrogen in the bordering nearby countries, if necessary. Africa is a continent in which these infrastructure systems are still under development, with large disparities variable region to region. The website Africa Grid Tracker, together with a report released in 2011 by the ICA (Infrastructure Consortium for Africa), provided a complete state-of-the-art overview about the African electrical grid, which interconnections are currently operative and which ones are to be implemented in the next years. As observed, several declared project in the report are now functioning and operative, while other are still under development. Africa is divided in five different Power Pools, acting as specialized agencies of their respective Regional Economic Community (RECs): (I) the Central Africa Power Pool (CAPP) for the Economic Commission for Central Africa States (ECCAS), (II) the Comité Maghrébin de l’Electricité (COMELEC) for the Union of Maghreb Arab (UMA), (III) the Eastern Africa Power Pool (EAPP) for COMESA, (IV) the Southern Africa Power Pool (SAPP) for SADC, and (V) the West Africa Power Pool (WAPP) for ECOWAS.

I. CAPP – the Central African Power Pool comprises of 10 member states: Angola, Burundi, Cameroon, Chad, Congo, Gabon, Equatorial Guinea, Central African Republic, Democratic Republic of Congo, and Sao Tomé. As reported in the document, DRC is the main energy exported, with a limited regional trade with Congo, Burundi, CAR, Rwanda, and Angola. DRC is either connected to Zambia and to the SAPP. Compared to the other Power Pools, CAPP’s countries average electrification rate is still the lowest. As previously mentioned, the Grand Inga project in DRC is expected to improve cross bordering transmissions, as well as the Chollet hydropower site between Congo and Cameroon. The biggest priority project consists of a "costal backbone", linking Angola to Chad, including DRC, Congo, Equatorial Guinea, Gabon, and Cameroon. Two bilateral interconnections are also to be implemented, linking respectively Cameroon to CAR and DRC to CAR. There are also several projects, not included in the ECCAS study, which could be significant, namely: interconnection between Inga (DRC), Cabinda (Angola) and Pointe Noire (Congo), Inga-Calabar (Nigeria), which aims to link the CAPP to the WAPP.

II. COMELEC – comprises of 5 members: Algeria, Libya, Mauritania, Morocco, and Tunisia. There is presently a number of: (i) 400 kV connections between Spain, Morocco, Algeria, and Tunisia, and (ii) 220 kV connections between Algeria-Tunisia-Libya and Egypt. Although Mauritania is officially a member of COMELEC, no electrical connection is currently linking this country to Morocco: nevertheless at the end of 2023, a MoU was signed between the Moroccan National Electricity Regulation Authority and the Mauritanian Electricity Regulation Authority, which is considered to be a first step towards an electricity interconnection between the two countries. Among the future interconnections, it has been considered to link Northern African countries (Tunisia, Morocco, Algeria, Libya) with Southern Europe (Spain, Italy); these projects include an Algeria-Spain interconnection, Algeria-Italy (Sardinia), Libya-Italy (Sicily) and Tunisia-Italy (Sicily). These plans all aim to link the Northern Africa and Europe electrical grids, potentially increasing the possibility of developing a green hydrogen economy, including renewable energy transmission for import and export.

III. EAPP – Current Members Countries are Burundi, DRC, Egypt, Ethiopia, Kenya, Libya, Rwanda, Sudan and Tanzania. It's relevant to notice that Libya is a member of the COMELEC; as reported by the ICA report, potential Member Countries are Uganda, Djibouti, Eritrea. In this power pool, Egypt have the greatest amount of energy production and consumption, representing in 2011 the 86,6% of the total generation; Egypt is interconnected to Libya and Jordan, effectively linking the Northern African Grid to the Middle East countries. Even if Egypt is part of the EAPP, its grid is separated from the other countries since no interconnection with Sudan is currently existing. Sudan, Ethiopia, and Djibouti grids were isolated until 2008, when interconnections between these countries have been commissioned; currently, Sudan is linked to Ethiopia and Ethiopia to Djibouti, but this grid is still not connected to Kenya and consequently to all the southernmost part of the EAPP. The cross-border hydro power plant Ruzizi II between DRC and Rwanda guarantees interconnection between these two countries; Rwanda, Uganda and Burundi are linked together and to Tanzania through Uganda. Therefore, the EAPP is de facto constituted currently by 3 separated grids, the southernmost one connected to the SAPP through DRC. The interconnection plans aim to strengthen the already operative lines and to connect Ethiopia with Kenya, Kenya with Tanzania, and Sudan to Egypt.

IV. SAPP – it includes 12 countries on the mainland African region, namely: Angola, Botswana, the DRC, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia, and

Zimbabwe. The DRC is also member of the CAPP and the EAPP, being the only country in Africa to be part of three different power pools; Tanzania is part of both the SAPP and the EAPP. South Africa has the greatest energy production among the member countries, being the main energy exporter to Namibia, Botswana, Mozambique, Lesotho and eSwatini. Angola is currently a non-operative member but is planned to reinforce its grid and develop a connection to DRC and to Namibia, with the shared Baynes dam. Similarly, Malawi is currently isolated but aims to develop electrical interconnection with Mozambique and Zambia. The DRC-Zambia interconnection is the only one that guarantees connection between SAPP and CAPP, but a future new line is expected to link Zambia to Tanzania and consequently to the EAPP.

V. WAPP – it represents the economic community ECOWAS, which includes Benin, Burkina Faso, Cape Verde, Ivory Coast, Gambia, Ghana, Guinea Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, and Togo. At the state of the art, this power pool appears to be completely isolated from the other ones: Senegal is connected to Mauritania, which is not connected with any other COMELEC country, and Nigeria is not connected with Cameroon. Currently there are several not operative countries, i.e. Guinea, Liberia, Sierra Leone, Gambia, and Guinea Bissau. The under-development facilities include the transmission expansion project by OMVS (Senegal River Basin Development Association), which aims to link Senegal with Gambia, Mali, Guinea and Guinea Bissau, the Ivory Coast-Liberia-Sierra Leone-Guinea redevelopment subprogram, and linking lines between Niger and Benin, Burkina Faso, and Ghana.

In the map shown below it's possible to compare all the currently existing and the projected interconnections with a map showing the power pools geographic borders within the whole continent.

Figure 1: African Power Pools

As it's possible to see by analyzing the map, the African power grid is basically formed by isolated grids that don't always correspond with the geographic division set by power pools; for instance, Egypt is a member of the EAPP but is connected only to COMELEC countries other than Jordan, the EAPP is fractionated in the Sudan-Ethiopia-Djibouti grid and the highly interconnected area build around the Lake Victoria. If the programmed lines will be built as projected, all the power pools would be technically connected one to the other, creating a single African grid that extends all across the continent.

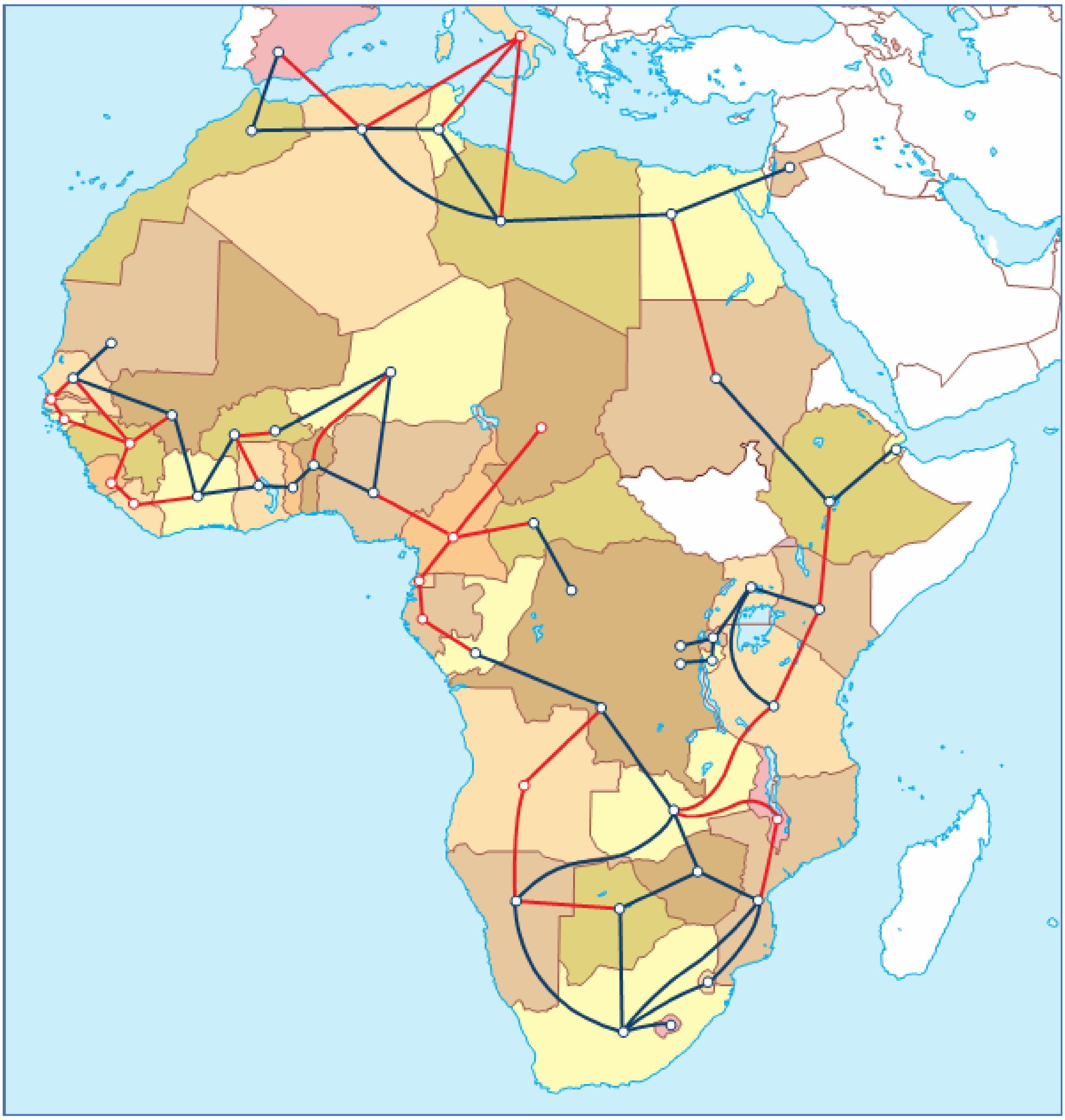


Figure 2: Operative lines (blue) and projected lines (red)

Obviously, the more the grid is widespread and branched out, the easier is for countries to develop an import-export market for energy, allowing to fully unlock the power of the energy systems which now are only partially operative or unused due to low energy demand. At the same time, green hydrogen production from surplus electrical energy would be more geographically flexible and would be possible to be produced and used for domestic use also for energy importers countries.

2.1.2 Socio-economic Data

According to IEA (Africa Energy Outlook 2019), Africa has great potential to be the first continent to base a significant portion of its economic and industrial development on clean and renewable energy sources. Although, in order to unlock its full potential of renewable energy and green hydrogen production, significant investments are needed to support the development of energy power facilities: renewable power stations, infrastructure, hydrogen related technology, as well as comprehensive frameworks and policies are necessary to develop a true hydrogen-based economy. For the purposes of this research, several socio-economic parameters were considered essential to identify which countries are the most suitable from a more political and investment direction perspective.

2.1.2.1 Political Stability Index

The index of Political Stability and Absence of Violence/Terrorism measures perceptions of the likelihood that the government will be destabilized or overthrown by unconstitutional or violent means, including politically-motivated violence and terrorism. The index is an average of several other indexes from the Economist Intelligence Unit, the World Economic Forum, and the Political Risk Services, among others (from *the Global Economy* website). The range of values of the index goes from a minimum of -2.50 to a maximum of 2.50, with the highest value held by Lichtenstein (1.64) and the lowest held by Somalia (-2.68); another comparison presents Italy at 0.58 and the USA at 0.00. The rank of African countries by Political stability index is pointed out in the table below.

Tab. 6 – Political Stability Index

RANK	COUNTRY	POLITICAL STABILITY INDEX
1	BOTSWANA	0,98
2	NAMIBIA	0,55
3	GAMBIA	0,18
4	RWANDA	0,17
5	GHANA	0,07
6	ZAMBIA	0,06
7	GABON	-0,09
8	MALAWI	-0,11
9	SIERRA LEONE	-0,16
10	SENEGAL	-0,17

2.1.2.2 Investment Freedom Index

The Investment Freedom Index, created in 1995 by the *Wall Street Journal* in cooperation with *The Heritage Foundation*, is one of the components of the Economic Freedom Index, and measures a variety of restrictions that are typically imposed on investment, such as restrict access to foreign investment, corruption, lack of basic investment infrastructure, political and security conditions (*The Heritage Foundation* official website). From an ideal score of 100, points are detracted based on quantity and type of restrictions. Currently, Luxembourg leads the global rank with a score of 95, while North Korea, Venezuela and Eritrea stand at the bottom with a score of 0; for instance, Italy stands at a score of 80, while the United States score is 85.

This specific parameter has been considered in this analysis in order to give a point of view of how the single nations are placed in relation to foreign investment: some economic constraints may block resources and make hard to develop a synergic economic market between African and European stakeholders. As shown below, the hereby table shows the rank of the first 10 African countries by Investment Freedom Index.

Tab. 7 – Investment Freedom Index

RANK	COUNTRY	INVESTMENT FREEDOM INDEX
1	IVORY COAST	75
2	GHANA	70
3	BOTSWANA	65
4	BURKINA FASO	65
5	EGYPT	65
6	GAMBIA	65
7	MALI	65
8	MOROCCO	65
9	NAMIBIA	65
10	CHAD	60

2.1.3 Energy Infrastructure Category

Since green hydrogen supply chain includes hydrogen transportation from producer to user, several hydrogen delivery scenarios have been analyzed in order to highlight which areas are strategically favorable by this point of view. For what concerns this category, the following parameters have been considered:

- Gas pipelines (2023 and forecast projects for 2040)
- LNG terminal (2023 and forecast projects for 2040)

As discussed in the next section, gas pipeline could be the most efficient and effective way to transport hydrogen to Europe in a short to middle time horizon. Hydrogen dedicated pipelines are currently object of study, however this solution might be not ideal in order to firstly introduce green hydrogen into the energy market since it requires an already set up hydrogen economy and significative quantities to be exported. Furthermore, looking at hydrogen export, sufficiently developed energy infrastructure systems could allow to connect the countries with the major renewable sources to the countries geographically more strategic for hydrogen transportation.

2.1.3.1 Gas pipelines

As reported by literature, when compared with other transportation modes such as tube trailers and truck tankers, pipelines provide an economic and efficient means to transport gaseous hydrogen with increased transportation capacity and a low energy loss. Aspired by rapidly increasing hydrogen demands, hydrogen pipelines will progressively be installed. A combination of newly built pipelines with the existing natural gas pipeline network is seen as a promising means of moving either pure or blended hydrogen from production sites to end users. Particularly, repurposing existing natural gas pipelines is "a low-cost option for delivering large volumes of hydrogen", while saving a high initial capital cost of construction of new hydrogen-dedicated pipelines and rapidly expanding the hydrogen delivery infrastructure.

Based on increasing experiences, the goal is to use the natural gas pipelines to become fully dedicated infrastructure for hydrogen transport; a small percentage of hydrogen blended with natural gas can be used to generate heat and electricity, while reducing the GHG emissions.

Today, it is recommended that a blending ratio of hydrogen to natural gas be maintained between 5% to 15% to ensure safety and system stability of the pipelines, as well as reduced risk to the public; the blending ratio can be varied by considering the pipeline performance conditions and the realistic hydrogen demands.

The website of the Global Energy Monitor association provides the "*Africa Gas Tracker*", an interactive map which points out every operating, dismissed or under development natural gas facility such as gas pipelines, LNG terminals, gas-fired power plants, and gas extraction sites.

2.1.3.2 LNG terminals

Tab. 8 – LNG terminal (2023)

RANK	COUNTRY	N° OF LNG TERMINALS 2023
1	ALGERIA	15
2	EGYPT	4
3	CAMEROON	4
4	EQUATORIAL GUINEA	1
5	SENEGAL	1
6	ANGOLA	1

As described in the previous paragraph, natural gas facilities could provide a strong advantage to the development of a hydrogen economy. With the data provided by the *Africa Gas Tracker*, a rank regarding African countries current number of LNG terminals has been drawn up.

By considering all the "under development" or "proposed" LNG terminal facility on the website, it's possible either to estimate the number of LNG terminals in the second period of analysis (2040).

Tab. 9 – LNG terminal (2040)

RANK	COUNTRY	N° OF LNG TERMINAL 2040
1	NIGERIA	18
2	ALGERIA	15
3	MAURITANIA	6
4	CAMEROON	5
5	MOZAMBIQUE	5
6	EGYPT	4
7	EQUATORIAL GUINEA	3
8	SOUTH AFRICA	3
9	MOROCCO	2
10	TANZANIA	2
11	CONGO	2
12	GUINEA	2
13	IVORY COAST	1
14	GHANA	1
15	SENEGAL	1

2.1.4 Civil Infrastructure

Despite hydrogen transportation by gas pipeline remains the most cost-effective and clean delivery system, alternatives are strictly necessary when pipelines are not available or ongoing between production site and users. In this section, the following parameters have been considered:

- Port infrastructure (TEUs per country)
- Liner Ship Connectivity Index
- Road Infrastructure, in terms of paved road system extension

Marine transportation remains the most flexible and widespread alternative to gas pipelines whenever this type on infrastructure is absent, especially when dealing with large quantities of product. Hydrogen can be industrially liquefied for a space-saving transportation or stock in the form of ammonia or other form of liquid hydrogen carrier.

Land transportation, i.e. roads, highways and railroad system are crucial for any type of product delivery from production site to local users as industries or cities, or from production site to ports, LNG terminals or other energy infrastructure, making the green hydrogen production process more flexible, as discussed earlier in paragraph 2.4.

2.1.4.1 Port infrastructure and Liner Shipping Connectivity Index

Shipping and road transportation are the most widespread and flexible carriage systems. In this paragraph, data about Port Infrastructure and Liner Shipping Connectivity Index will be analyzed and ranked in order to identify the most suitable countries and cities across the African continent for green hydrogen shipping. Port infrastructure analysis included the following aspects: the first one was identifying the major ports of Africa, based on the number of Twenty-foot Equivalent Unit (TEUs) transported, in order to spot the strategically more favorable locations for green hydrogen shipping. Moreover, to have a country-by-country perspective and matching this data with the former ones discussed, a rank of container port traffic (still by TEUs number) have been written up. For what concerns the research of a TEUs-based rank of the largest African ports, some difficulties have been experienced due to the lack of information or unreliability of the sources, as websites provided frequently very different and contradictory values or data which were referred on specific areas and not the whole continent. Therefore, a port-by-port research has been conducted, finding out the recently expanded cargo port of Tanger-Med in Morocco to be the leading African port with the total number of TEUs transported reaching 7,17 million. On the other hand, a country-by-country research gives information about general port infrastructure in the country; the data provided by *The World Bank* official website have been summarized in the table below.

Tab. 10 – TEUs per country

RANK	COUNTRY	TEUs PER COUNTRY
1	MOROCCO	8.457.129
2	EGYPT	7.321.888
3	SUDAFRICA	4.529.034
4	NIGERIA	1.627.142
5	ALGERIA	1.553.362
6	TOGO	1.500.611
7	KENYA	1.417.000
8	GHANA	1.079.247
9	IVORY COAST	994.646
10	REPUBLIC OF CONGO	921.000

Liner Shipping Connectivity Index (LSCI) indicates how well countries are connected to global shipping networks, namely how a country is actively involved in international trade and export-oriented; the higher the index, the easier it is to access a high capacity and frequency global maritime freight transport system and effectively participate in global trade. Therefore, just as the formerly presented Investment Freedom Index gave an analysis about a country economic openness, LSCI can be jointly considered as a measure of connectivity to maritime shipping and as a measure of trade facilitation. This index was firstly computed in 2004 by the United Nations Conference on Trade and Development (UNCTAD) on the hereby parameters:

1) Number of ships that are calling on a weekly basis
2) Deployed capacity
3) Number of shipping companies and services operating
4) Average vessel size, as this is correlated to lower shipping cost per TEU
5) Number of ports that are directly connected to the reference port

Tab. 11 – Liner Shipping Connectivity Index

RANK	COUNTRY	LINER SHIPPING CONNECTIVITY INDEX
1	MOROCCO	69,3
2	EGYPT	66,7
3	SOUTH AFRICA	39,1
4	GHANA	37,2
5	TOGO	36,2
6	DJIBOUTI	34,1
7	REP. OF CONGO	24
8	ANGOLA	23,4
9	NAMIBIA	22,2
10	NIGERIA	20,8

2.1.4.2 Road Infrastructure

Just as access to electricity and port infrastructures, the low density and the generally poor conditions of African road infrastructure make a significant limitation to the continent economic growth. The vast majority of them are still unpaved the maintenance is frequently inadequate, that causes millions of people, especially in rural areas, to be even more isolated from economic opportunities, services, and basic education. Although, investments in road infrastructure have recently increased: for instance, the Trans-African Highway network, developed by the United Nations Economic Commission for Africa (UNECA), the African Development Bank and the African Union, is an under-construction project which aims to develop 9 highways across Africa, covering a total of 56.683 km.

As long as green hydrogen transportation by truck is a strictly necessary stage of hydrogen delivery from the production site to the final user, both for domestic and export needs, several information about road conditions country by country were needed. The presence of paved roads is crucial not

only for hydrogen transportation and delivery, but also in order to ensure a safe connection between production sites, construction areas, energy-related facilities, and delivery points.
Unfortunately, just as port infrastructure data, numbers about road network in terms of kilometers of paved road by country were frequently diverse and incomplete. The *Logistics Cluster* official website provided most of the information needed for this part of the research, allowing the finalizing of the assessment country by country of the network of paved roads (*Tab. 12*).

Tab. 12 – Road Network Size (paved)

RANK	COUNTRY	ROAD NETWORK SIZE [km]
1	SOUTH AFRICA	158.124
2	ALGERIA	71.756
3	NIGERIA	60.000
4	EGYPT	48.000
5	MOROCCO	43.746
6	LIBYA	34.000
7	ZIMBABWE	18.481
8	GHANA	14.948
9	ZAMBIA	14.888
10	ETHIOPIA	14.632

2.2 Potential green hydrogen assessment - 2023

The main stage of this thesis was to evaluate the potential green hydrogen production and electrolysis capacity in Africa in both 2023 and 2040.
As previously highlighted, (§2.1) to calculate the total tons of producible green hydrogen in the different African Countries, starting from IRENA data, the following parameters have been considered and/or calculated:

- Installed Capacity [GW]
- Electricity Production [GWh]
- Electricity Consumption [GWh]
- Renewable Electricity share
- Operative Equivalent Hours

Still as formerly written, the data about Installed Capacity, Electricity Production, Renewable Electricity share and Operative Equivalent Hours in 2023 have been collected from IRENA updated energy profiles. For what concerns electricity consumption values, the latest data were not always available and frequently incomplete. Therefore, those numbers have been calculated by collecting the last available data on the World Bank Data website, dated back to 2014, then considering a

1% increase per year on the previous data until 2023. This calculation resulted in a total increase of about 10% on the 2014 electricity consumption data.
With this data collected on calculation models, it has been possible to know firstly which countries were energy importers or exporters by calculating the difference between electricity production and electricity consumption, obtaining the Net Energy Surplus (NES): by checking the sign of the Net Energy Surplus, a minus sign equals an "energy importer", while a plus sign equals an "energy exporter". Assuming that all hydrogen should be produced by exploiting the electrical energy provided by the NESs, this parameter determines the production of "grey" hydrogen, if the NES derives mainly from fossil fuels, otherwise "green" hydrogen if the NES derives only from renewable energy production (REP). It's relevant to underline that since access to electricity is still low in most African countries, the meaning of the NES indicator should be considered more as a difference between the energy fed into the grid by the local power plants and the energy effectively required by the grid.

Tab 13 – Net Energy Surplus (2023)

RANK	COUNTRY	NET ENERGY SURPLUS 2023 [GWh]
1	LIBYA	18.972
2	ALGERIA	10.512
3	EGYPT	10.333
4	SOUTH AFRICA	9.928
5	GHANA	8.068
6	ANGOLA	6.849
7	ETHIOPIA	5.955
8	SUDAN	3.090
9	TUNISIA	2.235
10	IVORY COAST	2.194

As presented in the above table, by keeping the previously mentioned hypothesis, all the African countries can be classified in to:

- "grey" countries if NES > REP, meaning a fossil energy surplus
- "red" countries if an energy deficit emerged, namely the country is currently importing energy from the bordering countries
- "green" if NES < REP, meaning a potential renewable surplus, on the basis of which the potential green hydrogen production in tons have been calculated.

Since the energy source of the NES is unknown, some hypothesis was needed to find out which countries could be a potential green hydrogen producer.
Firstly, the production of grey or blue hydrogen has not been considered, since the focus of this analysis is to estimate green hydrogen production from low-cost renewable energy. Also, the NES

was ideally assumed to be entirely used for hydrogen production and to be entirely consisting in renewable energy if NES value was lower than REP. These assumptions leaded to the following method:

- If NES > REP, the surplus energy is not guaranteed to be renewable
- If NES < REP, the surplus energy is ideally considered to be totally renewable

Tab 14 – Renewable Production (2023)

RANK	COUNTRY	RENEWABLE PRODUCTION IN 2023 [GWh]
1	EGYPT	24.064
2	ETHIOPIA	15.075
3	ANGOLA	13.926
4	ZAMBIA	13.036
5	D.R. CONGO	11.407
6	SUDAN	11.139
7	KENYA	9.563
8	SOUTH AFRICA	9.531
9	NIGERIA	8.289
10	GHANA	7.420

Therefore, the potential green hydrogen production in tons was calculated with the following formula:

$$Green\ H_2\ production\ [t] = 18 \cdot NES \quad (1)$$

Where 18 (kg of hydrogen per MWh) is an average production rate of an alkaline or PEM electrolyzer, where theoretically alkaline efficiency is a little bit lower than the PEM one.
This led to a total for the whole African continent of 655.038 tons of green hydrogen with significant contribution by Egypt, South Africa, and Ethiopia, producing more than half of the total production.

To obtain the electrolyzer capacity needed, for every "green" country the NES was divided by the total Operative Equivalent Hours (OEH); by summing the single values for every country, this resulted in a total capacity of 10,8 GW.

$$Total\ Electrolyzer\ Capacity\ [GW] = \sum_i \frac{NES_i}{OEH} \quad (2)$$

As verified by the following formula, the number of Electrolyzer Operative Hours amounted to a total of 3368,83.

$$Electrolyzer\ Operative\ Hours = \frac{Green\ H_2\ production}{18 \cdot Total\ Electrolyzer\ Capacity} \quad (3)$$

Relatively to the energy data collected, the hereby tables rank African countries by Renewable Energy Capacity.

Tab.15 – Renewable Capacity Installed (2023)

RANK	COUNTRY	RENEWABLE CAPACITY INSTALLED IN 2023 [GW]
1	SOUTH AFRICA	**10,44**
2	EGYPT	**6,49**
3	ETHIOPIA	**4,80**
4	MOROCCO	**4,06**
5	ANGOLA	**3,78**
6	D.R. CONGO	**2,77**
7	ZAMBIA	**2,69**
8	KENYA	**2,36**
9	MOZAMBICO	**2,29**
10	NIGERIA	**2,08**

As described previously, the NET allows to identify firstly “exporters” countries and “importers” countries, and secondly “fossil surplus” and “renewable surplus”. This data have been plotted in the hereby “Renewable Availability 2023” map (*Fig. 3*).

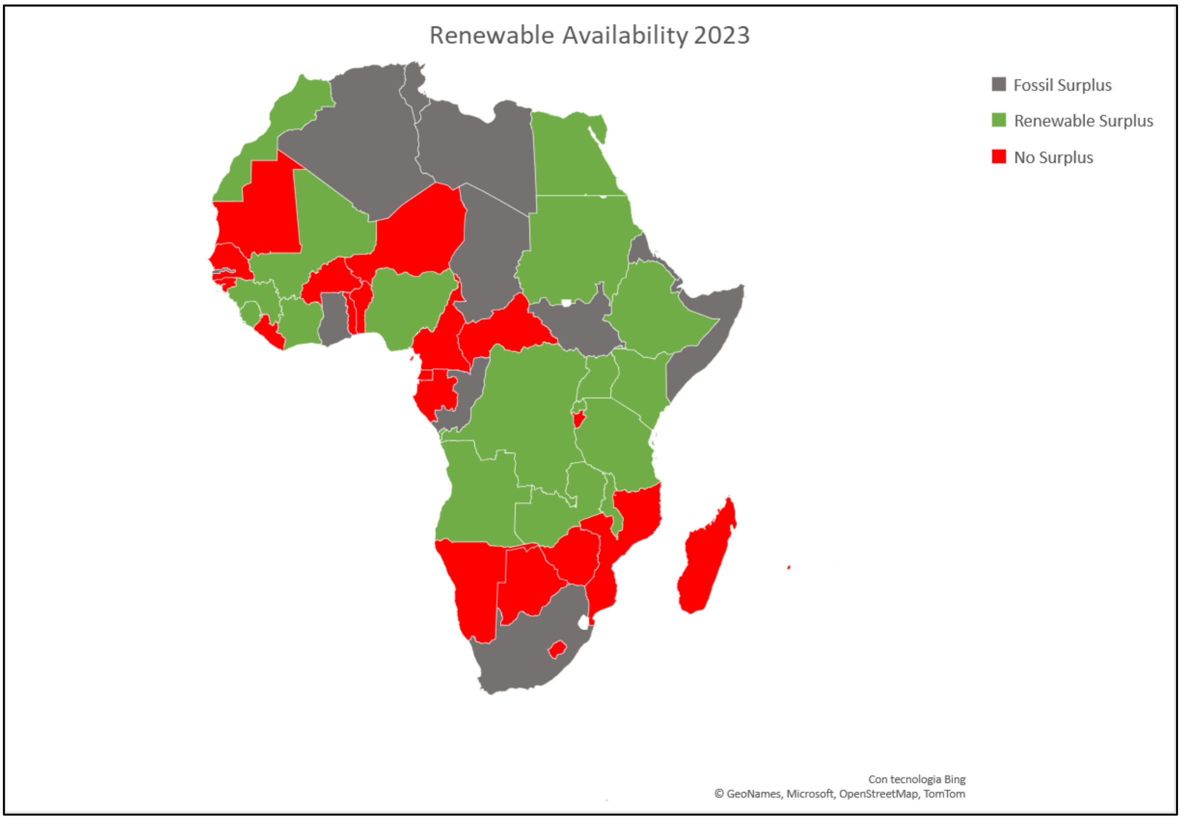


Figure 3: Renewable Availability 2023

Regarding green hydrogen potential production, the final results have been both ranked in *Tab. 16* and plotted in the map shown below (*Fig. 4*).

Tab. 16 Potential Green H2 production (2023)

RANK	COUNTRY	GREEN H2 PRODUCTION IN 2023 [t]
1	EGYPT	185.994
2	ANGOLA	123.282
3	ETHIOPIA	107.190
4	SUDAN	55.620
5	IVORY COAST	39.492
6	KENYA	28.206
7	NIGERIA	21.276
8	MOROCCO	20.628
9	UGANDA	16.344
10	MALAWI	15.426

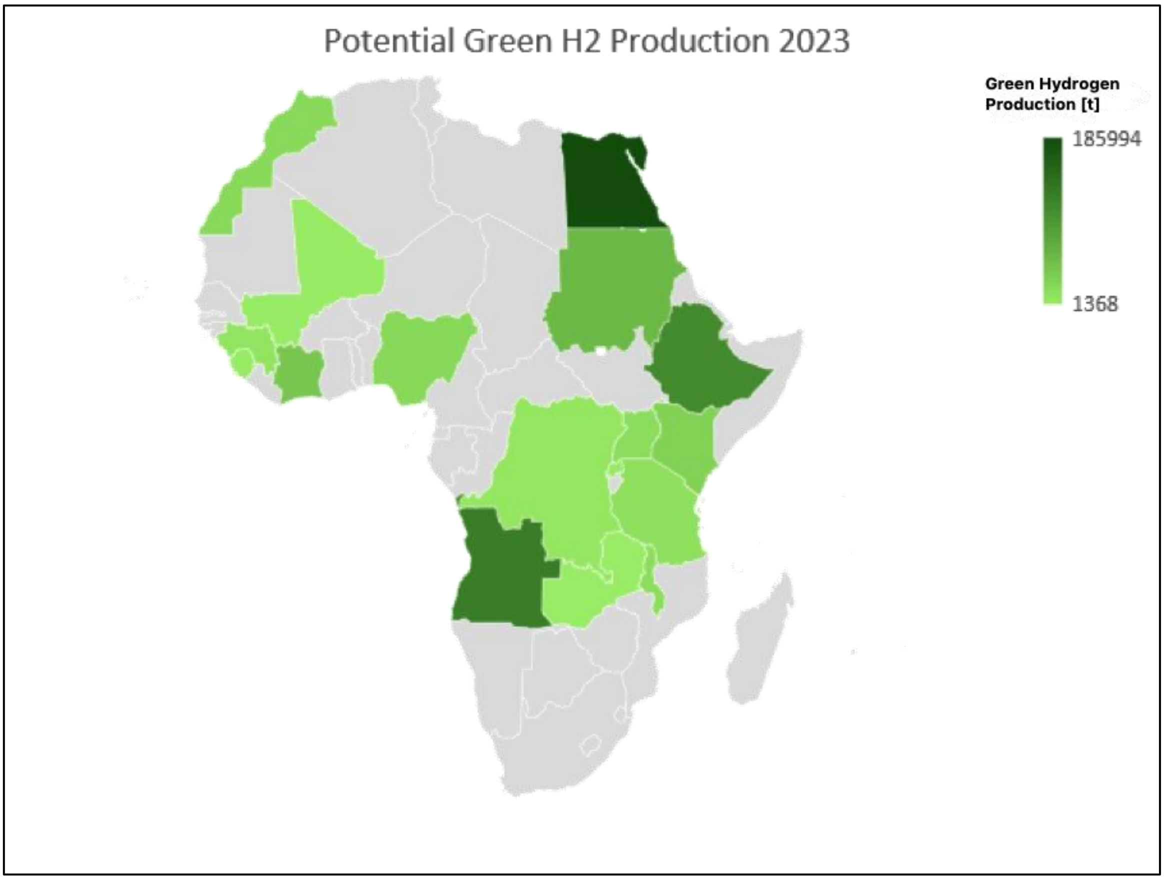


Figure 4: Potential Green H2 Production Map (2023)

The final step of the 2023 horizon scenario assessment was to plot green hydrogen production, showing only the “green” countries previously featured on the Renewable Availability map, highlighting with a darker green the countries with a larger production and fading to a lighter green for the smaller productions. Egypt is clearly the country with the larger potential green hydrogen production (185.994 tons) as it will be able to valorise the local large hydropower production; along with Morocco and Nigeria, which have a consistent renewable production and surplus, despite having a significative electric energy demand. While countries as Sudan, Ethiopia and Angola show a darker color which is caused by very low access to electricity rates, as well as a very limited consumption thus locally produced renewables (mostly hydropower) could be used to produce renewable hydrogen.

2.3 Potential green hydrogen assessment – 2040

In this chapter all the calculation made in order to evaluate the potential green hydrogen production in 2040 will be presented. Every parameter that influenced the final result will be described both in terms of mathematical calculation and hypothesis and final result with maps and rankings.

2.3.1 Electricity Consumption

Electricity consumption is certainly a difficult parameter to foresee, especially in mid-long term time periods. Furthermore, this parameter goes along with economic growth and technology development, which in developing countries is often unpredictable and can easily be destabilized by political issues or unpredictable phenomena (for instance, Covid-19 or environmental/climate catastrophes). Since electric energy consumption is generally increasing throughout the whole continent and is expected to further increase, the solution adopted for the 2023 assessment has been re-proposed, hypothesizing again a 1% increase per year (on the last year value). With the 2014 data being the latter data available, this resulted in a ~29,5% increase on the starting value.

2.3.2 Installed Capacity

In order to predict installed capacity in 2040, a deep research about nation's intentions about renewable power deployment in the next years was needed. Most African countries have set up a renewable energy plan or electrification act, with decarbonization targets and grid expansion projects. To the state-of-art, the vast majority of the renewable power to be installed consists in hydropower projects; among those, the most relevant ones are the already cited Grand Ethiopian Renaissance Dam and the Grand Inga, in the Democratic Republic of the Congo. Solar power plants are the second most common renewable power plant to be installed especially in North Africa and in the Sahara Desert zones.
To esteem installed capacity, since this parameter is generally proportional to energy consumption, a first stage rough value estimation for each country has been calculated trough the following proportion:

$$\frac{Installed\ Capacity\ 2040}{Energy\ Consumption\ 2040} = \frac{Installed\ Capacity\ 2023}{Energy\ Consumption\ 2023} \qquad (4)$$

In a second stage analysis, data about power plants currently under construction, under development or announced have been collected in terms of "expected" installed capacity: in this stage, priority was given to data from official policies regarding renewable capacity deployment or scientific literature; in many situations, where information was fragmentary and/or misleading, the first stage estimation calculated with equation (4) has been used as a counterproof value to be compared. In order to establish a definitive value of capacity to keep for the latter stages of the research, the following method was adopted:

- If the expected capacity exceeded the first stage value, the expected capacity value was kept
- If the expected capacity didn't exceed first stage value or no significant data were found, the first stage value was kept

By summing up all the esteemed installed capacities the result for the African continent is 518,85 GW.

2.3.3 Electricity Renewable Share

In order to determine the renewable energy production, an esteemed value of the electricity renewable share needed to be known. Renewable energy share is generally expected to increase due to the country's general intention to deploy new renewable capacity to decarbonize both the energy sector and industries and to meet the energy demand, which is expected to increase significantly both in Africa and Europe. Despite that, whereas renewable power projects and intentions are widely promoted and declared, data about forthcoming projects concerning fossil fuel-based power stations are frequently unavailable, especially in developing countries.

The first method used to determine the renewable share consisted in a research of the declared target of every country for renewable capacity or renewable production. Since declared targets are frequently referred to different years than 2040, the equivalent value was calculated by linear interpolation. Otherwise, if no information about renewable production were released or were not available, the following method has been adopted: by firstly hypothesizing ideally that a country is going to deploy only the renewable power facilities which have been announced or are under development and secondly that all the renewable facilities which are currently operating in 2023 will not be retired or shelved, the renewable installed capacity can be obtained by summing the installed capacity "to be deployed" to the renewable capacity of 2023, obtained by multiplying the total capacity by the percentage share on renewable power capacity. Finally, by multiplying this value by the OEH previously calculated, the Renewable Production in 2040 can be obtained.

In the hereby section the final rank about Renewable Production (*Tab. 4.1*) is showed.

Tab. 17 – Renewable Production 2040

RANK	COUNTRY	RENEWABLE PRODUCTION 2040 [GWh]
1	D.R. CONGO	185.283
2	EGYPT	128.465
3	MOROCCO	111.009
4	MAURITANIA	109.020
5	ALGERIA	93.682

6	ETHIOPIA	84.441
7	SOUTH AFRICA	81.605
8	MOZAMBICO	34.680
9	KENYA	30.114
10	ANGOLA	27.930

Following the same method adopted in the 2023 assessment, the NES was calculated, obtaining a new "Renewable Availability" map for 2040 (*Fig. 5*).

Tab. 18 – Net Energy Surplus 2040

RANK	*COUNTRY*	*NET SURPLUS 2040 [GWh]*
1	D.R. CONGO	172.160,1
2	MOROCCO	119.747,4
3	MAURITANIA	113.630,4
4	EGYPT	843.37,0
5	ETHIOPIA	73.704,3
6	ALGERIA	65.492,7
7	SOUTH AFRICA	53.511,0
8	MOZAMBICO	50.021,1
9	LIBYA	22.335,2
10	KENYA	17.863,3

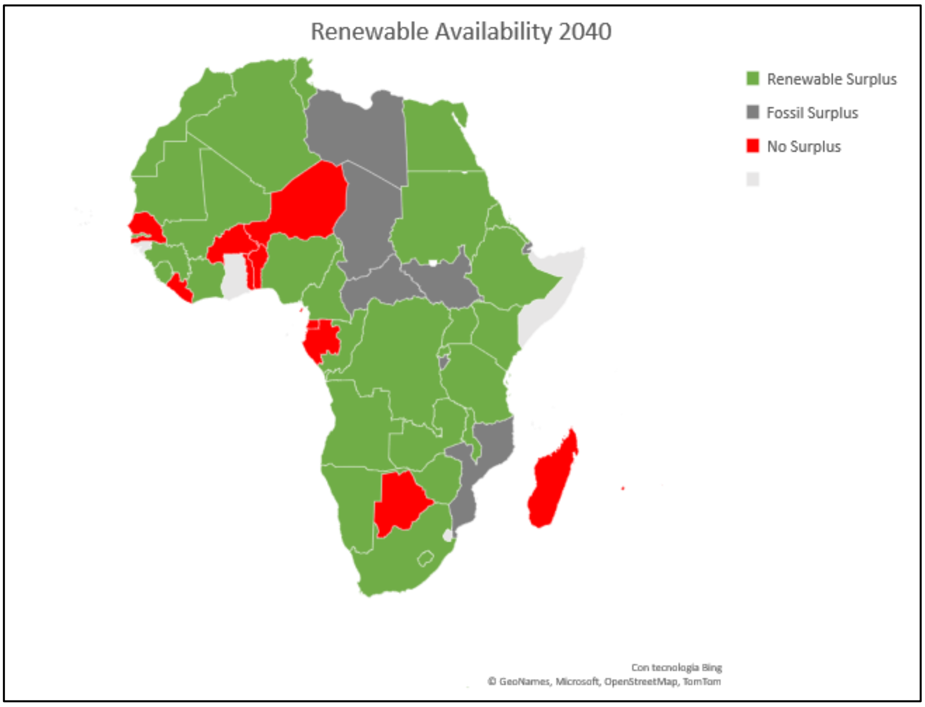


Figure 5: Renewable Availability 2040

2.3.4 Operative Equivalent Hours

Operative equivalent hours (OEH) is a relevant parameter which can determine deep variation on electricity production depending on the primary source. Considering all the renewable capacity of a country, the OEH parameter is generally a weighted average of the single values of the sources; for instance, some reference measures are:

- Photovoltaic: ~1000-2000 h
- Wind power: ~3000 h
- Hydro power: ~4000-5000 h
- Fossil: >5000 h

Since most countries are expected to deploy renewable energy and to significantly increase their renewable energy share, operative equivalent hours are also expected to change.

In order to calculate this value for 2040, firstly a comparison between current energy sources was made. As previously introduced, the OEH are normally calculated by dividing electricity consumption by the installed capacity; in this case, OEH were needed to estimate the future electricity production. By observing the 2023 data and comparing the most relevant energy source in 2023 and 2040, OEH has been arbitrary modified by reducing (solar predominant) or increasing it (hydro power predominant), only in the cases where significant amounts of renewable energy would be installed and consequently a significant increase or reduction of the OEH is expected.

The list hereunder indicates the countries in which OEH has been increased or reduced mostly according to the predominancy of local RES, particularly while considering a relevant contribution by hydropower plants.

Increased:

- Republic of the Congo (3275 to 3500)
- Ethiopia (3076,5 to 4200)
- Nigeria (2717,8 to 3000)
- Angola (3207,1 to 3500)
- Malawi (3388,6 to 3500)
- Mozambique (1639 to 4000)
- Zimbabwe (2781,7 to 3000)

Reduced:

- Tunisia (3498,5 to 3200)

2.3.5 Green Hydrogen Assessment

The final stage of the 2040 assessment consisted in the calculation of the green hydrogen potential, considering all the previously introduced parameters: by summarizing the former sections, the Net Energy Surplus was obtained by estimating the total Energy Consumption and subtracting it to the expected Energy Production, based mainly on the single countries intentions about renewable power deployments and private projects; this, verified that is a “green” energy surplus by comparing it with the estimated Renewable Production, have been used to calculate hydrogen production with the (1) equation. As expected, and as shown below (Fig 6 and Tab 19), many countries might be able to produce and export large quantities of green hydrogen. As will be further discussed, the relevant number of under development projects regarding new renewable capacity, in particular hydropower in Sub-Saharan countries, but also solar power plants in desert areas, allow to increase significantly the produced renewable energy; this, in presence of relatively increased energy demand, could lead to significative amounts of surplus clean energy. At the same time, a lower increase in energy demand could determine an under-utilization of the powerplants, that in some cases may be subjected to degradation, bad maintenance or shelve. Hydrogen production as energy storage system, as well as Power-to-X or Power-to-X-to-Power systems could guarantee a full power output throughout the year, except for meteorological conditions. A further expansion of this study could include this aspect, of which unfortunately the data available are still unclear.

Tab. 19 – Green Hydrogen Production 2040

RANK	COUNTRY	GREEN H2 PRODUCTION IN 2040 [t]
1	D.R. CONGO	3.098.881,00
2	MOROCCO	2.155.453,5
3	EGYPT	1.518.066,49
4	ETHIOPIA	1.326.676,91
5	ALGERIA	1.178.868,21
6	SOUTH AFRICA	963.198,67
7	KENYA	321.539,87
8	NAMIBIA	300.068,12
9	ANGOLA	273.362,15
10	GHANA	197.464,25

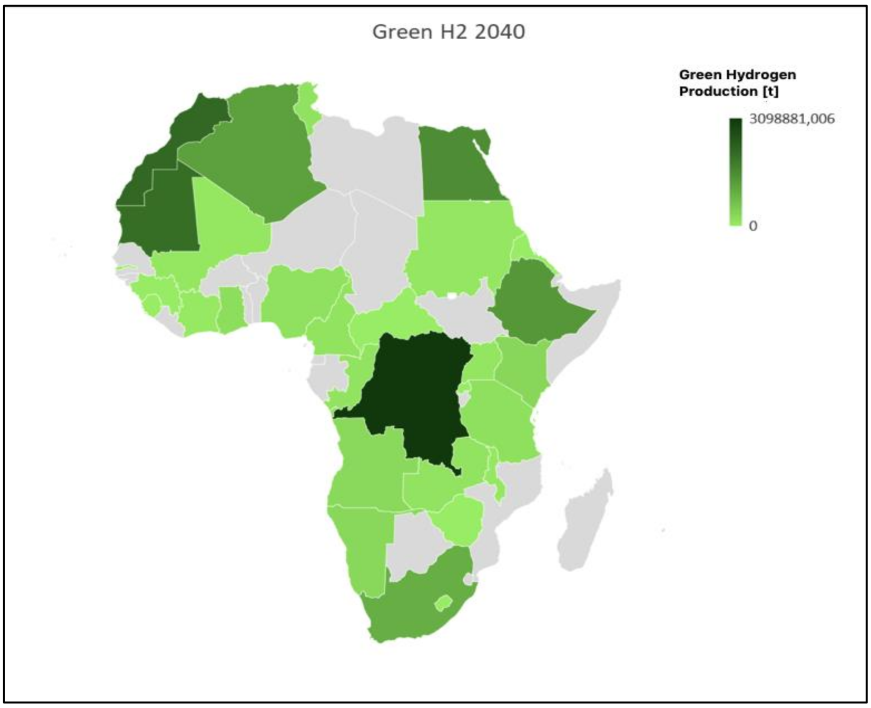


Figure 6: Green Hydrogen Production (2040)

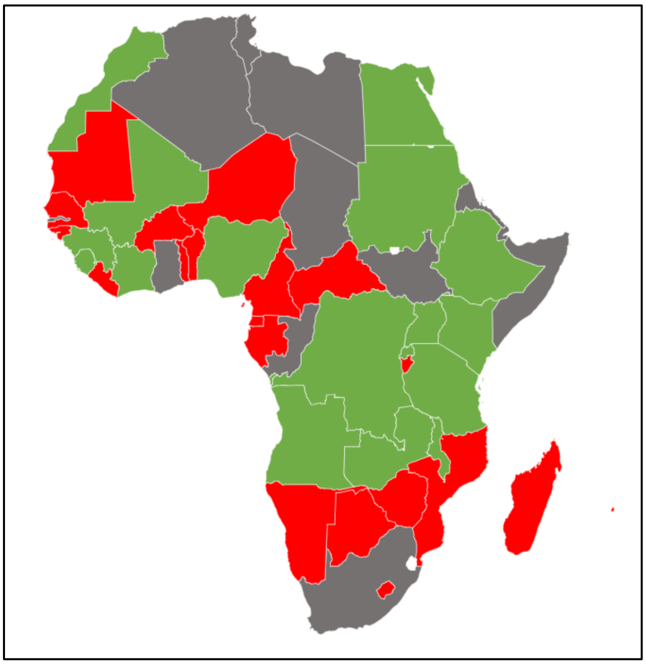
2.4 Critical Assessment of the Data Analysis

2.4.1 Data assessment results comparison

In this section, a critical comparison between the results assessed and calculated for the 2023 and 2040 scenarios will be presented, based on the maps and ranking obtained in chapters 3 and 4.

2.4.1.1 Net Energy Surplus

The first data obtained is the Net Energy Surplus, representing the potential renewable energy availability, in other words the production that a country is ideally able to unlock and dedicate completely to hydrogen production and utilization both as domestic power source and export product. Fig. 7 puts side by side the maps presented in chapters 2.2 and 2.3.



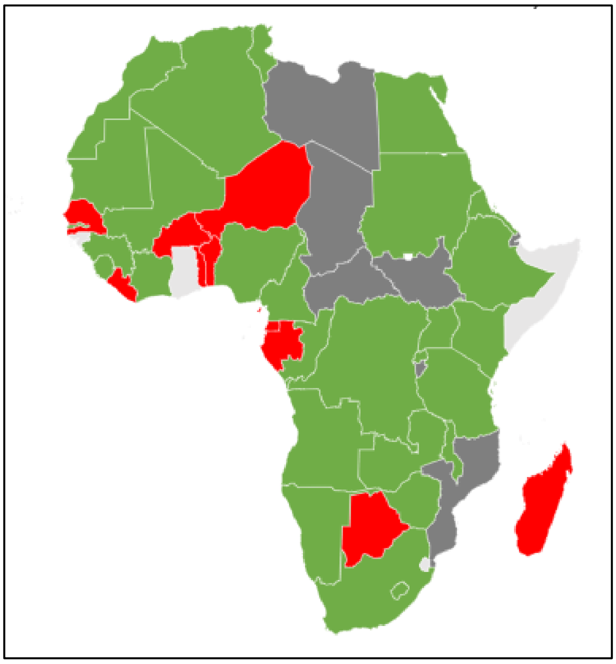


Figure 7: Renewable Availability 2023 and 2040

By comparing the maps figured out in the previous chapters, what stands immediately out is the number of countries that are expected to be classified as "green" countries in 2040, decisively increased in comparison to the current situation. This includes countries which are expected to have a transition from a fossil fuel-based surplus to a renewable surplus and the "red" countries which are currently in an overall deficit situation and are expected to reach not only the production target to satisfy the local demand, but also to have a renewable margin. The countries at issue are:

- "grey" to "green": Algeria, Tunisia, Republic of Congo, Eritrea, Gambia, South Africa
- "red" to "green": Cameroon, Mauritania, Lesotho, Namibia, Zimbabwe

It's possible to also identify several countries which are "red to grey": Mozambique, Central African Republic, and Burundi, which are expected to increase their production in order to meet the local energy demand but not to have significant renewable surplus. To further analyse this comparison, it's possible to place side-by-side either the rankings formerly obtained:

Tab. 20 – NES Ranking comparison.

RANK	COUNTRY	NES 2023
1	LIBYA	18.972
2	ALGERIA	10.512
3	EGYPT	10.333
4	S. AFRICA	9.928
5	GHANA	8.068
6	ANGOLA	6.849

RANK	COUNTRY	NES 2040
1	D.R. CONGO	172.160,1
2	MOROCCO	119.747,4
3	MAURITANIA	113.630,4
4	EGYPT	843.37,0
5	ETHIOPIA	73.704,3
6	ALGERIA	65.492,7

7	ETHIOPIA	5.955
8	SUDAN	3.090
9	TUNISIA	2.235
10	IV. COAST	2.194

7	S. AFRICA	53.511,0
8	MOZAMBICO	50.021,1
9	LIBYA	22.335,2
10	KENYA	17.863,3

The first immediate observation is the clear presence of more "green" countries in the 2040 rank: starting with the leading countries, which in 2023 are Libya and Algeria, both relying on fossil fuels, in 2040 are expected to be passed all by "green" countries. Secondly, the top three leading countries in 2040 are awaited to be the Democratic Republic of Congo, Morocco, and Mauritania: none of these countries are in the 2023 rank, Morocco due to its high energy demand, whereas both DRC and Mauritania currently have low electricity production and low electricity consumptions. Their increased value of the NES is due to their big installed power potential: in the 2040 panorama DRC could reach a total installed capacity of 45,4 GW thanks to the Grand Inga Dam, located across the Congo River, approximately 225 kilometers southwest of the capital city of Kinshasa. If built as planned, the power station would be the largest in the world. Morocco and Mauritania both have great solar and wind potential, due to their geographic location; it's relevant to cite one important project involving Mauritania like the AMAN project (current at feasibility study stage) involving up to 14 GW of mixed renewables[1] and targeting production of ammonia and other derivatives as well as Project Nour, signed by Mauritania's government and Chariot, aiming to deploy 10 GW of wind and solar renewable capacity towards green hydrogen production. Finally, it's relevant to highlight the geothermal potential of Kenya, which is expected to install 5,53 GW of renewable capacity by 2030, and the already cited Grand Renaissance Dam, in Ethiopia, with a total installed capacity of 6,45 GW.

2.4.1.2 Green Hydrogen Potential

As a direct consequence of the NES, green hydrogen production increases in the countries where low demand encounters big renewable electrical production. Following the comparison made for NES, it's relevant to notice that from 2023 to 2040 there is a significant increase of the number of countries able to produce green hydrogen, going from 17 in 2023 to 29 in 2040. This is immediately noticeable by placing side by side the maps showed in the previous chapters.

[1] https://cwp.global/projects/?p_id=338

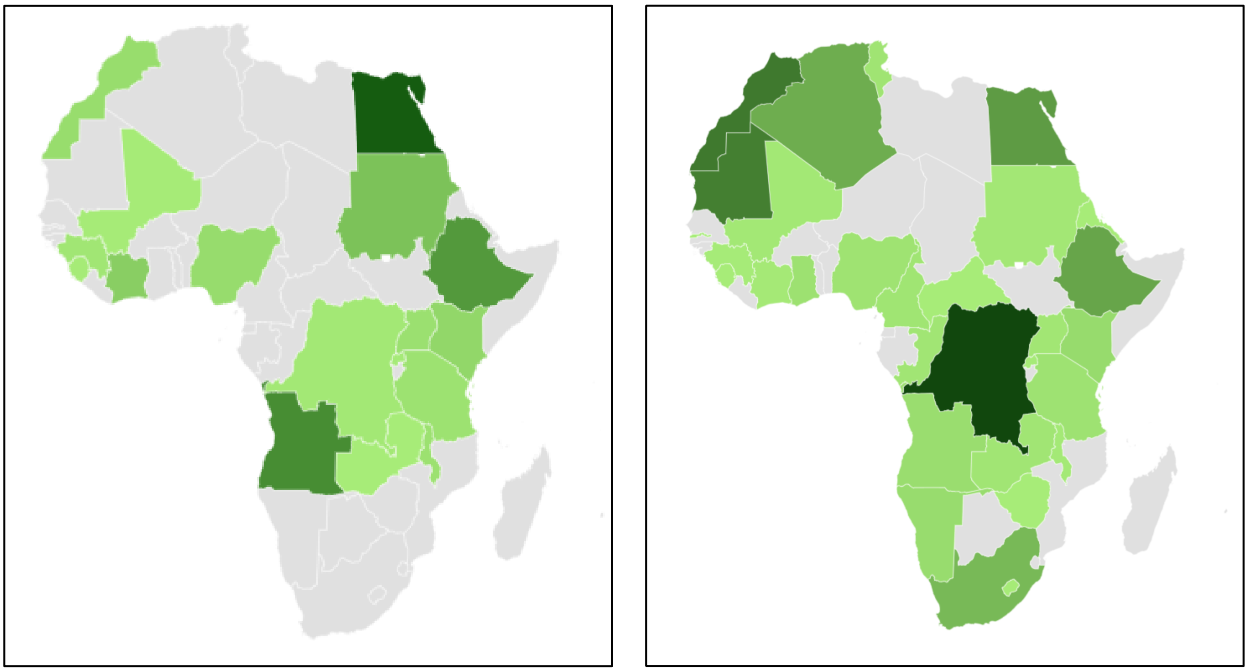


Figure 8: Green Hydrogen Production 2023 and 2040

With Egypt and Angola having the major renewable NES in 2023, they appear as the "greenest" countries in the map on the left, followed by Sudan and Ethiopia. Consequently, DRC, Morocco, and Mauritania, as either noticeable by comparing the hydrogen production ranks, are expected to be the first green hydrogen producers in 2040. For what concerns the countries featured in both the period of analysis, Angola drops from 2nd place to 10th, by slightly doubling their current value, while Egypt drops in 4th position despite increasing eight times its hydrogen production. Morocco increases more than a hundred times their current potential production; its projected hydrogen production in 2040 (~2,15 Mt) is not far away from the target mentioned in Morocco's official Hydrogen Roadmap, which as stands at 2,39 Mt per year in 2040. On the other hand, Namibia official framework declared a target of 5 to 7 Mt per year in 2040, theoretically superior to the total projected production of DRC. This would mean, considering the relatively low Operative Equivalent Hours value of Namibia (2607 hours equivalent per year), an installed capacity to be deployed of at least 106,5 GW. As calculated in this analysis and discussed in chapter 4, by considering the programmed renewable capacity to be installed in Namibia, the projected hydrogen production stands at around 0,3 Mt, therefore significantly far away from the declared intention. By putting side by side Tab. *15* and Tab. *19* the potential evolution of the green hydrogen scenario is possible to be visualized and then compared to the projected and declared green hydrogen targets reported in *D1.1* by African countries.

Tab. 21 –Green Hydrogen Ranking comparison.

RANK	COUNTRY	GH2 2023	RANK	COUNTRY	GH2 2040
1	EGYPT	185.994	1	D.R.C.	3.098.881,00
2	ANGOLA	123.282	2	MOROCCO	2.155.453,5
3	ETHIOPIA	107.190	3	MAURITANIA	2045347,97
4	SUDAN	55.620	4	EGYPT	1.518.066,49
5	IV. COAST	39.492	5	ETHIOPIA	1.326.676,91
6	KENYA	28.206	6	ALGERIA	1.178.868,21
7	NIGERIA	21.276	7	S. AFRICA	963.198,67
8	MOROCCO	20.628	8	KENYA	321.539,87
9	UGANDA	16.344	9	NAMIBIA	300.068,12
10	MALAWI	15.426	10	ANGOLA	273.362,15

2.4.2 Final Ranks for 2023 and 2040

The final objective of the analysis was to draw up two final ranks, for 2023 and 2040, in order to complete a comprehensive assessment of the whole African continent, including all the parameters discussed in chapters 2, 3 and 4; this operation required to "overlap" the single ranking obtained for every type of data, by properly weighting every parameter with a percentage share. As specified in the introduction of the chapter 2, not all the data were available for both the periods of analysis, or were either possible to evaluate.

For these reasons, the following data have been considered valid for both 2023 and 2040:

- Political stability index
- Investment freedom index
- Access to electricity
- Road infrastructure
- Port infrastructure (rank by TEU)
- Liner ship connectivity index

Parameters collected or calculated for 2023 and 2040:

- Installed capacity
- Electricity Consumption
- Number of Gas Pipelines
- LNG terminals
- Operative equivalent hours (depending on the main energy source)
- Shared power plants

2.4.2.1 Ranking calculation methodology

For what concerns the "weighting" of every rank, showed in the hereby pie chart (*Fig. 9*), the following method have been adopted: firstly, the data have been classified in 5 main categories, then for each of them a specific percentage value have been established, and multiplied for every country position in every single rank; this operation has been completed for 2023 and 2040, with the previously indicated criteria. Finally, by summing up every rank position's number, the two final ranks have been calculated. In the following section the 5 main categories with their relative evaluation strategy are presented.

I. "**Energy and Hydrogen":** this is the most important category, as its influence amounts for 65% of the total score; it includes a 25% of "Energy Data", which consists in the average score obtained with Installed Capacity and Renewable Production, and a 40% of "Hydrogen Production", consisting in the ranks obtained by the calculation of the potential green hydrogen production. In the hereunder chart, this category is associated with a green color.

II. **"Socio-Economic":** this category influences for a total of 10% in the final score, split in a 5% for the "Political Stability Index" rank and a 5% for the "Investment Freedom Index" rank. In the chart, this category is associated with an orange color.

III. **"Infrastructure":** this category either influences for a total of 10% on the total score. It's split in 3 sub-categories, consisting in the "TEUs per country" rank, amounting for the 5% of the final value, the "Road Infrastructure" rank, for 2,5% and the "Liner Ship Connectivity Index", for 2,5%. This category is associated with a blue color.

IV. **"Access to Electricity":** the total share for this category amounts for 5%, split in a 2,5% for the Total value and 2,5% for the Rural value. Both these ranks have been considered in their "Max to Min" version. This category is associated with a yellow color.

V. **"Gas Pipeline, Electrical Interconnections (and related bonus)":** this category, amounting for a 10% on the final score, have been calculated as an average of two ranks: the first one was obtained by getting the LNG rank presented and dividing by half the value if any natural gas pipeline is available within the borders of the country; the second rank was obtained by collecting and ordering the data about the number of electrical interconnections for every country, successively dividing by half the value if any shared power plant is installed at the country's border. Each of these ranks amounted for a 5% on the total percentage. This category is associated with a pink color in the below chart.

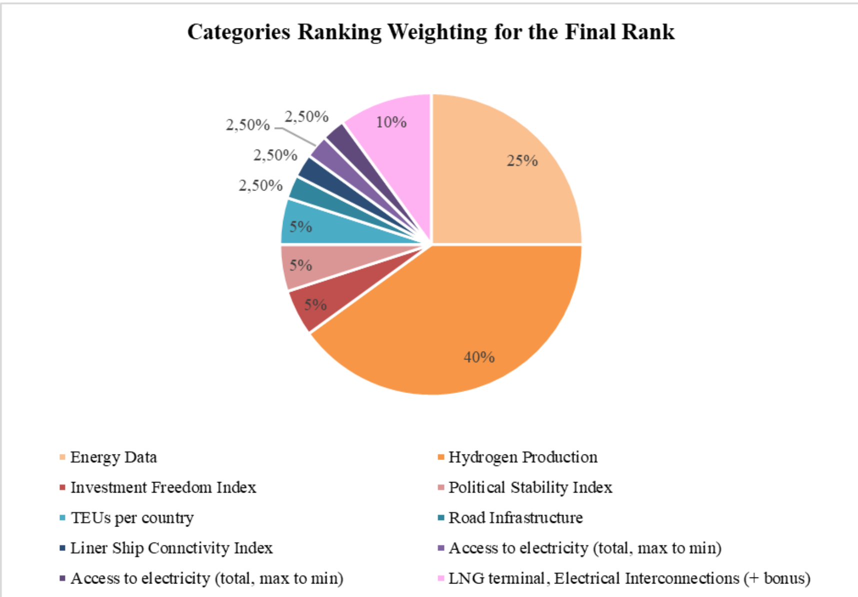


Figure 9: Categories Ranking Weighting for the final rank

2.4.2.2 Ranking Results Presentation

The comprehensive ranks for 2023 and 2040 are hereunder presented.

It's relevant to specify that these rankings are actually the balanced product of all the parameters presented in this thesis, therefore the countries located in higher position could have obtained a good score due to great hydrogen potential combined to average or good infrastructure, or a medium hydrogen potential but combined with a great infrastructure system and political situation. Hydrogen potential production occupies the biggest share of the total score (40%), reaching 65% by also considering the energy data; however, all the other scores leaded to a disadvantage of several countries, that even if with a great hydrogen potential, have poor infrastructure, lack in electricity facilities, or have a dangerous political situation. For instance, DRC scored first in the 2040 hydrogen production rank (*Tab. 21)*, but lacking infrastructure and access to electricity, combined with very low political stability and a closed economy resulted in a drop to 6th place. Despite that, if compared with the 2023 final rank, DRC increased significantly its potential due to the enormous increase of installed hydropower capacity that is expected to be deployed in the next years. On the other hand, South Africa didn't appear in the 2023 rank due to its fossil surplus, that couldn't guarantee any green hydrogen production; with its expected transition to renewable energy, South Africa scored 7th in the green hydrogen rank, but its extended road system and efficient port infrastructure allowed to reach the 3rd position in 2040, even if either its socio-economic parameters are not the greatest, if compared with other countries. The energy data are highly influenced by energy consumption since it changes the value of the Net Energy Surplus: for instance, Angola has currently a great renewable production but its low access to electricity and general low inhabitants number, resulted in a great hydrogen production; in 2040, Angola is expected to produce just a little more than the double of its actual production, that causes to drop from 2nd place to 12th. Morocco and Egypt both have a good green hydrogen potential, combined with a good infrastructure system, as well as interconnections with bordering countries; in the whole African panorama, Morocco, Egypt, and South Africa are all strong economies that will surely be protagonists within hydrogen production and export

Tab. 22 – Final Rank 2023 Vs Final Rank 2040

RANK 2023	COUNTRY	SCORE
V1	Egypt	3,59
2	Angola	6,63
3	Morocco	9,57
4	Nigeria	10,13
5	Ethiopia	10,85
6	Kenya	10,97
7	Ivory Coast	11,20

RANK 2040	COUNTRY	SCORE
1	Morocco	4,62
2	Egypt	4,92
3	South Africa	6,26
4	Algeria	6,41
5	Mauritania	8,67
6	D.R.C.	10,31
7	Ghana	11,06

8	Sudan	11,63		8	Nigeria	11,51
9	Tanzania	13,9		9	Namibia	11,92
10	Uganda	15,43		10	Kenya	12,02
11	Zambia	15,54		11	Ethiopia	12,67
12	D.R.C.	15,61		12	Angola	12,75
13	Malawi	17,33		13	Tanzania	12,9
14	Namibia	17,77		14	Tunisia	13,24
15	Guinea	18,06		15	Cameroon	15,11

2.4.2.3 Assessment of High, Medium and Low Priority countries

In this final section the result obtained by the previous analysis will be compared with the projection studied by the Africa Hydrogen Partnership. According to African Hydrogen Partnership (who is managing a living low carbon hydrogen database, constantly updated by the partner), African countries' commitment to developing green hydrogen projects can be segmented in three categories depending on the degree of maturity of their hydrogen strategy definition as well as on the analysis of locally in place initiatives. The first category, the "Tier 1", includes all the countries with rather well defined hydrogen strategy: all these countries have released national hydrogen roadmaps or have significant project regarding green hydrogen production, as well as projects about renewable power to be installed; the main projects enhanced by these countries have already been reported in *D1.1* and more initiatives will be presented in chapter 3.

The second tier of the AHP's study reports a series of 13 countries with elements of hydrogen ambition available: this means that no official roadmap has been released, however, hydrogen production may be mentioned in renewable energy act or policies. These countries may also have signed MoU or other agreements in order to produce green hydrogen, but these projects are still at their early stage.

The Tier 3 includes all the countries with no hydrogen ambition expressed.

Since the AHP report is exclusively based on expressed declaration for each African country, several countries with great renewable potential or well-developed infrastructure but no available framework are not considered; for instance, Ethiopia has already today a great amount of renewable energy from hydropower, Tunisia and Algeria are connected to Europe with gas pipelines, which are essential for hydrogen delivery. In the AHP's third tier feature relevant countries as Ghana, Mozambique, and Nigeria which, as is possible to see by comparing the ranks previously presented, have great hydrogen potential, as well as significant infrastructure system.

This tier system can be reproposed as well by using the data collected during this study and the evaluation previously discussed. By looking at the scores reported by the countries, it's possible to draw up four tiers for 2023 and four tiers for 2040. With reference to the scores reported in *Tab.22*, the UNIGE tier system have been decided on these criteria:

- Scores 1 to 10 – Tier 1 (2023 and 2040)
- Scores 11 to 20 – Tier 2 (2023)
- Scores 11 to 15 – Tier 2 (2040)
- Scores 21 to 30 – Tier 3 (2023)
- Scores 16 to 25 – Tier 3 (2040)
- Scores > 30 – Tier 4 (2023)
- Scores >25 – Tier 4 (2040)

The need for changing the criteria depending on the time period is due to the increasing scores of some countries from 2023 to 2040, which leaded to a similar number of countries for Tier 1, but a significantly increased number for the "11 to 20". The UNIGE tier system is specifically not based on declared target, but on existing and verifiable data; this concerns some relevant differences, as well as similarities, between the two methods. For instance, South Africa, which features Tier 1 in the AHP report, features UNIGE Tier 3 since despite great score in almost every non-energetic parameter, its energy production currently relies on fossil fuels, such as carbon and natural gas, therefore its Net Energy Surplus cannot be used for green hydrogen production, at least in a short-term period of time. The second tier drawn up by the AHP corresponds mostly with the 2040 Tier 2 and part of Tier 3, even if several countries such as Djibouti, Niger, and Botswana, based on the UNIGE assessment, have very low green hydrogen potential, mainly due to their energy deficit situation. Regarding AHP's Tier 3, Ghana, Tanzania, and Nigeria represent the biggest difference with the result of this thesis: Nigeria is classified in Tier 1 for 2023 and Tier 2 for 2040, due to its big renewable surplus and underway infrastructure, while Ghana and Tanzania are both in Tier 2 in 2040, while Tanzania is in Tier 2 in 2023. These countries may not be expected to produce big quantities of green hydrogen, but Ghana in particular has a good potential from a socio-economic point of view, since its positive political stability and economic freedom. Other than that, despite its limited geographical extension, Ghana develops a good road system and has good shipping infrastructure, for these reasons Ghana is 7th in the 2040 projection, if all its renewable power facilities will be built as planned. Another country which could be potentially in Tier 1 is Tunisia, mainly for its direct connection with Italy through gas pipeline; other than that, several projects and MoU are being signed, therefore new projects may be soon released, as well as the attended official hydrogen strategy. In both AHP tier 3 and UNIGE tier 4 feature all the countries which don't have particular relevance for a potential hydrogen market, such as insular countries, archipelagos and all the countries with unavailable data: unfortunately, some specific data may be not reliable or updated, especially for the countries which suffer bad economic condition or internal conflict.
In the table in the next page the AHP and UNIGE tier system are presented and put side by side.

AHP			UniGe – 2023				UniGe – 2040			
Tier 1	*Tier 2*	*Tier 3*	*Tier 1*	*Tier 2*	*Tier 3*	*Tier 4*	*Tier 1*	*Tier 2*	*Tier 3*	*Tier 4*
Algeria	Angola	Benin	Egypt	Ivory Coast	Sierra Leone	Rep.of Congo	Morocco	Ghana	R. of Congo	Gabon
Egypt	Botswana	Burkina Faso	Angola	Sudan	South Africa	Gabon	Egypt	Nigeria	Ivory Coast	Guinea
Kenya	Cameroon	Burundi	Morocco	Tanzania	Ghana	Togo	South Africa	Namibia	Zambia	Sierra Leone
Mauritania	Ivory Coast	Cape Verde	Nigeria	Uganda	Algeria	Mauritius	Algeria	Kenya	Mozambique	Togo
Morocco	Djibouti	CAR	Ethiopia	Zambia	Cameroon	Eq. Guinea	Mauritania	Ethiopia	Sudan	Gambia
Namibia	DRC	Chad	Kenya	DRC	Mozambique	Madagascar	DRC	Angola	Uganda	Madagascar
South	Ethiopia	Comoros		Malawi	Senegal	Lesotho		Tanzania	Guinea	Benin
Algeria	Niger	Rep. Of Congo		Namibia	Tunisia	Mauritania		Tunisia	Senegal	Liberia
	Senegal	Eq. Guinea		Guinea	Zimbabwe	eSwatini		Cameroon	Malawi	Mauritius
	Togo	Eritrea		Ruanda		Benin			Mali	Burundi
	Tunisia	eSwatini		Mali		Liberia			Ruanda	Niger
	Uganda	Gabon				Libya			Zimbabwe	Burkina Faso
	Zambia	Gambia				Botswana			Libya	Guinea-Bissau
	Zimbabwe	Ghana				Cape Verde			Lesotho	Eritrea
		Guinea				Burundi			Botswana	Djibouti
		Guinea-Bissau				Seychelles				eSwatini
		Lesotho				Burkina Faso				Cape Verde
		Liberia				Gambia				Seychelles
		Libya				Djibouti				S. Tomé & P.
		Madagascar				Eritrea				Comoros
		Malawi				Niger				Chad
		Mali				S. Tomé & P.				Somalia
		Mauritius				Somalia				CAR
		Mozambique				CAR				South Sudan
		Nigeria				Guinea-Bissau				
		Rwanda				Comoros				
		S. Tomé & P.				Chad				
		Seychelles				South Sudan				
		Sierra Leone								
		Somalia								
		South Sudan								
		Sudan								
		Tanzania								

2.5 Conclusions of UNIGE Study

The aim of the presented study was to evaluate the green hydrogen potential of each African country not only looking (as usual) to renewable energy potential (which is known and significant), with deeper considerations including socio-economic conditions, transport infrastructure and parameters about electrical grid extension.

The goal of the assessment was also to compare the results obtained in terms of green hydrogen production with the import needs for Europe declared in the RePowerEU plan, eventually identifying the most strategic countries which could be protagonist in a synergic hydrogen economy between Europe and Africa.

The analysis took into account multiple parameters which are influent not only from an energetic point of view but are significative particularly looking at investment that EU countries could put in place in Africa in terms of electrolyzers installation as well as setting up of strategic commercial routes and energy infrastructure for the import of this green hydrogen as well in order to further diversify energy supply and set up economic agreements. Several limitations of the study surely include the partial uncertainty of the data that have been used to calculate the 2040 scenario, especially the evolution of the political backgrounds which are currently unstable and cannot be predicted in a long-term view; also, some countries have very lacking or not updated data, which could be in contradiction with each other, or may be unavailable or unreliable.

The overall result of this study lead to the following considerations:

- The final rank is the product of different parameters which have been weighted differently, with hydrogen production accounting for a 40% of the total score, followed by a 25% for energy data. The remaining share accounts for socio-economic, civil, energetic, and energetic infrastructure.
- The total hydrogen production calculated in 2023 is equal to 0,6 Mt
- The total hydrogen production calculated in 2040 is equal to 12,6 Mt
- Egypt, Angola, Morocco, Nigeria, and Ethiopia are the most strategic countries in the 2023 horizon analysis, with particular attention to Morocco and Tunisia for their direct connection to Southern Europe via gas pipeline
- Morocco, Algeria, South Africa, Egypt, and Mauritania are the most strategic countries for the 2040-time horizon, considering their significative future renewable installed power capacity
- Morocco, Egypt, Algeria, Kenya, Namibia, South Africa, and Mauritania released hydrogen strategies, while Mauritania (who just released a pre-official policy) and Tunisia strategies are still under development despite this great potential highlighted above.

In order to proper follow up this first study, surely proved the possibility to produce large quantities of hydrogen from renewable sources, it's equally important to consider how to use it in a sensible and environmentally convenient way, based on the production country; for instance, looking from an European import perspective, northern African countries may be the most indicated for pure hydrogen export via gas pipeline injection, since exporting green hydrogen via fossil-fueled cargo ships which should cover entirely the distance from Southern Africa to Europe would be incoherent

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with the overall decarbonization goal and energetically very inefficient. However, Sub-Saharan countries could anyway benefit from the decarbonization of hard-to -abate industrial sectors: since Europe already currently imports several industrial product from Africa (steel, ammonia, chemical, fertilizers…), green hydrogen would allow to make carbonless a significative part of these product's supply chains, giving the chance for EU to import more sustainable products.
It's significative to highlight that the final ranking which has been presented is the outcome of the specific methodology approach that has been used: in other words, the scores calculated for every country not always give back a feasible and realistic output. For instance, DRC, as already discussed, ranks in the 2040's tier one even if for lack of the overall infrastructure system is practically very unlikely to be a "landing country", on the other hand, Morocco and Namibia may be considered as a "successful" output of the study, as Morocco is among the frontrunner countries in the hydrogen policies panorama, while Namibia was "disadvantaged" just enough in the final rank score.

For these reasons, it is still important to evaluate and consider each parameter individually.

In order to further improve this study, several enhancements might include the tracking of the energy import and export flows within the power pools between cross border countries, a deeper analysis of the African geopolitical scenario which may influence hydrogen supply, as well as an evaluation of how the current under-utilization of the power plants, especially hydro power, may influence green hydrogen production; finally, a sustainable transition should count a social factor other than the economic and environmental ones, by ensuring that the legal frameworks and the regulations adopted ensure technological improvement, economic growth and better conditions for the entirety of both African and European population, and not only a profit opportunity for stakeholders or limited circle of people. As reported by the Hydrogen Fact Sheet made by GIZ, most of north African countries shows socio-economic inequalities and conflicts, as well as high water stress: the sustainability criteria should consider not only the energy input, but the entire life cycle of hydrogen technologies such as fuel cells and electrolyzers, including soil use, water stress, usage of rare earth elements. A critical socio-economic situation, such as a very unequal income distribution within the population, could lead to the fact that only few people will benefit from hydrogen export; moreover, some countries still suffer from low human right standards, with no regulation convicting phenomena as slavery, exploitation of child labor and workers mistreatment. For this reason, regulatory laws and cooperation with international association are essential to create the right conditions for a real environmental benefit and just development.

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3. LOW CARBON HYDROGEN ON-GOING INITIATIVES IN AFRICA

As briefly presented in D1.1, it is relevant to highlight that despite its great potential, not so many African countries have developed their own hydrogen strategy, not they had a specific mention to hydrogen in their clean energy roadmaps.

The overall study presented in this chapter started from an assessment of the on-going/existing hydrogen policies in African countries.

Despite their significance, this data have not been directly used throughout the calculation of green hydrogen production assessment presented in chapter 2 and don't condition the final rankings of the overall study presented in chapter 2 nor the "Local assessments" presented in chapter 5. However, this chapter, realized with AHP support, provides a state-of-the-art view of green hydrogen policies in Africa, as well as a useful tool to compare countries intentions and the actual numbers that have been successively calculated.

Some difficulties were encountered during this stage of the research, since the documents concerning hydrogen implementation were frequently unclear and explicit numbers were rarely mentioned, especially for the least developed countries and in non-official documents; also, several sources could be considered as "reliable", such as scientific papers and national road maps (even if numbers are very often overestimated), while most sources such as press websites may be not so reliable, as information were exposed roughly and references were not mentioned.

It's relevant to highlight that only few countries have setup H2 plans (Egypt, South Africa, Morocco, Namibia, Algeria, Kenya) as presented in the next paragraphs; at the same time, several private enterprises signed for developing renewable power projects in order to set up green hydrogen production and export. The table below presents the green hydrogen production targets and the relative RES production for the countries which released official framework or have significant announced projects or signed MoU.

In addition to those, several relevant announcements and projects involve the countries of Angola, Ghana, Ethiopia, Uganda and Tunisia; regarding Tunisia, other than a great esteemed potential of 5,5 to 6 Mt of green hydrogen export, its strategic position toward Italy and the possibility to use the Trans-Mediterranean gas pipeline for hydrogen transportation make this country potentially ideal for hydrogen hubs and export to Europe; despite that, Tunisia's hydrogen roadmap is still under development and is expected to be released within 2023. Another country which represents a singularity among all the other is Mali: in the area near the village of "Bourakebougou" an underground hydrogen reservoir have been discovered, presenting unique geologic and geothermical features; the so-called "white" hydrogen, could have important developments in the next years, not only for the large quantities of hydrogen naturally hidden in the earth surface, but also for his potential underground storage in geological formations, such as subsurface depleted oil and gas reservoirs, aquifers, or cavern storage.

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For all the remaining countries, there is no programmed hydrogen road map and not much information can be found either about green hydrogen external projects, other than few announcements or agreements at the earlies stage, therefore no particular numbers or data have been specified yet.

3.1 On-going commercial, implementation and market ready initiatives about low carbon hydrogen currently promoted in Africa.

Africa is at the forefront of the global shift toward renewable and sustainable energy, with a focus on low-carbon hydrogen initiatives gaining traction because hydrogen can replace fossil fuels. As an example, Europe wants to raise its reliance on hydrogen as a source of energy from 2% now to 14% by 2050, achieving 50% of its hydrogen requirement through low carbon hydrogen by 2030 (Biogradlija, 02-2022). Africa's enormous potential of large landmass, abundant renewable energy resources such as solar, wind, hydropower and low labour costs can significantly reduce the cost of hydrogen production compared to other regions and make the continent a strong contender to produce a significant proportion of the world's low carbon hydrogen requirements.

According to Norwegian energy analyst Rystad Energy, to date African countries have announced a total of 52 low carbon hydrogen projects. Combined, these projects could produce a total of 7.2 million tons of hydrogen by 2035, amounting to 114 GW of electrolyzers. Having said that, only 13 MW have so far received a financial commitment. The major challenges to developing these projects are both the cost and complexity of developing the associated energy infrastructure and the need for financial investment (Rystad Energy, 2023). The African Development Bank (AfDB) has launched the Hydrogen Initiative to support the development of a low-carbon hydrogen value chain in Africa. The initiative focuses on promoting policy dialogue, research, and financing for hydrogen projects on the continent (AfDB, 2022). Over the last ten years the European Investment Bank has provided €5.3bn for green infrastructure investments in Africa, including hydrogen projects. According to AGHA, the cost of creating a low carbon hydrogen economy in AGHA's six member countries would require $450bn-$900bn of investment by 2050 (Financial Times, 2023). To put this into context, the IMF stated that fossil fuels were being subsidized at a rate of $13m a minute 2022, i.e. oil, gas and coal benefited from $7tn in support in 2022 despite being the primary cause of the climate crisis (Carrington, 2023) Separately, "Ukraine has received over $230 billion in aid since the Russian invasion in 2022. EU institutions and the U.S. together account for almost 70% of the total aid." (Visual Capitalist, n.d.)

These low carbon hydrogen projects are spread across a number of African countries and will undoubtedly alter the dynamics of the world's energy environment and have a direct influence on trade and business on the continent of Africa. Currently, a significant amount of the activities ongoing in Africa are focused on demonstrations of interest, feasibility studies and national hydrogen policy formulation. The current landscape of commercial and implementation market

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initiatives in Africa are in Northern Africa: Mauritania, Egypt, Morocco; East Africa: Kenya; and in Southern Africa: Namibia, South Africa, and Angola. Other African countries will also be involved in the transition to low carbon hydrogen, although it is likely that this hydrogen will be utilized domestically for energy, fuel, and industrial uses.

In close collaboration with the African Hydrogen Partnership (AHP), the only continent-wide African Hydrogen Association, Hydrogen Europe et al. published the paper "Green Hydrogen for a European Green Deal - A 2x40 GW Initiative" which paved the way for the EU's REPowerEU Initiative in April 2020 (van Wijk & Chatzimarkakis, 2020). As part of the REPowerEU initiative, the EU set a target of 10 million tons of domestic renewable hydrogen production and 10 million tons of imports by 2030, to replace natural gas, coal and oil in hard-to-decarbonise industries and transport sectors (REPowerEU, n.d.).

The Africa Green Hydrogen Alliance (AGHA) was started in 2021 to serve as a catalyst for pan-African momentum toward low carbon hydrogen (African Green Hydrogen Alliance, 2022). The member countries are Egypt, Kenya, Mauritania, Morocco, Namibia, and South Africa, with Angola and Ethiopia joining in 2023. According to a recent report by AGHA, the European Union, Middle East, Japan, and South Korea have been identified as priority export markets for low carbon hydrogen. Repurposed pipelines have been highlighted as the least costly method to transport hydrogen internationally. Due to North Africa's proximity to Europe and existing pipelines which run from Algeria to Spain and Italy, and from Libya to Italy, exports of hydrogen are expected to dominate in the long term from North Africa to Europe. There is the potential for this export market to reach 17 million tons by 2050 (African Green Hydrogen Alliance, 2022). For Namibia, South Africa and other countries in Southern Africa, the AGHA and other initiatives predict that hydrogen export will be through alternative means such as ammonia, methanol, or synthetic fuel, with a similar sized market and potential to reach 13 million tons (hydrogen equivalent) by 2050. Based on AGHA's predictions for 2050 landed costs of ammonia, multiple AGHA member countries could be among the top ten suppliers to Europe. For European exports, the lowest cost African countries are Morocco, Mauritania, closely followed by Egypt. In comparison, for exports to Japan, African countries South Africa, Namibia and Egypt are leading (African Green Hydrogen Alliance, 2022).

Ongoing low carbon hydrogen commercial and implementation initiatives range from memorandum of understanding agreements, feasibility studies, ambitious pilot projects to strategic collaborations between governments, industries, and international stakeholders. The applications of hydrogen within these initiatives range from energy transportation, vehicular and airline fuel, industrial application such as manufacture of iron and steel, grid balancing related to storing of renewable energy and agricultural uses including fertilizer. In Africa, Egypt currently has the largest low carbon hydrogen initiative pipeline, with 21 projects amounting to 2.5 million tons by 2035. Morocco is in second place, with 1.6 million tons by 2035, followed by Mauritania, South Africa, Namibia, and Angola (Rystad Energy, 2023). The African countries that currently demonstrate the most relevant potential are highlighted in picture below where the possibility to use locally produced green hydrogen is foreseen for both domestic and export markets.

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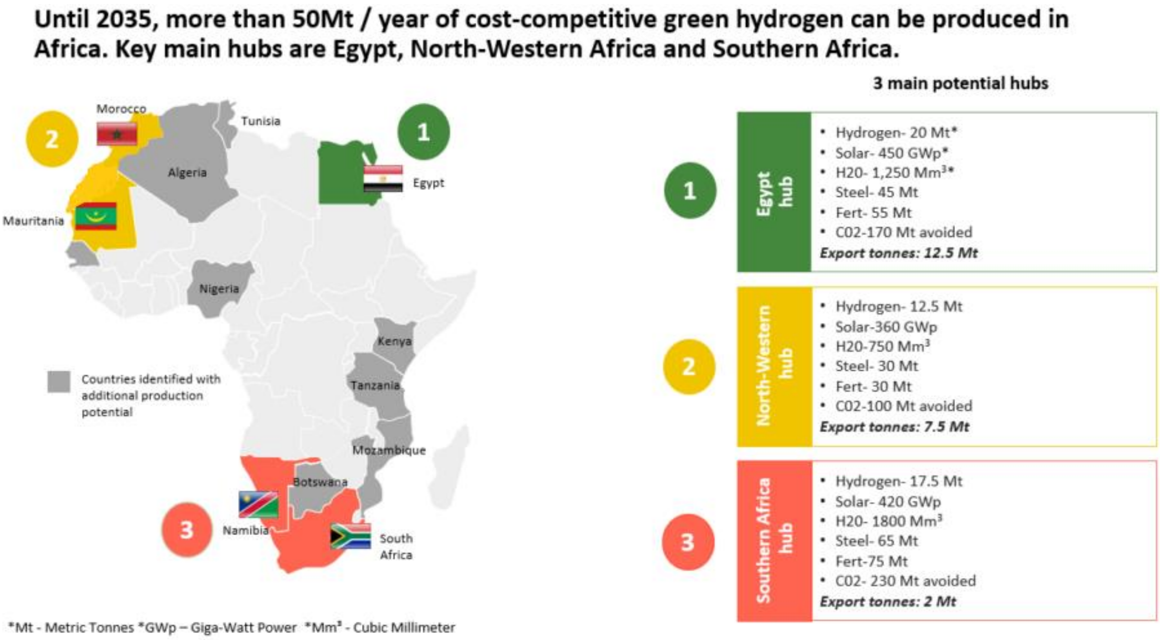

Figure 10: African countries with relevant hydrogen project looking at export and domestic markets

3.1.1 Angola

Angola's vast fossil fuels resources and abundance of water have created an opportunity for low carbon hydrogen development in the country. Angola does not have a hydrogen strategy but to signal its commitment to low carbon hydrogen in late 2023, Angola also joined the AGHA, alongside the original 6 member countries. Angola has no gas network so instead it plans to generate low carbon hydrogen and then use a combination of hydrogen storage and conversion to ammonia to export to other countries. One such initiative includes an agreement between the Angolan owned company Sonangol and Germany's H2Global green hydrogen auction platform to export low carbon ammonia. Exports of ammonia are expected to start in 2024 as part of a 10-year contact. This would potentially make Angola the first African nation to produce and export hydrogen (Biogradlija, 06-2022).

In addition, the Angolan government and Chevron, through Cabinda Gulf Oil Co. Ltd recently signed a MoU to investigate the feasibility of a broad range of emission-related initiatives, including hydrogen generation, carbon offsets, carbon capture, and biofuels (Biogradlija, 06-2022).

3.1.2 Djibouti

Djibouti does not have a hydrogen strategy, though hydrogen is included in its long-term strategic vision for the country "Vision 35" (Ministère de l'Economie et des Finances Charge de l'Industrie Djibouti, n.d.). The Djibouti government believes that it has the potential to become a major player in hydrogen due its location close to the Suez Canal, significant solar and wind resources, abundant available land, and easy access to the sea (Collins, 2022). Initiatives in Djibouti are currently limited to a 2022 MoU between the Djibouti government and Australian based energy company CWP

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Global. This agreement is regarding their intention to construct CWP Djibouti Hydrogen Solar PV Park. The project is a 10,000 MW solar project set to start construction in 2025 and begin operations in 2027 (Jacobo, 2022).

3.1.3 Egypt

Egypt aims to be one of the large exporters of hydrogen in Africa and it is in a strong position to achieve this. This is based on Egypt's location as a crossroad to Africa, Europe, and Asia; its control of the Suez Canal; being home to a wide range of energy intensive industries; and its leading deployment of renewable energy generation projects. In the 58th edition of Ernst and Young's Renewable Energy Country Attractiveness Index, Egypt was ranked 19th (Morocco was ranked 16th), but no other African countries were included in the top 30 countries (Ernst & Young, 2021). According to Rystad Energy, Egypt is currently leading in Africa, in terms of its low carbon hydrogen initiative pipeline, with a total of 21 projects (Rystad Energy, 2023). One of these initiatives is the Masdar Ain-Sokhna project located in the Suez Canal Economic Zone. It includes the construction of an $8 billion low carbon hydrogen plant using a 4 GW electrolyser and is expected to produce 2.3 million tons of low carbon ammonia annually. A 2021 MoU signed between Egyptian Electricity Holding Company and Siemens Energy includes exploration of hydrogen production, storage, transportation, and expansion of renewable energies (Siemens Energy, 2021). Other projects in Egypt's hydrogen project pipeline include financing for firm Egypt Green Hydrogen SAE to construct a 100 MW electrolyser and a $3.5 billion project by Saudi Arabia's Alfanar to produce low carbon ammonia.

3.1.4 Ethiopia

Ethiopia has recently published its hydrogen strategy which highlights the eastern region of Ethiopia for hydrogen investment. This is based on an abundance of underground water, an electric grid linked to Djibouti and existing renewable energy projects in the area. The railway network has also been highlighted as a method to transport hydrogen to Djibouti for export. In late 2023, Ethiopia (and Angola) joined the AGHA, alongside the original 6 member countries (Foundation Office Ethiopia / African Union, n.d.). A number of countries including Germany and America have shown an interest in investing in the area, though these agreements are in the early stages and further details are not available (Endale, 2022).

3.1.5 Kenya

Kenyan opportunities will be deeply presented in Chapter 5 but compared to some of the other African countries such as Egypt, Morocco and Mauritania, Kenya does not yet have the same scale of hydrogen initiatives. Kenya launched its Green Hydrogen Strategy and Roadmap at the Africa Climate Summit in 2023. As part of Kenya's Green Hydrogen Strategy, the EU agreed to invest €12m into Kenya's renewable energy infrastructure, supporting Kenya's plans to reach 100%

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renewable electricity by 2030 (African Business, 2023). Since 2022, Kenya has officiated a number of low carbon hydrogen initiatives.

In 2022, Kenya signed a framework agreement for collaboration with an unidentified investor to produce 30GW of low carbon hydrogen. Around the same time, a second agreement was signed with Australian company Fortescue Future Industries to construct a 300 MW low carbon ammonia fertilizer facility, starting in 2025. The facility will use existing geothermal capacity to produce hydrogen. The same FFI-Kenyan consortium is also looking to conduct two feasibility studies focused on scaling renewable energy generation, with the potential to produce and export up to 1.7 million tons annually (Hydrogen Insight, 2022).

Other low carbon hydrogen initiatives in Kenya include "KenGen" Green Hydrogen feasibility study which is intended to lead to a pilot project to manufacture a low carbon hydrogen, ammonia, and fertilizer plant (Green Hydrogen Organisation, n.d.). Another initiative is Renewstable Kenya project, which is a collaboration with "Hydrogène de France" to deploy a 180 MW photovoltaic solar farm combined with a 500 MWh hydrogen battery storage unit (Africa Business+, 2023). The Kenyan government in collaboration with Dubai-based AMEA Power company will be constructing a low carbon hydrogen facility with a 1 GW electrolyser in the port of Mombasa. The facility will use geothermal energy to power the electrolyser (Green Hydrogen Organisation, n.d.).

The Ministry of Energy of Kenya in partnership with the German Development Cooperation created a substantial report in 2022 which details the potential for low carbon hydrogen in Kenya. The report highlights potential to produce hydrogen and fertilisers. A number of locations were assessed, and pilot projects suggested, including projects in Mombasa and Lake Lurkana (Koros, 2022).

3.1.6 Mali

In Mali, a reserve of natural hydrogen has been discovered. Natural hydrogen, also referred to as white hydrogen, was initially discovered by accident in the village of "Bourakébougou" in western Mali in the 1970s. More recently, company "Hydroma" has been carrying out extensive surveying of the region finding that the natural hydrogen reserves cover an area of more than 8 km.

The study of natural hydrogen is a relatively new field and there are a number of theories about how the gas is produced. According to "Hydroma", such reserves are fluid, with the ability to regenerate or refill over decades, in comparison to fossil fuels which take millenia. These properties could mean natural hydrogen could be harnessed as a competitively priced source of renewable energy (Hydroma, n.d.). Natural hydrogen has also been found in Europe, Australia, and North America (Prinzhofer & Prinzhofer, 2018). A number of start-up companies have begun exploring these opportunities, with Some oil companies including Total, Engie, Repsol making moderate investments into exploration for natural hydrogen.

For over 7 years the village of Bourakébougou has been participating in Hydroma's non-commercial pilot project, benefiting from free electricity generated from the natural hydrogen. Hydroma has begun the exploitation phase which will use natural hydrogen for large scale national and

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international uses including electricity generation, transport, and other applications. The extent of the natural hydrogen reserve in Mali is currently unknown (Hydroma, n.d.).

3.1.7 Mauritania

Mauritania has the potential and is positioning itself to become a major player in the low carbon hydrogen market. This is based largely on its close proximity to Europe. The country has the potential to develop a significant iron and steel production sector which could benefit from the production of low carbon hydrogen. Though Mauritania is yet to publish its Green Hydrogen Roadmap it is working hard to develop a range of commercial agreements (Green Hydrogen Organisation, n.d.). According to AGHA, the landed cost of ammonia between now and 2050 could be similar for both Morocco and Mauritania (African Green Hydrogen Alliance, 2022).

There are currently three main low carbon hydrogen commercial and implementation market projects in Mauritania namely Project Aman, Project Nour and Green Steel with ArcelorMittal, all of which are at the MoU stage. Project Aman is an agreement between the Mauritanian government and Australian renewable energy company CWP Global to develop a low carbon hydrogen facility. The construction costs are $450 billion. It will have hybrid renewably powered wind and solar generators with a capacity of 30 GW will generate 110 TWh of electricity annually, producing 1.7 million tons of hydrogen (CWP Global, 2021). Similarly, Project Nour is a MoU between Chariot energy company and the Mauritian government, following the completion of a feasibility study. The project could be one of the world's largest low carbon hydrogen plants, with a potential capacity of 10 GW. Finally, state backed Société Nationale Industrielle et Minière de Mauritania has signed an MoU with ArcelorMittal to construct a renewably powered steel manufacturing site. The project is set to produce 3.5 million tons of low carbon steel (Green Hydrogen Organisation, n.d.).

3.1.8 Morocco

Moroccan opportunities will be deeply presented in Chapter 5, nevertheless it is worthy to highlight that Morocco currently has the second largest low carbon hydrogen initiative pipeline in Africa after Egypt, with a potential output of 1.6 million tons of hydrogen annually by 2035 (Rystad Energy, 2023). Morocco established its National Hydrogen Commission in 2019 and published its Green Hydrogen Roadmap in 2021 (Green Hydrogen Organisation, n.d.). Morocco is located in close proximity to Europe, has an established renewable energy sector and has invested significantly to create a secure legal and financial framework to further encourage internal and international investment into its renewable energy infrastructure. As such, Morocco ranks high on the Renewable Energy Country Attractiveness Index (RECAI) (Ernst & Young, 2021).

As early as 2005 NATO's "Science for Peace" financed two hydrogen-based projects in Mauritania and Morocco. The project was based at two universities and harnessed the trade winds that blow along the Atlantic coast from Morocco to Senegal to drive 30 kW wind-based electrolyzers. The hydrogen generated was used for campus power back-up. Today, the Universities are offering renewable and sustainable energy programs, demonstrating their readiness to take these pilot

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programs and the resulting research to develop the skills of a new workforce (Benhamou et al., n.d.,).

Other more recent low carbon hydrogen projects in Morocco include its MoU with the Moroccan government, CWP Global and North American firm Bechtel to build a 15 GW solar hydrogen plant in Amun with a potential annual hydrogen generation of 0.9 million tons (Jacobo, 2022). Total Energies has proposed the construction of a Moroccan 10 GW hybrid solar and wind plant, with the aim of producing 0.7 million tons of low carbon hydrogen annually from 2027 (Green Hydrogen Organisation, n.d.). In November 2023 it was announced that Hydrogène De France (HDF) Energy and Morocco-based Falcon Capital Dakhla plan to develop a 17 GW hybrid wind and solar hydrogen plant with hydrogen production expected from 2028 (Petrova, 2023). The German Moroccan Energy Partnership (PAREMA) agreement will enable Morocco to generate hydrogen and export it to Germany.

3.1.9 Namibia

Namibia has the potential and is positioning itself to become a global leader in low carbon hydrogen exports. This is largely based on its Namibia potential to offer low-cost hydrogen. According to the AGHA, it has the lowest levelized cost for low carbon hydrogen and hydrogen derivatives compared to the other members of the AGHA (African Green Hydrogen Alliance, 2022). This is based on Namibia's access to renewable energy, particularly wind and solar and its scarce population. Namibia released its low carbon hydrogen road map in 2022 at COP27. The strategy focuses on the developing structures, frameworks, and legislation to support the development of the hydrogen industry. This is also underpinned by building knowledge through pilot projects and training (Green Hydrogen Organisation, n.d.).

The Namibian government in collaboration with German company Hyphen Hydrogen Energy has signed a feasibility and implementation agreement for the Hyphen Tsau Khaeb Project, a $9.4 billion initiative that has the goal of producing 350,000 tons of low carbon hydrogen a year from 5GW of renewable energy. Construction is expected to begin in 2025. The German government offered significant financial support throughout the earlier stages of the project (Reuters, 2023). The Namibian government has also signed an MoU with Germany and Netherlands for export of low carbon hydrogen to Europe.

Hydrogène De France (HDF) Energy, the French Power Producer launched into Africa by establishing HDF Energy Namibia in 2021. The Renewstable Swakopmund (RSWK) collaboration between HDF Energy Namibia and the Namibian government is another initiative. It is set to build Africa's first integrated solar-hydrogen project, scheduled to start in 2024 with the aim to increase local generation from 624 MW in 2020 to 879 MW by 2025 (HDF Energy, n.d.). In December 2022, HyIron Oshivela Project was given the formal go-ahead. This initiative uses low carbon hydrogen with direct reduction techniques to produce reduced iron. The project is initially expected to manufacture 15,000 tons of directly reduced iron annually, with a potential to grow to 1 million

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tons iron per year. The initiative is projected to avoid 1.8 million tons of carbon dioxide equivalent annually, with the potential to reduce carbon emissions on a global scale (HyIron, n.d.).

A further pilot which is currently in the finance approval stage is a collaboration between TransNamib, Hyphen Technical, CMB.TECH, and others to pilot hydrogen fueled locomotive technology. The pilot project will involve the conversion of two locomotives and a supporting wagon to transport the hydrogen fuel (Dokso, 2023).

3.1.10 Nigeria

At present, Nigeria does not have a national hydrogen strategy or specific hydrogen projects at the national level. The Nigerian government has recognised the importance of transitioning to cleaner and more sustainable energy sources, setting a net zero target of 2060. As part of this transition there is a growing interest in hydrogen as a potential clean energy source. Nigeria's energy transition strategy recognises the opportunity to leverage the country's natural gas resources to produce hydrogen using carbon capture and storage for domestic consumption and potential export (Ashurst, 2022). Other hydrogen initiatives include the setting up of the German-Nigerian Hydrogen Office in Abuja in late 2021. The office is supported by the German company Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), with the purpose of providing expert advice on hydrogen (Mammoser, 2022).

3.1.11 South Africa

South African opportunities will be deeply presented in Chapter 5, anyhow it's relevant to highlight that South Africa has published its hydrogen roadmap since 2021. The program aims to develop a hydrogen economy leveraging on the country's renewable energy resources. It involves partnerships between the government, industry, and research institutions and includes potential pilot projects and feasibility studies including catalytic green hydrogen hubs, carbon capture, combining hydrogen and pollutants to make value-added products and the adoption of hydrogen fuel cells in a wide range of vehicles and buildings. The program also recommends using the existing natural gas network to transport hydrogen nationally (White Case, 2022).

Currently, within South Africa there are a number of initiatives focusing on sustainable aviation fuel (SAF) including a consortium comprising South African energy company Sasol, Linde, Enertrag and Navitas Holdings and the German H2Global auction platform (Rystad Energy, 2023). A $4.6-billion low carbon ammonia plant is planned with Hive Hydrogen at the Port of Ngqura with construction completion expected 2027, producing 0.78 million tons of low carbon ammonia annually (Hive Energy, n.d.).

The German government has also approved a €15 million subsidy for consortium Linde, Sasol, Enertrag and Hydre-gen Energy to fund the HySHiFT 200 MW electrolyser project in Mpumalanga which will use renewable hydrogen to generate synthetic kerosene. Another project, the Boegoebaai project is a feasibility initiative linked to South Africa's hydrogen program. It is looking

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at the feasibility of a low carbon hydrogen / ammonia export hub in Northern Cape (Green Hydrogen Organisation, n.d.).

Sasol's site in Sasolburg is home to an electrolyser which is being recommissioned to produce low carbon hydrogen. In June 2023 during the commissioning phase low carbon hydrogen was successfully produced, once the site is fully operational in 2024 it is expected to produce up to 5 tons of low carbon hydrogen daily once fully operational in 2024. Sasol has set aside $19 million which includes being connected to a 69 MW solar farm (Creamer, 2023).

BMW in partnership with the South African National Energy Development Institute (SANEDI) and research organisation Hydrogen SA (HySA) have been developing hydrogen fuel cell (H2 FC) vehicles through research, pilot projects, demos and real-world testing. The BMW vehicles use hydrogen fuel cell technology to generate zero-emission electricity. In October 2023 BMW Group South Africa, Anglo American Platinum and Sasol South Africa Limited signed a collaboration agreement to bring H2 FC vehicles and refuelling technology to South Africa. The adoption of H2 FC vehicles is still in the early stages, and challenges include infrastructure development and cost (BMW Group, 2023).

3.1.12 Tunisia

The Tunisian hydrogen strategy is currently under development. Based on Tunisia's location, renewable energy potential, stable political situation the country has potential to become a significant producer of low carbon hydrogen. Domestically, Tunisia could use hydrogen within its steel, iron, and glass industries as well as within farming. It could also be an international exporter of hydrogen, particularly to Europe. There are a number of early-stage international hydrogen initiatives taking place. In 2022 the German government partnered with Tunisia to run a 10-month Bavarian-Tunisian technology and innovation hub for low carbon hydrogen. The initiative focussed on strategic, regulatory and technical knowledge sharing for low carbon hydrogen projects. It also included an academic exchange program (GIZ, 2022). At a recent hydrogen workshop hosted by Austria, the repurposing of the existing gas pipeline between North Africa and Southern Europe for low carbon hydrogen was discussed (UNIDO, 2023).

3.1.13 Zimbabwe

Sable Chemicals produced green fertilizer for decades using renewable energy from the local hydropower dams. The company needed to stop the green fertilizer production in 2015 due to higher energy cost caused by Climate Change which impacted the water levels of the hydropower dams.

3.2. Domestic Market Development

As detailed above, low carbon hydrogen technologies are available within Africa and could be deployed on a large scale. A significant proportion of the ideas, projects and initiatives detailed focus on export, particularly to European countries. These export-based initiatives include many

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assumptions and as a result have innate uncertainty and risk associated with them. To get these initiatives up and running, they will require significant subsidies for the next ten to twenty years.

The cost of hydrogen is based on three components: production; transportation; and making hydrogen available. These components need to be defined: "hydrogen production" can be defined as either finding and accessing naturally occurring hydrogen or making it through a process of electrolysis. "Hydrogen transportation" can be defined as the process of moving hydrogen from its site of production to the site of off-takers. "Making hydrogen available" can be defined as the process or technique of enabling off-takers to access the hydrogen, for example using refuelling vehicles. If any of these three cost components can be reduced, then the total cost of hydrogen is also reduced. It has been established above that the production cost of hydrogen within specific regions in Africa is relatively low. This is due to readily available resources to produce hydrogen at large scale (including renewable energy, abundance of land and access to water). In comparison, hydrogen transportation is very expensive. This is because hydrogen's chemical composition is such that it has a low volumetric energy density. Also, it is highly flammable. So, it is costly to transport hydrogen, particularly over long distances. In contrast if hydrogen is consumed where it is produced, the total cost of the hydrogen is reduced significantly. This means if hydrogen produced in Africa is specifically for local consumption, there is a significant cost saving. As a result, emerging African industries and economies could take advantage of this cost saving in comparison to competitors from hydrogen export markets.

The African Hydrogen Partnership is primarily focused on identifying and developing new domestic low carbon hydrogen opportunities in, and for Africa. African economies are largely based on hard-to-abate sectors including mining, metal production and agriculture. Due to the significant amounts of energy required in these industries, they are difficult to decarbonise with renewable energy alone, but hydrogen can be used as part of this transition. Based on the suitability of low carbon hydrogen for these industries, in addition to the readily available resources in Africa to produce hydrogen at large scale, it is reasonable to expect that over time these industries will move their production facilities to the production sites of hydrogen in Africa. This will in-turn attract foreign investment to Africa.

Large hydrogen export projects require highly subsidised markets, which also require financial derivatives. In contrast, many domestic hydrogen projects could be cash market projects which are less complex and carry less. Currently, the import of costly (refined) fossil fuels is an economic and financial burden for African nations. Domestically produced African hydrogen could reduce this burden. More than 650 million people do not have access to electricity in Africa and the challenge of increasing the power generation and distribution capacities are significant and complex. In many regions of Africa centralized electricity grids cannot be developed easily due inefficiencies, infrastructure costs and security costs.

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To put this problem in perspective, in 2022 the Netherlands reached a cumulative solar PV capacity of 16.5 GW (Bellini, 2023). In contrast, in the same period the cumulative solar capacity of Africa reached around 12.6 GW (Statista, n.d.). Similarly, the Nigerian energy sector illustrates both the power generation and distribution challenges and the hydrogen related opportunities. Nigeria has a total population of 220 million people, and its realized central power generation capacity is 5.5 GW. In comparison, France, Germany, and the UK combined have a similar total population, but a total installed power generation capacity of approximately 450 GW. Since people in Nigeria need access to electricity, a large market of more than 40 GW diesel generators has developed (Statista, n.d.). These generators are highly pollutive. In order to overcome the constraints and restrictions of Africa, hydrogen will be needed. Hydrogen is also a necessity for the decarbonisation of many regions of Africa.

More than 80% of the World's population live in the Global South and many countries in the Global South face similar challenges to those detailed in Africa. The energy market development techniques of Europe and other Global North regions cannot simply be applied to Africa. New approaches are needed that focus on internal market development. Members of the African Hydrogen Partnership are currently working on a range of initiatives that are focused on new commercial concepts to support the creation of new domestic low carbon hydrogen opportunities. Since subsidies are not readily available, the African Hydrogen Partnership initiatives are focused on commercially feasible and financially sustainable projects.

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4. LOW CARBON HYDROGEN POTENTIAL IN DIFFERENT AU AREAS

With a population nearing 1.3 billion and averaging an annual growth rate of approximately 2.5% over the past decade, Africa stands at a critical juncture in its developmental journey. Nearly 50% of Africa's population lacks access to energy, whilst Africa is also experiencing the most adverse effects of climate change. The tri-factor of lack of energy access, adverse impacts of climate change and demographic expansion not only signifies an increasing demand for resources – especially energy – but also necessitates a corresponding expansion in infrastructure to support this growth. Central to the continent's sustainable development, and critical in the global effort to mitigate climate change, is the establishment of a comprehensive energy system predominantly driven by renewable energy sources (RES). This ambitious goal underscores the importance of collaborative efforts and international partnerships, particularly between African and European nations, to devise and implement climate-friendly solutions.

In this context therefore, JUST GREEN AFRH2ICA initiative emerges as a significant collaborative endeavour. It represents a synthesis of African Union (AU) and European Union (EU) experiences and expertise, aiming to explore the potential of green hydrogen (H2) and its derivatives as a primary energy vector. This initiative seeks to balance environmental sustainability with social responsibility, thus contributing to the broader goals of both AU and EU in achieving sustainable development.

The primary aim of JUST GREEN AFRH2ICA is to develop a Green Hydrogen Just Transition Roadmap. This roadmap is envisioned to facilitate a synergistic and sustainable transition for both African and European nations towards hydrogen-based energy systems. A crucial aspect of this roadmap is its focus on avoiding any form of "hydrogen colonisation" of Africa, instead fostering a relationship of mutual benefit and collaboration. This partnership therefore aims to advance the development of independent yet interconnected hydrogen economies, research and development ecosystems, and value chains across both continents.

The initiative is designed to be a foundational step in establishing a collaborative hydrogen roadmap. This roadmap will be developed based on an analysis of various green hydrogen scenarios within the African context, examining socio-economic and technical aspects through the tools and expertise of the involved partners.

In this sense the assessment of the African context (with focuses on specific areas) is of paramount importance and it has been contacted by the four "Area Leader" (IRESEN – North Africa, NWU – South Africa, STRATH – Central Eastern Africa, JULICH – Western Africa) via their own channels and tools, thus both analysing existing literature and policies (as introduced in D1.1), interacting with local stakeholders and thanks to their own experience related to previous studies, modelling tools…

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4.1 Northern Africa Potential Assessment

The North African countries are investing in green hydrogen projects to reduce their dependence on fossil fuels and promote sustainable development. Green hydrogen is produced by using renewable energy sources such as solar and wind power to split water into hydrogen and oxygen. The hydrogen produced can be used as a clean fuel for transportation, heating, and electricity generation. North Africa has abundant solar and wind resources, making it an ideal location for green hydrogen production. The development of a green hydrogen economy in North African countries is expected to create new job opportunities, attract foreign investment, and contribute to the region's economic growth.

The development of a green hydrogen economy in North African countries is a promising and innovative solution to the region's energy challenges. It is expected to reduce greenhouse gas emissions, improve air quality, and enhance energy security. The use of green hydrogen can also help North African countries meet their commitments under the Paris Agreement on climate change.

The emergence of hydrogen initiatives in North African nations presents a profoundly compelling opportunity to establish robust connections with the European Union. This strategic development not only underscores the potential for symbiotic cooperation but also signifies a pivotal turning point in regional energy dynamics. The prospect of leveraging North Africa's abundant renewable resources, such as solar and wind power, for green hydrogen production aligns perfectly with the European Union's ambitious clean energy goals and increasing demand for sustainable energy sources. As both regions share a geographical proximity and an intrinsic need to address climate change and energy security concerns, the collaborative pursuit of hydrogen production and trade opens doors to enhanced economic interdependence, technology transfer, and a strengthened commitment to a greener, more resilient energy future. This pivotal intersection of interests holds the promise of transforming North Africa into a significant green hydrogen exporter while bolstering the European Union's renewable energy portfolio, ultimately fostering a mutually beneficial partnership that transcends borders and fosters sustainable development.

To form the strongest possible international alliance for utilizing Africa's hydrogen potential and creating markets and green wealth in Africa, EU and AU hydrogen stakeholders must indeed work together to facilitate the collaboration between governments, industry, technology and financial institutions and large end consumers of hydrogen across continents. JUST GREEN AFRH2ICA aims therefore to create awareness and to make compelling propositions at 360° (technological – financing – regulatory/policy) for the benefit of AU/EU of developing green hydrogen economies. This sub-chapter t focuses on the current state of the art of the hydrogen economy in the North African region in terms of strategies, policies, orientations, and projects and it has been prepared under IRESEN leadership.

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4.1.1 Morocco Hydrogen Context and general overview

Morocco is in the northwest corner of Africa, bordered by the Atlantic Ocean to the west and the Mediterranean Sea to the north. It shares land borders with Algeria to the east and southeast, and Mauritania to the south. Its strategic location makes it a bridge between Africa and Europe.

Morocco's position on the Strait of Gibraltar at the crossroads of major international communication axes between Europe, Africa, and the Middle East, and good port connectivity make it an important player in regional trade.

Despite lacking hydrocarbon resources like neighboring countries (Algeria, Tunisia, Libya), Morocco has made significant strides in becoming a future renewable energy leader. The National Renewable Energy Strategy launched in 2009, along with the Moroccan Agency for Sustainable Energy, facilitated remarkable growth. Renewable electricity generation surged from 1.7% in 2010 to 20% in 2020, with a parliamentary goal of 52% by 2030. A $40 billion investment plan supports these ambitions. However, coal still contributed 68% to the energy mix in 2020

Morocco's proximity to Europe offers export opportunities. However, addressing logistical challenges is crucial for realizing this potential.

Furthermore, Morocco is in an area that benefits from a high solar radiation potential of more than 3,000 hours per year, equivalent to about 1,825 kWh per square meter. The country has a coastline of 3,500 km along the Atlantic Ocean with a wind speed of between 7.5 and 11 meters per second. The potential of hydropower production is estimated for Morocco at 3700 MW. However, by setting the production of electricity from hydropower at 2000 MW by 2020, only 55% of its potential would be used.

Renewable energy sources, such as solar, wind, and hydro, play a significant role in Morocco's energy landscape, with a total installed capacity of 4,067 MW (Table 23). The National Renewable Energy Strategy launched in 2009, along with the Moroccan Agency for Sustainable Energy, facilitated remarkable growth. Renewable electricity generation surged from 1.7% in 2010 to 20% in 2020, with a parliamentary goal of 52% by 2030.

Table 23 - The installed capacity of renewable energies in Morocco

Renewable sources	Installed Capacity
Solar energy	831 MW
Wind energy	1466 MW
Hydropower	1770 MW
Total	**4067 MW**
Integration percentage	**37.08%**

4.1.1.1 Green hydrogen roadmap

The successful development of the green hydrogen market in Morocco has been attributed to an in-depth understanding of technology, demand, and market size. Several initiatives and studies

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have evaluated the country's potential, including a 2018 study by the World Energy Council and a report by "Dii". Detailed analyses, such as Fraunhofer ISI's in 2019, have explored Power-to-X (PtX) opportunities in Morocco. Specific studies on electrolytic hydrogen and a 100 MW project have also been conducted.

Morocco launched its national green hydrogen strategy in January 2021, which aims to achieve a world market share of 4% by 2030. The country is considering exports, especially to the European Union, as well as its use in the production of ammonia. Morocco accounts for 70% of the world's reserves of phosphates, which are used to manufacture fertilizers that require ammonia.

A green hydrogen roadmap for Morocco has emphasized the potential of PtX across various sectors. Intermediate results have confirmed the socio-economic and environmental benefits of this sector in Morocco. Short-term actions recommend cost reduction and infrastructure development, while medium-term measures focus on electricity storage and PtX regulation in transportation. In the long term, a regulatory framework is needed to extend PtX to heat production.

Morocco has developed a National Roadmap for Green Hydrogen in 2021, which builds on the recommendations and results of previous studies. The document highlights that Morocco has the potential to produce a significant amount of green hydrogen, which could be used to meet local demand, export to other countries, and create new economic and industrial opportunities.

The National Roadmap outlines three main axes for the implementation of the green hydrogen strategy (Figure 11).

The National Roadmap also identifies eight specific actions that need to be taken to develop the green hydrogen sector in Morocco:

1. Cost reduction: Morocco will need to reduce the cost of green hydrogen production by improving the efficiency of solar and wind power plants, developing innovative technologies for hydrogen production, and increasing the scale of production.
2. Research and innovation: Morocco will need to invest in research and development to improve the efficiency of green hydrogen production and develop new applications for the gas.
3. Local content: Morocco will need to increase the local content of green hydrogen production by developing domestic manufacturing capacity for electrolyzers and other equipment.
4. Industrial cluster: Morocco will need to develop an industrial cluster for green hydrogen production, which would bring together companies from different sectors to share resources and expertise.
5. Domestic markets: Morocco will need to create domestic markets for green hydrogen by developing new applications for gas, such as in the transportation and industrial sectors.
6. Technological development and cost savings: Morocco will need to invest in research and development to improve the efficiency of green hydrogen production and reduce its cost.
7. Investment and procurement: The government will need to attract investment in green hydrogen projects and develop the necessary infrastructure.

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8. Market and demand: Morocco will need to create demand for green hydrogen by developing new applications for the gas, such as in the transportation and industrial sectors.

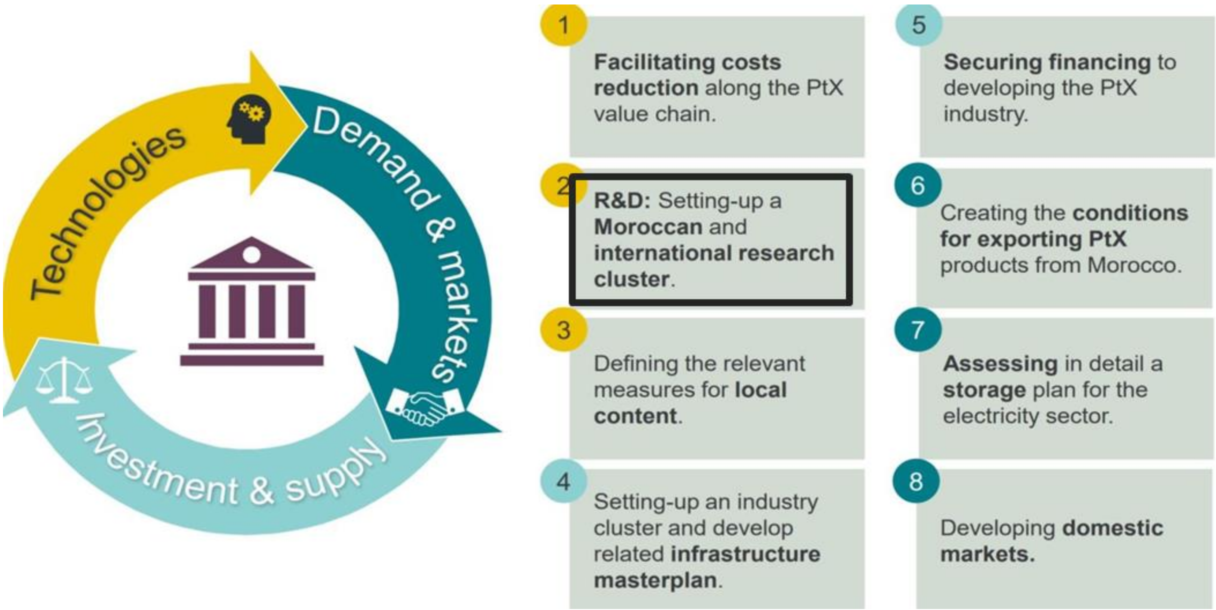

Figure 11: Moroccan national hydrogen roadmap main axes and actions

Morocco has planned to develop green hydrogen in a progressive manner to ensure optimal exploitation of its potential for both the national economy and exportation. The development of green hydrogen will be implemented between 2020 and 2030. In the short term, two pillars will be considered for the development of the green hydrogen industry in Morocco: local use as a raw material in the industry, particularly to produce green ammonia in the fertilizer industry, and the export of green hydrogen products to countries committed to ambitious decarbonization objectives. During this period, the costs of green hydrogen products would remain higher than those of conventional products. The development of the hydrogen industry would be based on various pilot and development projects supported by public authorities and subsidized by national and international financial institutions. In the period between 2030 and 2040, the development of economically viable projects for green ammonia and hydrogen at national and international levels will be possible due to specific favorable conditions, such as the reduction in the cost of green hydrogen products and the implementation of environmental regulations. The adoption of encouraging environmental regulations in importing regions of green hydrogen derivatives such as Europe presents opportunities for Morocco to gradually develop exports of synthetic liquid fuels such as kerosene, diesel, gasoline. The local use of green hydrogen products in the electricity sector, as a carrier for energy storage, and in transportation as a fuel, could support the expansion of the hydrogen industry in Morocco. Pilot projects for these sectors could be launched in the short to medium term to evaluate the technology applications and readapt them to the Moroccan context, with a view to optimizing their long-term deployment.

In the energy sector, green hydrogen can be used as a carrier for energy storage to reduce network congestion and improve the flexibility of the national power system. Between 2040 and 2050, the

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business cases for ammonia, hydrogen, and green synthetic fuels for exportation are expected to improve. The development of green hydrogen technologies and industry is expected to accelerate globally, including in our country. The expansion of this industry will be further facilitated by the local use of green hydrogen in the industry, for heat production, in the residential sector, and in urban mobility as well as air transport. However, the demand for these sectors for green hydrogen or synthetic methane, particularly in the case of the residential sector, is expected to be low due to potentially low demand volumes associated with high investment requirements for the development of major distribution infrastructure. In the transportation sector, long-term development opportunities are primarily in heavy ground transportation and aviation. Some demand may emerge in the transportation sector, likely associated with green hydrogen used for freight, mining, and public transportation in pilot projects (Figure 12).

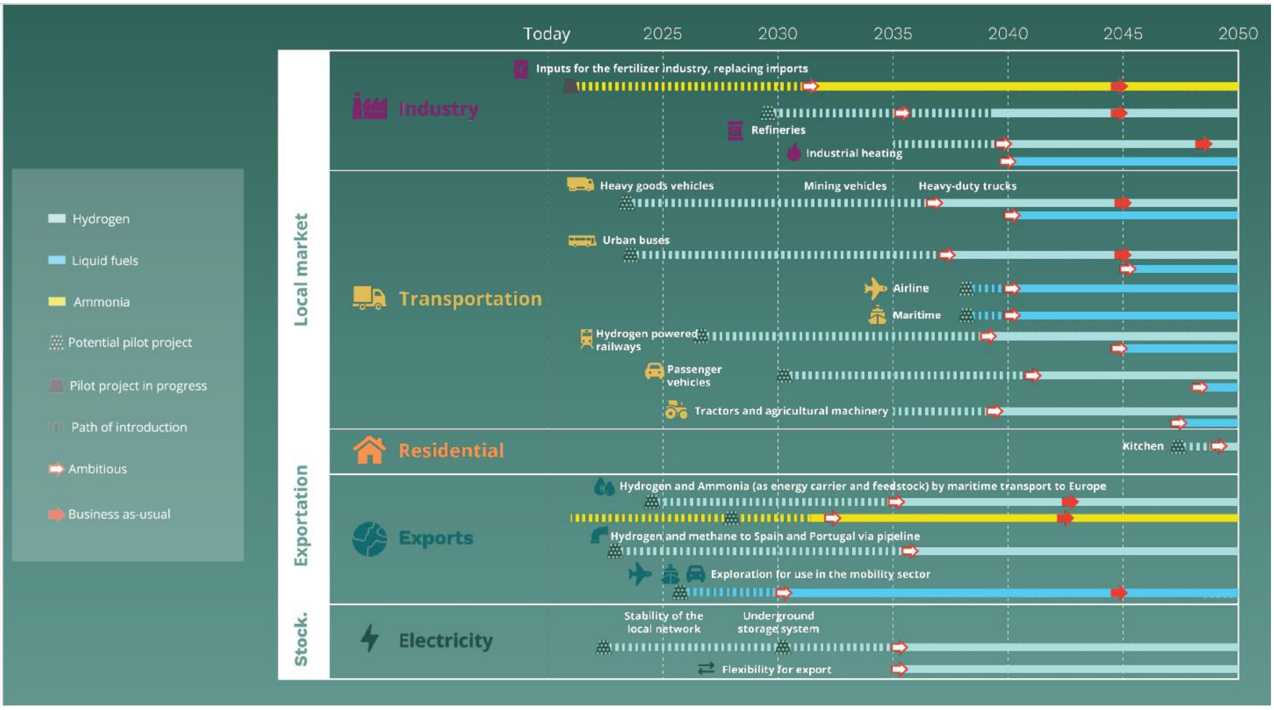

Figure 12: Evolution of green hydrogen usage in Morocco from 2020 to 2050.

4.1.1.2 Green hydrogen stakeholders

The value chain associated with power to X is intricate, encompassing multiple sequential stages. It commences with the generation of electricity derived from renewable energy sources. Subsequently, it proceeds to the phases of seawater desalination and electrolysis and culminates in the production, storage, and transportation of green molecules. This intricate sequence of activities underscores the holistic approach required to harness clean energy and ensure its efficient utilization, spanning from the initial renewable energy generation to the final distribution and utilization of environmentally friendly molecules.

Morocco's public and private sectors are diversified and strong, which is an essential asset for the country. In the renewable energy sector, the Ministry of Energy Transition and Sustainable

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Development and the National Water and Electricity Office (electricity branch) as the Transmission System Operator (TSO) are key players. The Moroccan Agency for Sustainable Energy (MASEN) is responsible for managing renewable energy in Morocco.

The roadmap for water in Morocco clearly states that desalination will be the source of water used for electrolysis. Several public sector players are involved in this, including the Ministry of Transport and Equipment and the National Water and Electricity Office (water branch).

The "Office Chérifien des Phosphates" (OCP) is one of the major potential end users of renewable energy in Morocco. Transport and storage are represented by various players, including the "Office National des Hydrocarbures et des Mines" (ONHYM). R&D and financing are also strongly represented.

A

B

Figure 13: Mapping of stakeholders involved in the hydrogen value chain in Morocco (A: Renewable energies + Desalination + Financing/ B: Transport and storage + End users + Research and development)

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4.1.1.3 Cluster Green H_2: example of stakeholder organization

The Morocco Hydrogen Cluster is a national initiative aimed at organizing the green hydrogen sector and its derivatives. The cluster will achieve this by fostering collaboration among regional players and facilitating connections across various stakeholders. The initiative will take both physical and virtual forms, encompassing economic, relational, and territorial dimensions. The cluster's key tasks include providing support for public policies, driving research, development, and innovation, offering technological assistance and services to businesses and industries, and delivering training and capacity-building programs. The cluster's strategic goals involve assisting public policies through technical expertise in regulatory matters, catalyzing the growth of a green molecule industrial sector by connecting value chain participants and encouraging new local players through collaborations, promoting value creation and employment opportunities via comprehensive training that harnesses advanced technologies and expertise for the development of the national green hydrogen sector and engagement with international stakeholders. The Cluster's missions include enhancing the technical and technological capacities of national stakeholders, fostering innovation within the hydrogen sector, supporting national industrial players, assisting the National Hydrogen Commission in establishing a regulatory and incentive framework to promote the development of the hydrogen sector, promoting, and developing hydrogen production in Morocco, contributing to the promotion of Moroccan hydrogen at the regional and international levels. The Morocco Hydrogen Cluster aims to strengthen the technical and technological capacities of national players to produce, use, and enhance hydrogen. The cluster also aims to develop innovation in the hydrogen sector and support national industries. Additionally, it will support the National Hydrogen Commission in creating a regulatory and incentive framework for the development of the hydrogen industry. The cluster will encourage and develop the production of hydrogen in Morocco and contribute to the promotion of Moroccan hydrogen on a regional and international scale .

4.1.1.4 International cooperation

International cooperation is crucial to unlocking the potential of green hydrogen. Policymakers, industry leaders, and global agencies must work together to mitigate the effects of global warming and stop climate change. The Hydrogen Council states that international multilateral cooperation is needed to realize the benefits of global hydrogen deployment. No one country or company can do it alone. To deal with global problems, you need global solutions, and no one company, industry, or government will reach the Paris Agreement vision acting on its own. International cooperation can help to create a level playing field for hydrogen technologies, which can help to reduce costs and increase efficiency. International cooperation can help to create a stable regulatory environment for hydrogen technologies, which can help to reduce risks and increase investment. By working together, countries can share knowledge and resources, develop new technologies, and create new markets for green hydrogen. This will help to accelerate the transition to a low-carbon

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economy and create a more sustainable future for all. Morocco has signed several agreements to develop and establish a green hydrogen economy. Germany has pledged to allocate €38 million (MAD 408 million) to support the construction of Morocco's first green hydrogen plant, as part of bilateral efforts to consolidate diplomatic and economic ties between Rabat and Berlin. With substantial investments and renewable energy assets, they consider themselves leaders in the sector. Morocco has shown significant growth potential in solar and wind energy. Bolstered by bilateral relations, this partnership seeks to strengthen economic ties and drive progress in the clean energy domain. MASEN has undertaken an ambitious project for producing green hydrogen from renewable sources. This project involves the establishment of a hybrid photovoltaic and wind power plant to supply a green hydrogen production facility with an electrolysis capacity of approximately 100 MW. The commercial operation of the site is planned between 2024 and 2025. Morocco's significant advantages in terms of renewable energy potential (solar and wind), well-developed infrastructure, proximity to international consumers, and the presence of a promising local market have been considered for this endeavour. Morocco and Portugal have signed a comprehensive agreement aimed at advancing sustainable development in the green hydrogen sector. The agreement underscores the strategic importance of decarbonizing their economies and embracing green hydrogen as a catalyst for this transition. Morocco has already made significant strides by establishing the National Hydrogen Commission and engaging in research and development initiatives. Portugal is equally committed and plans to host an international conference on clean energy. Both nations will establish a joint working group to craft a roadmap for hydrogen and ammonia and develop a memorandum of understanding. Morocco and the Netherlands are focusing on cooperative efforts in green hydrogen development. Discussions at the "World Hydrogen Summit & Exhibition 2022" in Rotterdam revolved around leveraging Morocco's renewable energy potential for green hydrogen. Both countries, represented by public and private sectors, explored partnerships to enhance green hydrogen production. Upcoming collaborative projects were also unveiled. The Dutch government's recent Africa strategy aligns with this cooperation, recognizing Morocco's potential in solar and wind energy.

In 2023 Moroccan Prime Minister Aziz Akhannouch and Dutch Prime Minister Mark Rutte met in Rabat to deepen cooperation between the two countries, especially in the field of renewable energy. They participated in a high-level working meeting with the aim of benefiting from the experiences and resources of both countries to promote the development and use of green hydrogen as an alternative energy source.

4.1.1.5 Green Hydrogen Large scale projects

Large-scale green hydrogen projects are essential for the establishment of a green hydrogen economy. These projects aim to produce green hydrogen from renewable sources such as wind, solar, and hydroelectric power. GW-scale projects have been announced globally, with a current global total of 80GW. These projects are expected to bring down the cost of green hydrogen through economies of scale, in the same way, that the prices of wind and solar power have fallen

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exponentially over the past decade. Large-scale projects can also help to create a level playing field for hydrogen technologies, which can help to reduce costs and increase efficiency. By working together, countries can share knowledge and resources, develop new technologies, and create new markets for green hydrogen. This will help to accelerate the transition to a low-carbon economy and create a more sustainable future for all. Three major projects have been announced in Morocco's green hydrogen initiative:

HEVO Ammonia Morocco Project: This initiative is Morocco's most significant green hydrogen and green ammonia project, with a projected investment exceeding 7.5B dirham (840M USD). Fusion Fuel and Consolidated Contractors Group S.A.L. ("CCC") are set to collaborate on this endeavour [9]. The project will have an impressive 600 MW of electrolyzer capacity and yield 183,000 tons of green ammonia production annually, offsetting a substantial 280,000 tons of CO_2.

Total Energies Project: Total Energies plans to invest $10.69 billion in a major green hydrogen and ammonia project in southern Morocco. The project aims to combine solar and wind energy for over 10 GW of power, with approval granted by the Regional Investment Commission. Initial production is expected by 2027, aligning with Morocco's vision of an expanded energy market.

AMUN Project: CWP Global is developing the 15 GW AMUN project in the Guelmim-Oued Noun region of Morocco. The project will involve installing 3 GW of wind energy and 3 GW of solar energy to produce green hydrogen, which will then be used for local ammonia synthesis and could also be suitable for export via LOHC. A second phase of the project will add an additional 9 GW of wind and solar production capacity. (figure 14).

Figure 14: Preparing to set up the AMUN project.

One such initiative involves the partnership between Moroccan company Gaia Energy and Israeli company H2Pro, forged during COP27 on November 8, 2022, in Charm El-Cheikh. This collaboration aims to implement a pilot project in Morocco with the intent of producing substantial quantities of green hydrogen and ammonia, starting with an initial capacity of 10-20 MW. Concurrently, they are actively pursuing the scaling of H2Pro's electrolyzer technology on a multi-

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GW scale for specific Gaia Energy projects, while also establishing a Giga factory for electrolyzer production in Morocco to enable local integration of technology.

In parallel, Chinese energy engineering procurement and construction contractor, Energy China International Construction Group, has entered into an agreement with Saudi conglomerate Ajlan Bros and Morocco's Gaia Energy. This partnership envisions the development of a major green hydrogen project in Morocco, focusing on a green ammonia plant with an estimated annual output of 1.4 million tons, derived from about 320,000 tons of green hydrogen. Additionally, the project includes a 2-GW photovoltaic solar plant and a 4 GW wind power project, with provisions for facility operation and maintenance post-completion.

4.1.1.5 Green Hydrogen R&D Projects

Morocco's commitment to green hydrogen development includes the establishment of research and development projects to demonstrate its dedication to sustainable energy solutions. A pioneering research platform, known as "**GreenH2A**," has been initiated through collaboration between IRESEN, Mohammed VI Polytechnic University (UM6P), and OCP. This platform, referred to as the "**Green Hydrogen & Applications Platform**," aims to become a center of excellence in research, innovation, and development within the green hydrogen domain and its associated derivatives, particularly focusing on "Power-to-X" applications.

The primary objectives of the "GreenH2A" initiative are to advance "Power-to-X" applications, encompassing green hydrogen, green ammonia, green methanol, synthetic fuels, and water treatment. In its mission to foster socio-economic growth, the initiative actively collaborates with universities and research institutions, offering technical tools and expertise to bolster the potential of the green hydrogen sector. While the initial focus is on green raw materials in industry and fertilizer production, the initiative's influence is set to extend to a wide array of sectors.

The "GreenH2A" initiative is strategically positioned to serve as the nucleus of the Morocco Hydrogen Cluster, forming a hub for the green hydrogen and derivatives ecosystem. By promoting research, innovation, and development, it contributes to the growth of a sustainable and promising economic sector. Morocco's dedication to advancing green hydrogen and its derivatives is exemplified through this initiative, reinforcing the country's commitment to sustainable and clean energy solutions. This research platform plays a pivotal role in fostering socio-economic growth and promoting the development of a sustainable energy sector with the potential to impact diverse industries (Figure 15).

The platform has launched two pilot projects to demonstrate the feasibility and potential of green hydrogen and its applications in the fertilizer and fuel sectors. These projects are:

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Figure 15: Laboratories of the "GreenH2A" research platform

<u>Green Ammonia Pilot Project (GAPP)</u>: The project aims to establish a compact unit for green ammonia production, using green hydrogen produced from renewable energy-powered electrolysis and nitrogen from the air. Green ammonia is a valuable raw material for the fertilizer industry, as it can be used to produce urea, ammonium nitrate, and other nitrogen-based fertilizers. The project is set to accommodate a daily production capacity of 4 tons of green ammonia, supported by an electrolysis capacity of 4MW. The project also involves the development of sustainable solutions for biotechnological phosphorous modification and electrocatalytic ammonia synthesis. The project is expected to enhance the collaboration between Morocco and Germany in integrating green hydrogen and green ammonia into the fertilizer industry.

Figure 16: Official signing of the GAPP project Consortium members

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PtX Pathways: This project is a program that supports the Ministries of Energy, Environment, and/or Research in developing allocation scenarios for hydrogen/PtX products, including the analysis of associated value chains. PtX stands for Power-to-X, which refers to the conversion of electricity from renewable sources into various forms of energy carriers or chemicals, such as synthetic fuels, methanol, or hydrogen. The project conducts cost-benefit analyses and makes recommendations to improve the regulatory framework for the integration of PtX and its derivatives. In Morocco, a pilot PtX (e-fuel) plant with direct air capture will be established to demonstrate the entire PtX value chain and to develop human capacity. The objectives of this project are:

- Evaluation of green fuel synthesis technologies and carbon capture.
- Assessment of Scale-Up Prospects.
- Identification of potential applications: Local and Export markets.

These pilot projects are expected to contribute to the development of a green hydrogen economy in Morocco and Africa, as well as to reduce greenhouse gas emissions and foster innovation. In addition to the GAPP and PtX Pathways projects, the GH2A platform also hosts other research projects that aim to explore the potential of green hydrogen and its derivatives in various applications. One of these projects is the **Power-to-X µPilot**, a 20 kW micro-pilot system that produces green hydrogen from solar energy. This project is a collaboration between IRESEN, a research institute for renewable energy, and UM6P, a polytechnic university.

Figure 17: "Power-to-X µPilot " research Pilot for hydrogen production

The project aims to generate green fuels, such as green ammonia and green methanol, using green hydrogen and carbon dioxide captured from the air. The project also aims to explore sustainable mobility and renewable energy storage solutions based on green hydrogen. The micro-pilot system serves as a research, innovation, and training platform for IRESEN, UM6P personnel, and partners within Morocco's hydrogen ecosystem, including the national hydrogen commission and the Green H2 Morocco cluster.

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This project is expected to contribute to the development of a green hydrogen economy in Morocco and Africa, as well as to reduce greenhouse gas emissions and foster innovation.
The GH2A platform also hosts other studies and partnerships that aim to support the transition to a green hydrogen economy in Morocco and the MENA region. These include:

MENALINK: This project is a collaboration between IRESEN, Regional Center for Renewable Energy and Energy Efficiency (RCREEE), Islamic Development Bank (ISDB), Renewables Academy AG (RENAC), Edis, Fraunhofer ISI, Royal Scientific Society (Jordany), Alcor, and MRC Group. The project objectives are:

- Enable professionals at all levels to engage and participate in the industry's transition.
- Support the implementation of the Paris Agreement (via the Nationally Determined Contributions).
- Demonstrate the technical and economic feasibility of renewable energy integration and sectoral coupling technologies.
- Develop strong national and regional partnerships in both the public and private sectors within the MENA region.
- Strengthen the capacity of trainers in the field of sectoral coupling.
-

MELHY: MELHY is a feasibility study of hydrogen storage in saline cavities in Morocco in 2021. The project is a collaboration between Green Energy Park, ENAGAS, Ibn Tofail University, SOMAS, and HDF Energy. The project aims to demonstrate the technical, economic, and environmental feasibility of underground storage of hydrogen in salt cavities with frequent withdrawals and injections. The project also aims to showcase the technical possibility of storing hydrogen in a salt cavity, adapting to the operational modes required by new hydrogen uses. The project objectives are:

- Investigate the feasibility of storing green hydrogen in salt cavities.
- Evaluate the national potential in terms of salt cavities.
- To demonstrate the technical feasibility of hydrogen storage in a salt cavity, adapting to the operational modes required by new hydrogen uses.
- Propose an infrastructure enabling Morocco's energy independence and the export of high-value-added green molecules.
- Implement an operational economic model.

ONHYM, as a partner in the consortium, is currently exploring the possibility of naturally occurring hydrogen within underground reservoirs. Through ONHYM's mapping and modelling efforts, two specific regions with significant hydrogen concentrations have already been identified.

4.1.1.6 SWOT Analysis

In assessing the prospects for the integration of renewable energy (RE) and green hydrogen technologies in Morocco, a comprehensive SWOT analysis highlights the inherent strengths, weaknesses, opportunities, and threats within the context of this transition.

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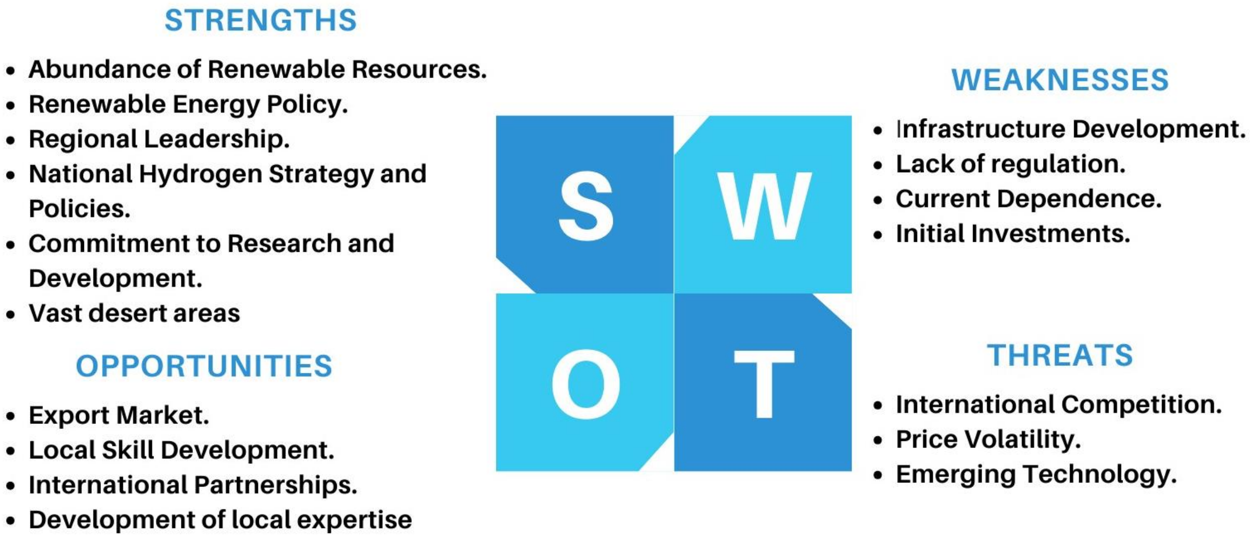

Figure 18: SWOT analysis for the Moroccan hydrogen context

Strengths: Morocco's strengths in this transition towards green hydrogen are manifold. The nation possesses a high area and generation potential for RE and green hydrogen, driven by its abundant solar and wind resources. The potential for hybrid systems, particularly the combination of wind and photovoltaic technologies, offers the promise of achieving very high full-load hours. Furthermore, the existing pipeline infrastructure connecting to Spain facilitates the export of green hydrogen, emphasizing the region's connectivity to international markets. In addition to its geographical advantages, Morocco enjoys substantial government and political support for renewable energy initiatives, further bolstered by a well-defined national roadmap extending from 2020 to 2050. Ongoing research and development (R&D) activities and commercial projects contribute to a robust foundation for the industry. The presence of diverse stakeholders throughout the value chain enhances the overall resilience of the green hydrogen sector in Morocco, while strong maritime and pipeline connectivity to Europe underscores the strategic geographical advantage.

Weaknesses: Despite its strengths, Morocco faces certain inherent weaknesses in the adoption of green hydrogen. A notable weakness is its high dependence on fossil fuels, reflected in the domination of the power grid by such energy sources. The absence of a dedicated regulatory and legal framework for hydrogen economy represents a significant challenge in the transition to green hydrogen. Additionally, there is no pipeline linking the optimal green hydrogen production areas in the southern regions to Europe, necessitating alternative long-distance transportation methods.

Opportunities: The transition to green hydrogen in Morocco presents several promising opportunities. The nation's commitment to decarbonization is underscored by ongoing efforts and engagements. Furthermore, the extensive Moroccan coastline, spanning 3,500 kilometers, offers

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the potential for marine-based green hydrogen production, particularly on the Mediterranean and Atlantic coasts. The OCP's strategy to shift towards local green ammonia production, replacing imported grey ammonia, aligns with sustainability goals. Moreover, the development of new ports, such as Dakhla and Nador, holds promise for facilitating the export of green hydrogen. The implementation of hydrogen valleys represents an innovative approach to leveraging the nation's renewable energy resources for green hydrogen production.

Threats: Several threats loom on the horizon. One critical concern is the possibility of delayed commissioning of hydrogen projects, which can impede the progress toward a green hydrogen-based economy. Additionally, the social acceptance risk of green hydrogen technologies should not be underestimated, as community and environmental concerns may slow down countries' project development. The necessity for long-distance transport of green hydrogen is another notable threat, entailing logistical complexities and costs. Effective brine management is yet another challenge, particularly in regions where desalination is employed for hydrogen production, as it demands careful attention to environmental impact and sustainability (figure 18).

4.1.2 Algeria Hydrogen Context and General overview

Algeria, situated in North Africa, is flanked by the Mediterranean Sea to the north, Tunisia and Libya to the east, Niger to the south, Mali, and Mauritania to the southwest, and Morocco to the west. The geographic location of Algeria assumes substantial significance in the context of green hydrogen production and distribution. Positioned at the crossroads of North Africa and the Mediterranean, Algeria enjoys a unique advantage poised to make a substantial contribution to the potential of green hydrogen. Its extensive desert landscapes and abundant sunlight make it an ideal candidate for harnessing solar energy, an indispensable component in the production of green hydrogen through electrolysis.

Furthermore, Algeria's strategic placement along key trade routes and its proximity to Europe create an auspicious opportunity for exporting green hydrogen to neighbouring nations and potentially beyond. By capitalizing on these geographical assets, Algeria has the capacity not only to exploit its renewable energy potential for domestic consumption but also to emerge as a significant player in the global green hydrogen market. Such positioning not only aligns with Algeria's commitment to cleaner energy solutions but also establishes the nation as a pivotal contributor to the transition to sustainable energy solutions on both a regional and international scale. In this context, Algeria's abundant sunlight resources, exceeding 2000 hours annually and offering a solar potential of 5.2 million trillion kWh per year, are particularly noteworthy. The country boasts an average solar potential of over 2200 kWh/m^2 per year, providing a solid foundation for solar-based green hydrogen production. Additionally, while Algeria's wind potential is moderately rated at 2 to 6 m/s, emerging microclimates along its coasts and high plateaus promise more favorable wind speeds in certain areas, particularly in the southern regions where speeds can reach up to 6 m/s. This diversified renewable energy potential, complemented by the availability of hydropower resources in the northern and Saharan regions, with an annual potential

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of 18 billion m^3, underscores the nation's prospects for sustainable energy development (table 24 & Figure 19).

Table 24: The installed capacity of renewable energies in Algeria

Renewable sources	Capacity
Solar energy	448 MW
Wind energy	10 MW
Hydropower	228 MW
Total	**686 MW**
Integration percentage	**3%**

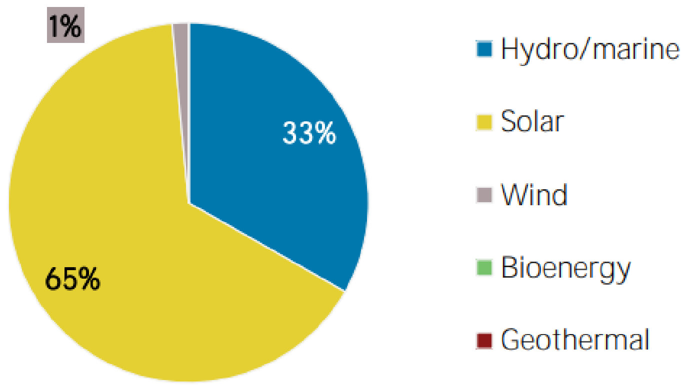

Figure 19: Breakdown of renewable capacity installed in Algeria according to type

4.1.2.1 Current use & future demand

Algeria, a prominent African economy, occupies a pivotal role in the realm of oil and gas production and exportation. The nation boasts substantial reserves of these vital resources, and it relies on its refining facilities to process crude oil effectively. Within the refining process, techniques such as hydrotreating and hydrocracking necessitate the use of hydrogen. Presently, the demand for hydrogen in Algeria remains stable, but it is poised for a considerable upsurge as global standards for cleaner fuels become increasingly stringent. Nonetheless, a shift is anticipated beyond the year 2030, where the pace of hydrogen demand growth may decelerate. Consequently, it is imperative to advance the production of hydrogen through eco-friendly methodologies, aiming to mitigate the greenhouse gas emissions emanating from these refineries. Algeria's engagement in the ammonia sector is characterized by three production complexes. Notably, Sorfert Algeria, established in 2013 through a partnership involving OCI NV (51% shareholder) and Sonatrach (33% shareholder), stands out. This petrochemical complex represents a substantial investment of $1.6 billion, with two ammonia units, each boasting a capacity of 2,200 tons per day, along with a granulated urea production unit with a capacity of 3,450 MT per day. Impressively, Sorfert Algeria exports 95% of its urea production and the entirety of its ammonia output. In addition to Sorfert, the Ammonia and Urea Complex in “Arzew”, a collaboration with the Egyptian company "Orascom Construction Industries (OCI)," contributes significantly to Algeria's ammonia production landscape. This

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complex comprises two ammonia units, each with a production capacity of 1.5 million tons per year, accompanied by a urea unit with a production capacity of 1.1 million tons per year. Moreover, the Ammonia and Urea Complex in Mers El Hadjadj (Arzew), established in collaboration with the Omani partner "Suhail Bahwan Group Holding (SBGH)," enhances Algeria's ammonia production with two ammonia units collectively capable of producing 1.3 million tons per year and two urea units with a total capacity of 2.3 million tons per year. Notably, the Spanish group “Fertiberia” operates two production centers in Algeria, yielding between 650,000 and 700,000 tons per year of ammonia from its Annaba and Arzew facilities. In the domain of iron and steel production, Algeria employs both the basic oxygen furnace (BOF) process for primary steel manufacturing and direct reduction techniques with an electric arc furnace (DRI-EAF). Both processes necessitate hydrogen production. Algeria's steel complex in El Hadjar, Annaba, under the management of Sider El Hadjar, exemplifies the nation's commitment to the steel industry. In addition, two other key facilities contribute to Algeria's steel production landscape: “Tosyali Algérie”, specializing in concrete reinforcement bars using ferrous waste, and The Algerian Qatari Steel Company (AQS), a partnership between Algeria and Qatar, which operates a steel complex in “Jijel”, focused on the production of wire rods and reinforcement bars . The cement and glass industries, notorious for their reliance on high-temperature heat derived primarily from fossil fuels, present unique challenges, and opportunities in Algeria. While hydrogen holds the potential to substitute for these fuels, its integration remains intricate and cost-intensive. In the Algerian context, the direct utilization of low to moderate-temperature solar thermal energy emerges as a more feasible alternative. Although possibilities for hydrogen use in high-temperature heat applications may emerge with technological advancements in the long run, short and medium-term adoption remains constrained. Algeria's transport sector, responsible for a significant portion of CO_2 emissions, stands at the precipice of transformation. Hydrogen-based fuels, capable of powering a spectrum of vehicles from automobiles to aircraft, are poised to revolutionize the nation's transportation landscape. While cost competitiveness remains a hurdle at present, the viability of these green technologies is projected to improve by 2030. For Algeria, which heavily relies on the transport sector, the introduction of supportive regulations and incentives will be instrumental in harnessing the potential of hydrogen-based fuels to reduce emissions and enhance sustainability.

4.1.2.2 Hydrogen strategy

Algeria has recently unveiled a comprehensive national hydrogen roadmap with the goal of producing and exporting 30-40 TWh of gaseous and liquid hydrogen, as
well as hydrogen derivatives, by the year 2040. It's worth noting that one million tons of hydrogen contain approximately 33 TWh of energy.

The Algerian hydrogen roadmap is structured into three distinct phases. The first phase, referred to as the "start-up" phase, spans from 2023 to 2030 and includes the implementation of pilot projects. Subsequently, the roadmap enters the "expansion and market creation" phase from 2030 to 2040, followed by the "industrialization and market competitiveness" phase from 2040 to 2050.

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Crucially, this strategic plan encompasses several key components, including the pursuit of foreign financing and grants and the formation of international strategic partnerships. It also emphasizes the necessity of reducing the cost of renewable energy production in Algeria, along with the expenses associated with electrolyzers. Moreover, strengthening the local electricity grid is seen as a critical prerequisite for successful hydrogen production and export.

Strategic objectives outlined within the Algerian national hydrogen roadmap encompass:

- Accelerating the nation's energy transition to diminish its carbon footprint.
- Reducing domestic reliance on fossil gas for energy needs.
- Creating a holistic ecosystem that fosters the development of clean hydrogen, including fostering "industrial integration."
- Establishing new centers of excellence dedicated to research, development, and training in the field.
- Gradually building a national hydrogen economy and its associated derivatives, such as ammonia, methanol, and synthetic fuels, with a specific focus on applications in the iron and steel industry.
- Paving the way for the establishment of a hydrogen production and export hub that aligns with the nation's long-term hydrogen objectives.

4.1.2.3 Projects & partnerships

In January 2023, Germany and Algeria initiated a collaborative endeavour named the "GREEN HYDROGEN FORUM," bolstered by support from government bodies and research institutions. This cooperative program, comprised of 15 biweekly webinars scheduled until June 2023, is designed to foster their alliance in the realm of green hydrogen . A noteworthy project in this context is the one introduced by the German international cooperation entity GIZ-Algeria, in close coordination with the Minister of Energy and Mines. This project is geared towards advancing the development of a green hydrogen economy to stimulate growth and employment.

Its third phase objectives encompass various areas such as research, training, and consultancy for pilot projects, technology, and market exploration. The overarching goal of this initiative is to furnish an assessment and database detailing the potential applications of green hydrogen in Algeria while offering support to research institutions. Furthermore, in the realm of projects and collaborations, an important development is the memorandum of understanding (MoU) inked between ENI, an Italian energy and fuel company, and Sonatrach, Algeria's national oil company. This MoU is designed to expedite gas and green hydrogen projects in Algeria, seeking to enhance energy cooperation and reduce carbon emissions. The agreement involves an evaluation of gas potential in fields previously identified by Sonatrach, with a projected gas production of three billion cubic meters annually, potentially leading to increased exports to Italy through the Transmed pipeline. Additionally, the collaboration aims to implement a green hydrogen pilot project in Algeria's Bir Rebaa North region to decarbonize operations at the BRN gas plant. The MoU also outlines plans to leverage pipeline capacity for flexible energy supply, progressively escalating gas volumes from 2022 to nine billion cubic meters annually in 2023-24. ENI strategic plan includes the construction

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of 1 GW of solar energy capacity to generate green hydrogen. However, the dependence on solar energy alone imposes limitations, with electrolyzer utilization restricted to 20-25% due to idle periods during the night and mornings/evenings. Consequently, the cost of producing green hydrogen from solar energy in Algeria is estimated to be around $4.40 per kilogram or $4,000 per tonne, exclusive of storage, distribution, and leakage expenses. This cost is approximately 11 times higher per unit of energy than natural gas and three times more expensive than current prevailing energy prices. To fully transition all of Algeria's natural gas exports to green hydrogen, an astounding 500 GW of solar energy would be required, a magnitude significantly exceeding Algeria's current solar capacity. Moreover, Sonatrach has formalized a memorandum of understanding with the German gas company VNG AG (VNG), with the shared objective of exploring collaborative opportunities in the hydrogen and green ammonia sectors and exporting these products to Germany. The collaboration begins with a focus on scientific and technical aspects, with an emphasis on infrastructure and prospective commercial projects. The proposed plant's production capacity is set at 50 MW, signifying an important step towards enhancing the German-Algerian hydrogen economy. Germany's intention to import substantial quantities of green hydrogen to meet domestic demand, coupled with Algeria's inclusion in the national hydrogen roadmap and its solar potential, positions Algeria as an attractive source of green hydrogen. Additionally, the existing gas infrastructure under VNG's management is expected to play a pivotal role in the future hydrogen distribution network in Germany.

4.1.2.4 SWOT Analysis

Strengths: Algeria possesses several notable strengths in its quest for green hydrogen production. It boasts abundant renewable resources, including high solar irradiance and promising wind potential. These resources provide a robust foundation for sustainable green hydrogen production and contribute to environmental sustainability. Furthermore, its strategic geographic location positions it favourably for international partnerships and green hydrogen exports, given its proximity to Europe and extensive coastline. The vast desert areas in Algeria, with abundant solar resources and significant wind potential, offer prime opportunities for renewable energy production to support green hydrogen facilities.

Weaknesses: Several weaknesses and challenges are associated with Algeria's green hydrogen aspirations. These include inadequate infrastructure and technological capacities, necessitating substantial investments in the construction of essential facilities and distribution networks. A notable issue is the lack of specific regulations for green hydrogen production and use in Algeria, reflecting the slow progress in adopting renewable energy sources. The absence of a clear strategy or roadmap for green hydrogen development is another weakness, potentially hindering sector growth. Additionally, Algeria's historical dependence on hydrocarbons poses a challenge in transitioning to green hydrogen, requiring intricate economic and structural adjustments. The

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endeavour also demands significant investments, both in infrastructure and research and development.

Opportunities: Algeria's green hydrogen ambitions are accompanied by several promising opportunities. International collaborations with countries experienced in green hydrogen can accelerate local capacity development and knowledge exchange. The increasing global demand for green hydrogen, particularly in Europe with its emissions reduction goals, opens export opportunities for Algeria. Developing national strategies and policies can create a favorable regulatory environment, attracting investments and stimulating innovation. Green hydrogen can serve as a catalyst for economic diversification in Algeria, reducing hydrocarbon dependency and generating new employment prospects. Furthermore, investing in training, education, and R&D can cultivate a skilled workforce capable of designing, operating, and maintaining green H2 facilities.

Threats: Certain threats loom over Algeria's green hydrogen prospects. International competition in the green hydrogen sector may limit Algeria's market share, with other countries also investing in green hydrogen production. Fluctuations in fossil fuel prices and hydrogen technologies can impact the economic viability of green hydrogen, affecting its competitiveness in the market. Moreover, the development and integration of green hydrogen technologies, such as water electrolysis, present technological and financial challenges that may slow progress and necessitate significant research and development investments (figure 20).

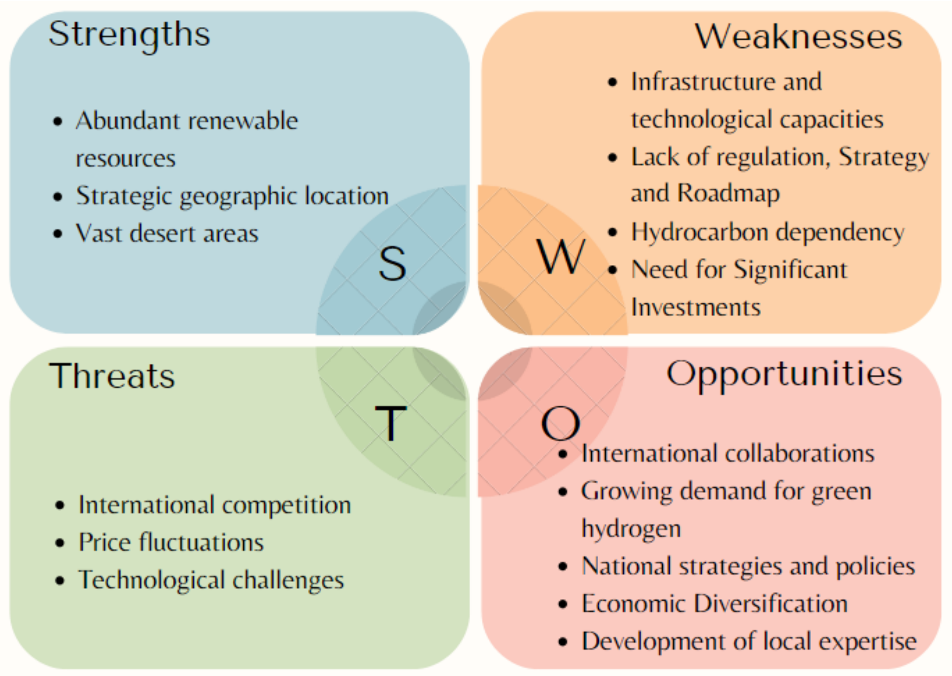

Figure 20: SWOT analysis for the Algerian hydrogen context

In addition to the SWOT analysis, there are specific technical challenges and considerations regarding hydrogen transportation in Algeria. Algeria's existing LNG export shipping facilities could be converted for hydrogen transport, but this process is complex and costly. Liquifying hydrogen consumes three times the energy compared to natural gas, leading to significant energy losses due

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to boil-off. Blending hydrogen with natural gas in pipelines is also energy-inefficient, requiring more of the blend to achieve the same energy output and incurring higher transportation costs. Furthermore, reusing existing natural gas pipelines for hydrogen transportation presents issues like metallurgical problems, increased energy requirements, and the need for costly infrastructure upgrades. These challenges make existing pipelines less suitable for hydrogen transport and necessitate thorough consideration in the hydrogen distribution strategy.

4.1.3 Tunisia Hydrogen Context and General overview

Tunisia, situated in North Africa, exhibits a compelling potential to produce green hydrogen. This potential is primarily attributed to its abundant sunlight and its advantageous geographic location along the Mediterranean Sea, which provide an exceptional opportunity for the generation of clean hydrogen through solar and wind energy sources. Tunisia's strategic geographical positioning between Europe and Africa positions it as a potentially significant contributor to the global green hydrogen production and trade landscape. Nevertheless, realizing this potential necessitates considerable investments, international collaborations, and a holistic approach that factors in environmental and social considerations. Tunisia's strategic geographic location, its considerable renewable energy potential, and its stable political environment collectively establish ideal conditions for the country to emerge as a prominent green hydrogen producer, catering to both domestic and international markets. Tunisia boasts a promising outlook for renewable energies, with a specific focus on solar and wind resources. The solar energy potential in Tunisia is remarkable, with over 3000 hours of annual sunshine. The average global horizontal solar radiation (GHI) reaches approximately 1850 kWh/m², translating into an annual production of about 1650 kWh/kWp for photovoltaic solar arrays.

The wind power potential, characterized by wind speeds exceeding 7 m/sec at a height of 60 meters, is particularly concentrated in regions like Nabeul, Bizerte, central Kasserine, “Tataouine”, “Medenine”, and “Gabes”. The wind potential is estimated to be around 8000 MW. In contrast, hydropower resources in Tunisia are relatively limited due to the absence of major rivers and continuous production sites. Currently contributing only around 1% of the total energy supply, the feasible capacity is estimated at approximately 250 GWh, with 160 GWh being economically viable, and an installed capacity of 70 MW. Tunisia currently possesses a total renewable energy capacity of 472 MW, constituting 8% of its overall electricity production capacity. Wind power constitutes the predominant share, followed by solar power and hydropower. This transition to renewable energy sources holds substantial advantages, including a reduced dependence on imported fossil fuels and enhanced air quality. This transition underscores Tunisia's commitment to a more sustainable and economically advantageous energy future (table 25).

Table 25 The installed capacity of renewable energies in Tunisia

Renewable resources	capacity
Solar energy	166 MW

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Wind energy	244 MW
Hydropower	62 MW
Total	**472 MW**
Integration percentage	**8 %**

4.1.3.1 Current use & future demand

Refining: Tunisia, as a modest crude oil producer, largely relies on ETAP for its oil production. Nonetheless, its production has dwindled over time, necessitating oil imports. While the expansion of refining capacity is a consideration, it must be weighed against global decarbonization initiatives. Presently, there is no substantial demand for green hydrogen in Tunisian refining; future demand prospects are uncertain considering global sustainability goals.

Ammonia: Tunisia primarily imports ammonia for its fertilizer industry. The nation boasts two major fertilizer manufacturers employing local phosphate rocks to produce various fertilizers, some requiring ammonia. As global demand for low-carbon-footprint fertilizers increases, Tunisia could contemplate the production of green ammonia via renewable energy sources. This transition would require substantial investments in green ammonia production capacities and the expansion of renewable energy sources (figure 21).

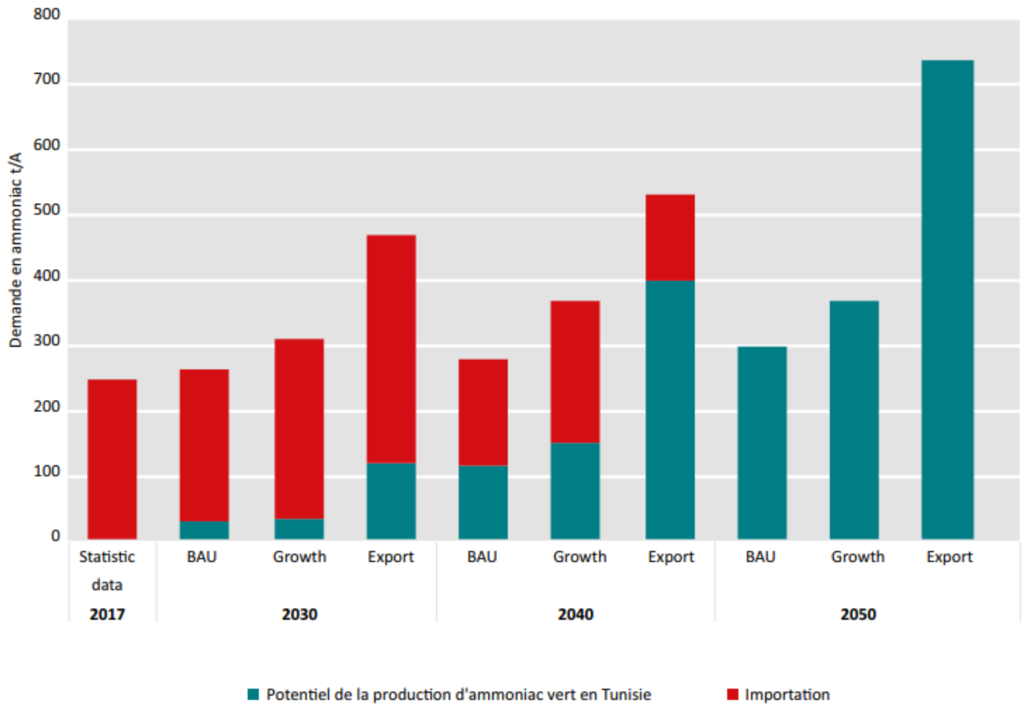

Figure 21: Ammonia demand and production scenarios for Tunisia (in kt per year)

Iron and Steel: Tunisia's steel sector relies on electric arc furnaces for secondary steel production, which is less emissions-intensive but electricity-dependent. The country's existing steel facilities

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face financial challenges, and there is currently no notable hydrogen demand. Decarbonizing steel production with green hydrogen remains uncertain for Tunisia by 2050.

Methanol: Global methanol demand has surged, and Tunisia could consider green e-methanol production. Three scenarios evaluate domestic demand and production potential, relying on renewable energy sources and CO_2 sources. However, profitability hinges on market incentives and decarbonization trends. (figure 22).

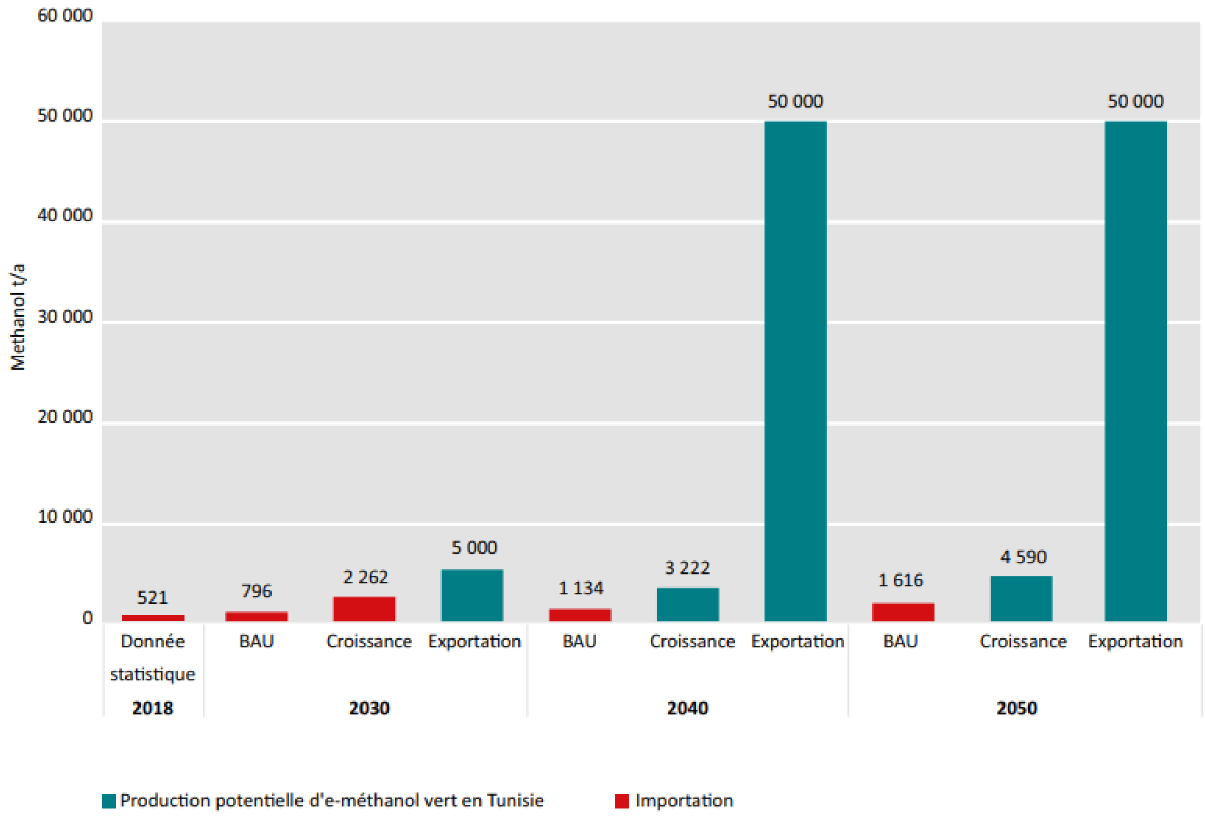

Figure 22: Green e-methanol demand and production scenario for Tunisia (in tons per year)

High-Temperature Heat: Tunisia's industrial heat demand could benefit from direct solar thermal energy, given its solar potential. Hydrogen is a consideration for high-temperature heat in sectors like cement and metals, but challenges related to its properties make its short-to-medium-term transition economically and technologically infeasible.

Aviation: Sustainable solutions in aviation are critical for reducing carbon footprints. Tunisia, with its solar potential, could explore PtL (Power-to-Liquid) fuel production to address aviation's decarbonization challenges and associated emission costs.

Maritime Transport: Advancements in ammonia and hydrogen-powered ships present opportunities in the maritime sector. Tunisia could explore the use of existing infrastructure, such as ammonia-handling facilities at the Port of Gabes, to embrace ammonia as a sustainable fuel source for shipping operations. The collective efforts of international organizations are poised to drive potential demand for ammonia as a viable fuel option in maritime transport.

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Railway: Hydrogen-powered trains are gaining traction globally, offering a solution for un-electrified railway tracks. Tunisia's railway sector can modernize operations and contribute to sustainable transportation adopting H2 trains, particularly for long-distance freight lines.

Land Transportation: Tunisia can embrace greener transportation solutions, particularly electric fuel cell vehicles (FCEVs). The national bus sector, supported by the government, could pioneer FCEV adoption, especially for heavy vehicle fleets with centralized routes and recharging points. PtL fuels also hold potential for the transition to cleaner and sustainable mobility in Tunisia.

4.1.3.2 International cooperation

EU Cooperation: EU and Tunisia maintain a mutually advantageous partnership, with a growing interest in expanding their collaborative endeavours in the green hydrogen sector. Tunisia, with its significant potential for large-scale deployment of renewable energy and green hydrogen projects, plays a pivotal role in ensuring energy security, industrial growth, job creation, and economic development. The European Union, as part of its decarbonization and energy security goals, aims to import 10 million tons of green hydrogen by 2030, with a particular focus on the Southern Central Corridor, connecting Tunisia to Europe. This corridor, known as the "SoutH2 Corridor," is designed as a hydrogen-ready pipeline supported by major European Transmission System Operators, including Italy's SNAM, “Trans Austria Gasleitung” (TAG), “Gas Connect Austria” (GCA) in Austria, and “Bayernets” in Germany.

German Cooperation: Preliminary findings from a study assessing the potential of Power to-X technologies in Tunisia reveal that the country possesses substantial technical capabilities for hydrogen production, coupled with highly competitive production costs. Tunisia is well-positioned to establish a strategic foothold in the green hydrogen sector, offering environmentally friendly employment opportunities through the early adoption of Power-to-X technologies. This collaborative initiative is a result of joint efforts by the Tunisian Ministry of Industry, Energy, and Mines (MIEM) and the Federal Ministry for Economic Cooperation and Development (Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung or BMZ) of Germany. This endeavour falls under the broader framework of the Tunisian-German Energy Partnership, implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the German Federal Ministry of Economics and Energy (Bundesministerium für Wirtschaft und Energie or BMWi). Energy cooperation will play a prominent role in Tunisian-German relations in the future, with a specific focus on the production of 'green hydrogen and climate-neutral fuels,' often referred to as "Power-to-X products”. In December 2020, BMZ and the Tunisian Ministry of Energy forged an alliance with the aim of developing the Power-to-X sector in Tunisia and initiating joint pilot projects in this field.

4.1.3.3 SWOT Analysis

<u>**Strengths:**</u> *Abundant Solar Resources:* Tunisia boasts a significant abundance of sunshine, a valuable resource for potential hydrogen production through solar-driven water electrolysis. Leveraging solar energy for green hydrogen production aligns with global clean energy trends and offers an environmentally friendly solution

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Strategic Mediterranean Location: Situated as a Mediterranean nation, Tunisia enjoys a strategic geographical advantage for hydrogen exportation, particularly to Europe and various international markets. Its proximity to Europe positions it favorably as a potential key player in the global hydrogen trade.

Weaknesses: *Lack of Production Infrastructure:* Tunisia currently lacks the requisite large-scale hydrogen production infrastructure, presenting a challenge to immediate entry into the green hydrogen industry. The absence of established facilities may impede the country's ability to meet potential future demands.

Lack of Regulation: The absence of specific regulatory frameworks for hydrogen production and usage within Tunisia poses a considerable weakness. Effective regulation is essential to ensure safety, efficiency, and the orderly development of the hydrogen sector.

Lack of Strategy and Roadmap: Tunisia currently lacks a clear and comprehensive strategy or roadmap for the development of green hydrogen. This absence of strategic planning may hinder the country's ability to navigate the complexities of the hydrogen industry and realize its full potential.

Water Scarcity for Hydrogen Production: Electrolytic hydrogen production requires substantial water quantities, which could be challenging for Tunisia due to water scarcity issues. This could potentially limit the country's capacity for large-scale hydrogen production.

Fossil Fuel Dependency: Tunisia's primary reliance on fossil fuels for energy production presents a substantial obstacle to transitioning to clean hydrogen production. Shifting to a green hydrogen-based economy necessitates significant investments in new technologies and infrastructure.

Required Investments: Developing a thriving hydrogen industry demands substantial investments in research, infrastructure, and technology. The financial challenges associated with these investments present a notable weakness.

Opportunities: *Global Energy Transition:* The global demand for clean hydrogen is on the rise, driven by efforts to reduce carbon emissions. Tunisia is well-positioned to capitalize on this opportunity, potentially becoming a major player in clean hydrogen production and export. This could contribute to both economic growth and environmental sustainability.

International Partnerships: Tunisia can establish partnerships with countries at the forefront of hydrogen technologies. Collaborating with these advanced nations can expedite the establishment of the hydrogen industry within the country, fostering knowledge transfer and technological advancement.

National Strategy and Roadmap: The development of a national strategy and roadmap for green hydrogen is a valuable opportunity for Tunisia. It can serve as a catalyst for a coordinated transition to a low-carbon economy, promoting sustainable economic development. Additionally, this positions the country as a key player in the regional energy transition.

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Export Market: Tunisia's rich renewable energy resources and its proximity to Europe, a major market for hydrogen, create opportunities for the country to become a significant green hydrogen exporter. This strategic advantage aligns with the country's strengths and geographical location.

Development of Local Expertise: The development of local expertise in green hydrogen is a pivotal opportunity for Tunisia. This involves investment in training, education, and research, fostering a skilled workforce capable of designing, operating, and maintaining green hydrogen facilities.

Threats: *Political Changes*: Shifting government policies and political instability can impact the development and sustainability of hydrogen projects in Tunisia. These changes may introduce uncertainties and challenges to the hydrogen industry.

Regulations and Standards: National and international regulations in the field of clean energy and hydrogen may influence how Tunisia shapes its hydrogen industry. Compliance with evolving standards and regulations is essential for industry growth.

International Competition: Tunisia faces competition from other countries also striving to become significant players in clean hydrogen production. The global competition for market share may intensify, affecting Tunisia's market position.

Energy Price Fluctuations: Fluctuations in energy prices, particularly in electricity needed for hydrogen production, could affect the economic viability of the hydrogen industry. These uncertainties may influence investment decisions and industry stability (figure 23).

Figure 23: SWOT analysis for the Tunisian hydrogen context

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4.1.4 Egypt Hydrogen Context and General overview

Egypt, located in northeastern Africa and bounded by the Mediterranean Sea to the north and the Red Sea to the east, occupies a strategically vital position at the intersection of Europe, the Middle East, Asia, and Africa. Capitalizing on its advantageous access to maritime routes via the Suez Canal and its substantial involvement in global trade agreements, the nation serves as a pivotal hub for investment and emerging markets. With its rich renewable energy resources, robust natural gas infrastructure, technical expertise, and industrial capabilities, Egypt is well-positioned to assume a pivotal role in advancing a prominent hydrogen-based economy, both domestically and within its neighboring markets. Regarding hydropower, Egypt primarily harnesses its hydroelectric potential from the Nile River, with the most significant utilization occurring in the Aswan region. This region hosts multiple power stations that collectively yield an annual power output of 13 545 GWh. In the realm of wind energy, Egypt benefits from formidable winds along the Gulf of Suez, boasting an average wind speed of 10.5 meters per second. In 2022, Egypt's capacity for wind-generated power approached nearly 7 GW. In terms of solar energy, Egypt enjoys an annual direct solar radiation ranging from 2 000 to 3 000 kilowatt-hours per square meter per year. With the sun shining for approximately 9 to 11 hours daily, spanning from the northern to the southern regions, and a few cloudy days, Egypt possesses a favorable solar energy environment.

Table 26: The installed capacity of renewable energies in Egypt

Renewable resources	Capacity
Solar energy	1724 MW
Wind energy	1643 MW
Hydropower	2832 MW
Total	**6199 MW**
Integration percentage	**20%**

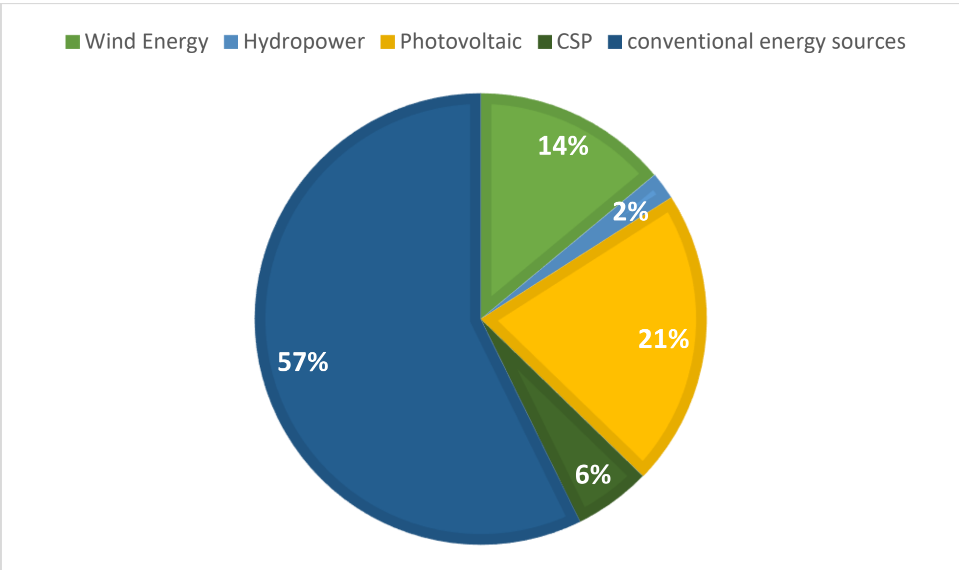

Figure 24: Breakdown of renewable capacity installed in Egypt according to type.

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4.1.4.1 Current use & future demand

Fertilizers: In the realm of fertilizers, hydrogen plays a vital role in the domestic production of ammonia, a fundamental component of nitrogenous fertilizers. As of 2019, Egypt's ammonia production amounted to 4.2 million tons, according to the 2020 report from the US Geological Survey. Considering hydrogen's approximate contribution of 18% to the ammonia's weight, it can be reasonably estimated that the fertilizer industry in Egypt consumed approximately 756 thousand tons of hydrogen in the same year.

Steel Industry: The steel industry in Egypt serves as a significant consumer of hydrogen, primarily in the process of Direct Reduction Iron (DRI), used for reducing iron ore. Prominent steel producers in the region, such as Ezz Steel, Beshay Steel, and Suez Steel, operate Direct Reduction Plants (DRPs). Ezz Steel, boasting a substantial 5-million-ton capacity, operates four DRPs, while Beshay Steel annually produces 2 million tons. Suez Steel Company, the third-largest player, utilizes zero reformer technology to produce 1.95 million tons. Collectively, Egypt's DRI plants yield 8.95 million tons annually. The country's iron and steel exports were valued at $1.72 billion in 2021, as reported by the United Nations "COMTRADE" database.

Refining: The refining industry represents the largest global consumer of hydrogen, though precise consumption figures are challenging to ascertain due to varying factors in the refining process. Hydrogen plays a critical role in hydrotreating, a process that stabilizes petroleum products by removing impurities. Egypt sources its crude oil from three primary blends: Suez, Belayim, and Western Desert, with the latter accounting for 56% of the country's production and exhibiting a sulfur content of 0.34%. In 2019, Egyptian refiners utilized an average of approximately 300 thousand tons per annum (KTPA) of hydrogen.

Petrochemicals: Information provided by the Egyptian Petrochemical Holding Company (ECHEM) in 2018 reveals that Egypt's methanol production reached roughly one million tons in the same year (Nouran, 2019). Approximately 50% of this production was distributed within the local market, while the remaining portion was earmarked for export. It's noteworthy that methanol contains approximately 12.5% hydrogen by weight. As a result, based on the production of 1 Mt of methanol in Egypt, an estimated consumption of approximately 125000 t of hydrogen can be derived.

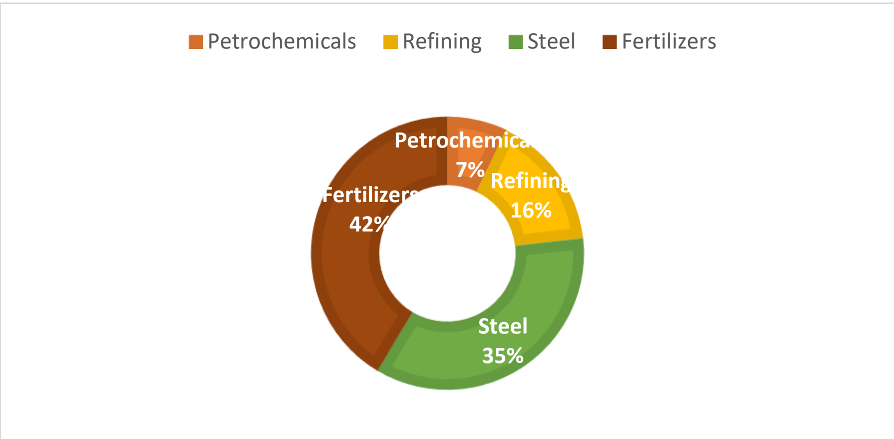

Figure 25: Hydrogen Industrial Demand Use in Egypt

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The incorporation of green hydrogen in Egypt presents a significant opportunity to mitigate greenhouse gas emissions, enhance air quality, and promote the transition to a sustainable and eco-friendly economy, primarily within the industrial and transportation sectors. Green hydrogen stands as a viable, clean, and renewable energy source for various Egyptian industries. Heavy sectors, including steel manufacturing, petrochemicals, and ammonia production, can adopt green hydrogen as a sustainable alternative to fossil fuels, thereby reducing the carbon dioxide emissions linked with these processes. By incorporating hydrogen as both a raw material and an energy source, these industries can effectively reduce their carbon footprint and contribute to Egypt's sustainability objectives. Green hydrogen can also play a pivotal role in decarbonizing Egypt's transportation sector. Hydrogen-powered vehicles, encompassing cars, buses, and trucks, can be deployed to offer an eco-friendly transportation solution, emitting zero greenhouse gases at the vehicle's tailpipe. Commercial vehicle fleets can make the transition to green hydrogen, consequently aiding in the reduction of air pollution in urban areas and decreasing dependence on fossil fuels. To achieve its green hydrogen objectives, the government can play a significant role by providing financial support, infrastructure development, and incentives for both the industrial and transportation sectors.

4.1.4.2 Hydrogen strategy

Egypt is actively working towards positioning itself as a regional epicenter for green hydrogen production and aims to export 10 Mt of renewable hydrogen to Europe (equal to RePowerEU Plan forecast). In this endeavour, the European Bank for Reconstruction and Development (EBRD) is closely collaborating with the European Union (EU) to support green hydrogen initiatives within the Suez Canal Economic Zone. Simultaneously, there are ongoing efforts to formulate a green hydrogen strategy in Egypt in partnership with the Ministries of Electricity and Petroleum. The Cabinet has unveiled Egypt's ambitious plans to bolster its economy by $10 to $18 billion by 2025 through the forthcoming official announcement of the "National Strategy for Green Hydrogen".

This strategic advantage positions Egypt to strive for an ambitious objective of capturing 8% of the global hydrogen market. The strategy, prepared by the EBRD, projects a global demand for hydrogen of approximately 90 Mt, with Egypt's hydrogen demand anticipated to represent around 2% of this global figure. Europe is expected to emerge as a pivotal hydrogen import market. The strategy also offers an in-depth analysis of the status of the hydrogen market, both globally and in Egypt, and outlines a phased approach to the development of a hydrogen-based economy within the country. This approach encompasses three distinct phases: the Pilot Phase (2020s), the Scale-up Phase (2030s), and the Full Implementation Phase (2040s and beyond).

Initial Phase (Pilot): Egypt's hydrogen strategy's Initial Phase aims to establish the fundamental framework for developing a hydrogen-based economy within the nation. This phase encompasses the establishment of essential governance structures, the initiation of pilot projects, and the conduct of research and development activities. Anticipated completion for the Initial Phase is set for the conclusion of 2023 or the commencement of 2024. It will serve as the groundwork for the

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subsequent, more ambitious Expansion Phase, which will primarily emphasize the expansion of hydrogen production and utilization in Egypt.

Expansion Phase (Scale-up): Egypt's hydrogen strategy's Expansion Phase is dedicated to the expansion of hydrogen production and utilization throughout the country. This phase will entail the development of innovative hydrogen technologies, substantial investments in hydrogen infrastructure, and the promotion of hydrogen adoption across diverse sectors. The Expansion Phase is projected to conclude at the end of 2028 or the start of 2029. It will lay the groundwork for the full-fledged implementation of the hydrogen-based economy in Egypt, which will be the central focus of the Comprehensive Implementation Phase.

Comprehensive Implementation Phase (Full implementation): The Comprehensive Implementation Phase of Egypt's hydrogen strategy will emphasize the full-scale implementation of the hydrogen-based economy within the nation. Key objectives include the establishment of a sustainable hydrogen market, the cultivation of export opportunities for hydrogen, and the endeavour to decarbonize Egypt's economy. Anticipated completion for the Comprehensive Implementation Phase is expected at the conclusion of 2040 or the commencement of 2041. It signifies the culmination of Egypt's determined efforts to transition towards a low-carbon hydrogen economy.

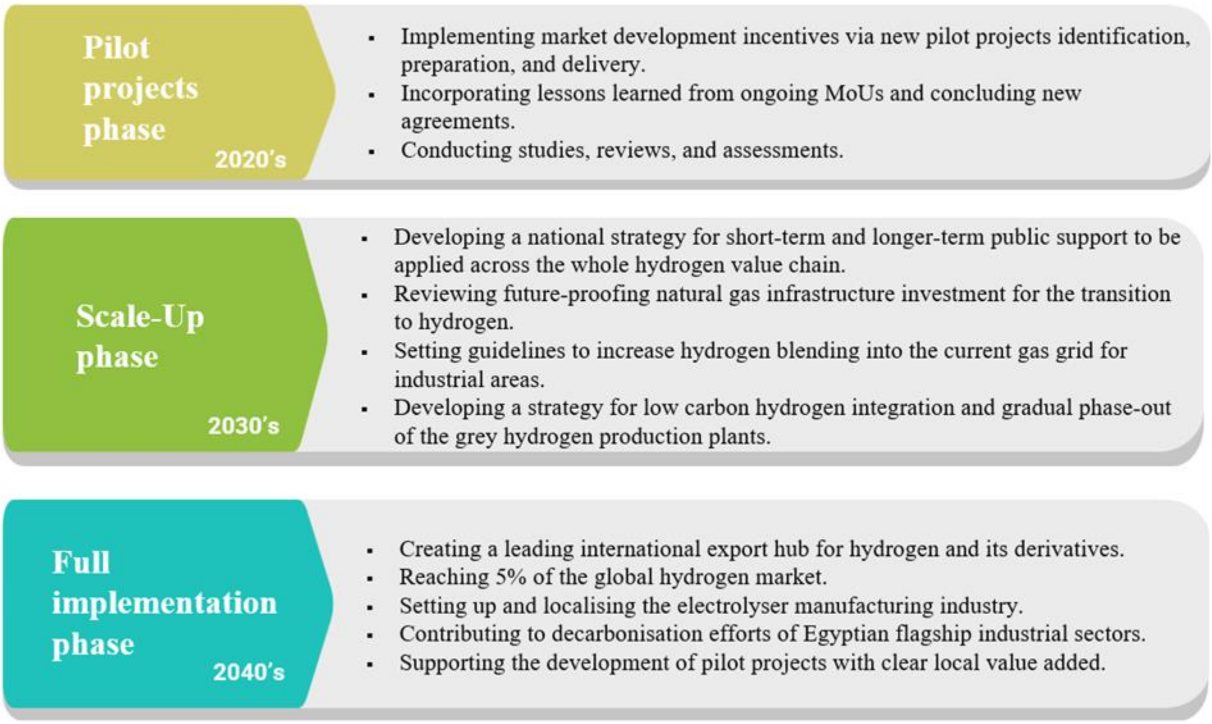

Figure 26: Egypt Hydrogen strategy implementation phases

4.1.4.3 Partnerships & Agreements

EU: During COP27 in Sharm El Sheikh, Egypt, and the European Union (EU) formalized a Memorandum of Understanding (MoU) with the purpose of enhancing collaboration in the realms

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of green hydrogen production, consumption, and trade, including its derivatives. The MoU serves as a catalyst for investments in hydrogen infrastructure, spanning areas such as distribution, storage, and export, as well as the generation of renewable energy. This strategic partnership underscores the unwavering commitment of Egypt and the EU to advance energy cooperation that aligns with the objectives set forth in the Paris Agreement. Egypt's aspiration to evolve into a regional center for low-carbon hydrogen is a central feature of this partnership.

Germany: On November 3rd, Egypt and Germany formalized two Memorandums of Understanding designed to fortify their cooperative efforts in the domain of green hydrogen production and liquefied natural gas (LNG) trade. These agreements lay the foundation for Germany's assistance to Egypt in establishing a sustainable green hydrogen supply chain. The agreements comprise the following key provisions:

- Facilitating the reciprocal exchange of knowledge and technological expertise, as well as harnessing German technology for the integration and adaptation of cutting-edge technologies in entrepreneurial ventures in Egypt. These initiatives have a specific focus on technologies related to green hydrogen.
- Undertaking specific initiatives pertaining to the production, refinement, utilization, and transportation of green hydrogen.
- Nurturing the growth of a green hydrogen sector.
- Encouraging collaborative investments, research initiatives, and the execution of projects encompassing various aspects of hydrogen, including its processing, transportation, and utilization, with active support for the implementation of such projects.

4.1.4.4 Large Scale projects & Agreements with leaders

Siemens: Siemens Energy, a prominent German enterprise, has signed a Memorandum of Understanding (MoU) with the Egyptian Electricity Holding Company (EEHC) to collaborate on the development of a hydrogen-based industry in Egypt with export potential. This partnership is focused on attracting investments, facilitating technology transfer, and launching hydrogen projects driven by renewable energy sources within Egypt. It builds upon a prior letter of intent signed between the two entities in January and sets the groundwork for a prolonged partnership to expand Egypt's hydrogen industry. Siemens Energy and EEHC will jointly promote investment, technology transfer, and the implementation of hydrogen production projects driven by renewable sources. The initial phase of this partnership includes the development of a pilot project featuring an electrolyzer with a capacity of 100MW-200MW. This project aims to advance early technology deployment and assess regulatory and certification processes. Importantly, this collaboration is in line with Egypt's objectives to harness its renewable energy resources for industrial growth.

MAERSK: An essential Memorandum of Understanding was forged between the General Authority for the Economic Zone of the Suez Canal (SCZone), the Sovereign Fund of Egypt, the New and Renewable Energy Authority (NREA), the Egyptian Electricity Transmission Company (EETC), and

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Maersk International, one of the world's largest container shipping lines. The purpose of this MoU is to establish a project for producing green fuel to supply ships within the Suez Canal Economic Zone. This endeavour involves substantial investments totaling 15 billion U.S. dollars .

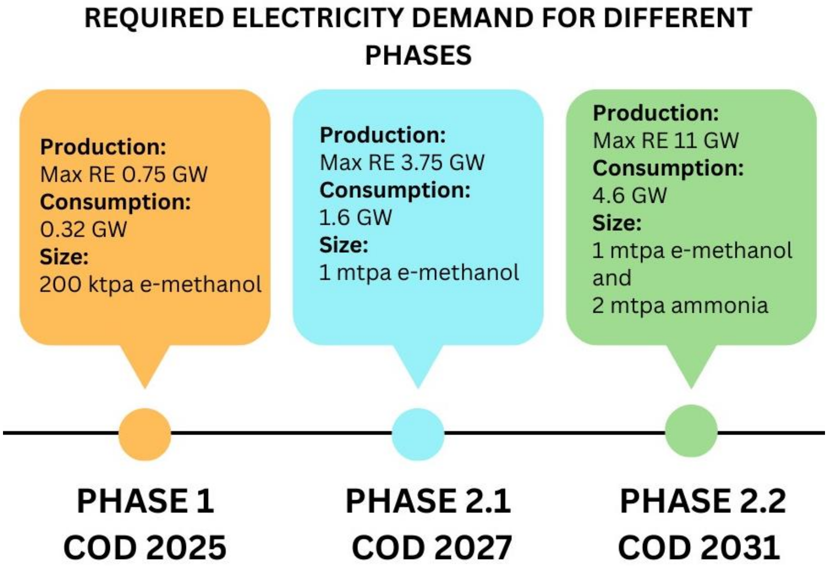

Figure 27: MAERSK Hydrogen Partnership steps

Belgian Consortium DEME, FLUXYS, PORT OF ANTWERP: In March 2021, a cooperation agreement begun between various key entities, including the Egyptian electricity holding company, Aboukir Ports Construction and Management company, Egyptian National gas Holding company, and a Belgian consortium composed of DEME Group, Fluxys, and Antwerp Port. This Belgian consortium, renowned for its expertise in the field of energy and green hydrogen, initiated a feasibility study for the HYPORT-EGYPT" project.

Aligned with the project's objectives, the initial phase seeks to generate 700 MW of wind power and 800 MW of solar energy, which is expected to offset 600,000 tons of carbon dioxide emissions. Additionally, the consortium plans to establish 500 MW electrolysis facilities near Gargoub Port in Marsa Matrouh, with the resultant hydrogen slated for export to Europe. Notably, this project holds the potential to generate over 2 000 jobs during the construction phase and more than 500 permanent positions upon operationalization, in addition to indirect employment opportunities.

Orascom, Norwegian company (Scatec), Fertiglobe: On October 14th, 2021, The Sovereign Fund of Egypt entered into an agreement with Orascom, Scatec, and Fertiglobe to collaboratively develop a green hydrogen plant with a capacity ranging from 50 to 100 MW, intended to supply green ammonia production. On November 8th, 2022, the commissioning of the first phase of Africa's inaugural integrated green hydrogen plant took place in Ain Sokhna, Egypt, marking a significant milestone for Fertiglobe and its partners, including OCI N.V., ADNOC, Scatec ASA, Orascom Construction, and The Sovereign Fund of Egypt. This pioneering facility, combining 100 MW of electrolyzers with 260 MW of solar and wind energy, is designed to produce approximately

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15,000 tons of green hydrogen, serving as feedstock for producing up to 90,000 tons of green ammonia annually in Fertiglobe's existing ammonia plants. Located strategically in Ain Sokhna, near the Suez Canal Economic Zone, this project leverages renewable electricity for industrial activities close to global shipping routes. The project underscores the synergy between Egyptian engineering expertise and advanced technology from Orascom Construction.

EDF: The first of EDF Renewables' agreements entails collaboration with several key entities, including the General Authority of the Suez Canal Economic Zone, the Sovereign Wealth Fund of Egypt, the Egyptian Electricity Transmission Company, the New and Renewable Energy Authority (NREA), and the Zero-Waste Egypt Alliance. This agreement, witnessed by various members of the Egyptian government, aims to produce hydrogen and its derivatives from the port of Ain Sokhna in the Gulf of Suez. Consistent with the strategy endorsed by Egyptian authorities, EDF Renewables intends to invest in infrastructure capable of producing 350 000 tons of hydrogen and green ammonia annually. The project will be executed in three distinct phases, with the initial phase targeting a yearly capacity of 140 000 tons. The construction of these facilities is set to commence in 2024, with the first quantities of hydrogen and green ammonia anticipated for export to the global market via ships beginning in 2026.

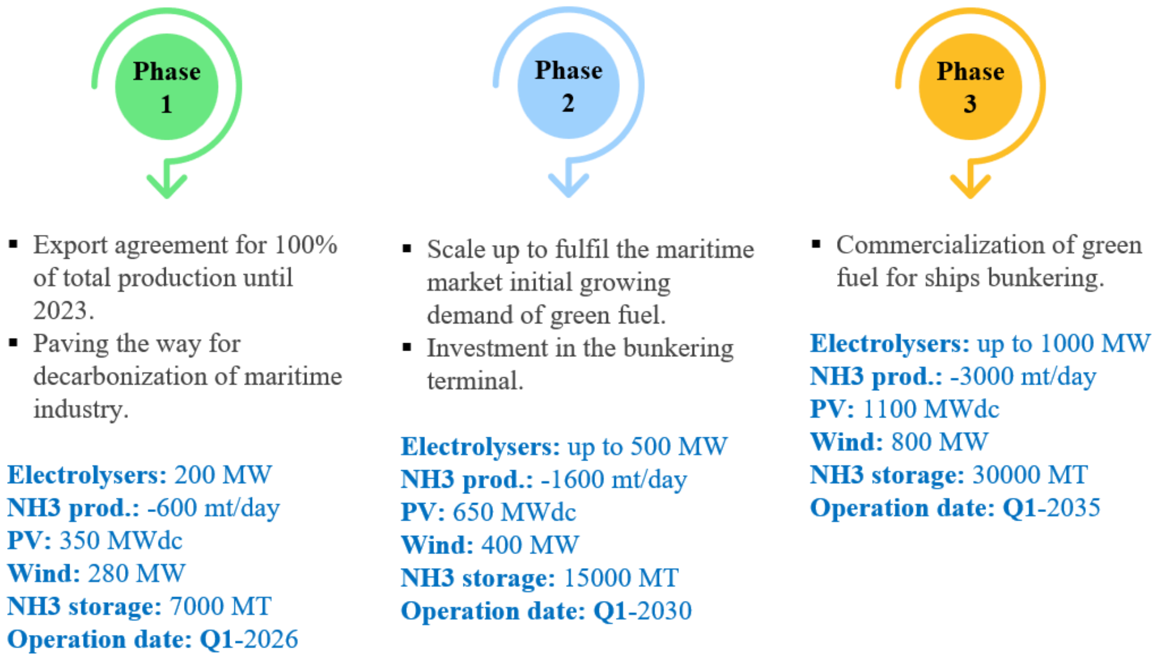

Figure 28: EDF Green Hydrogen project objectives

Masdar, HASSAN ALLAM Utilities: Two separate Memoranda of Understanding have been established to initiate collaborative efforts:

- The first MoU brings together various key stakeholders, including the Suez Canal Economic Zone (SCZone), the Sovereign Fund of Egypt, the Egyptian Electricity Transmission Company

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(EETC), the New and Renewable Energy Authority (NREA), Abu Dhabi Future Energy Company (Masdar), a global leader in renewable energy, and Hassan Allam Utilities Company, the development arm of Hassan Allam Holding Group.

- The second MoU encompasses the Sovereign Fund of Egypt, EETC, NREA, Masdar, and Hassan Allam Utilities Company.

These agreements outline the joint endeavour between Masdar and Hassan Allam Utilities to establish green hydrogen production facilities in two strategic locations: the Suez Canal Economic Zone and the Mediterranean coast. These facilities will employ electrolyzers with a combined capacity of 4 GW, with the aim of producing up to 480,000 tons of green hydrogen annually.

MASDAR's offer, involving the implementation of a 4 GW electrolyzer in the Suez Canal Economic Zone by 2030, seeks to achieve three primary objectives:

- Providing green fuel for ships.
- Exporting green ammonia to Europe.
- Supplying green ammonia for local industry.

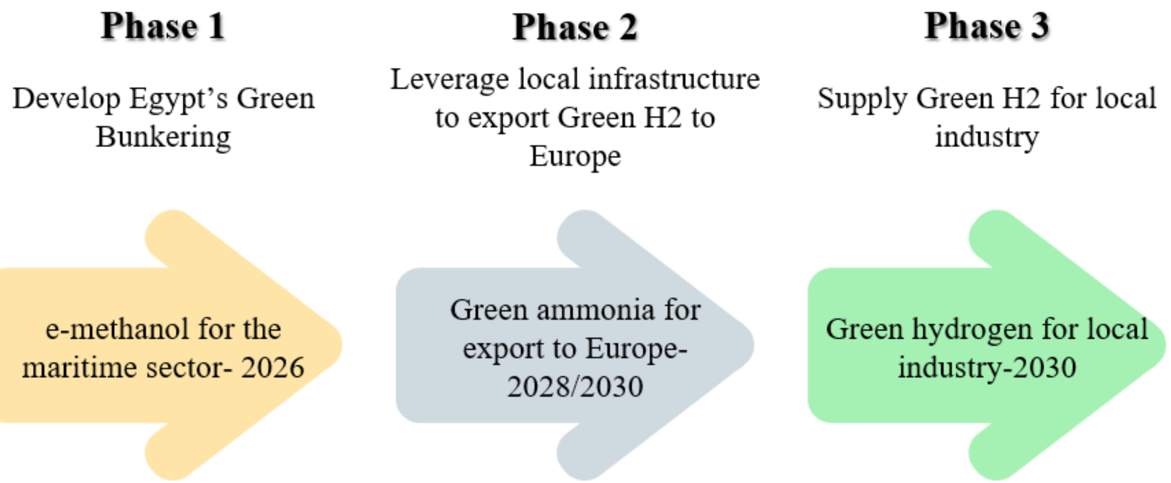

Figure 29: Masdar HASSAN ALLAM Utilities Hydrogen collaboration phases

AMEA POWER: Dubai-based AMEA Power and Egypt have established a framework agreement to develop a 1 000 MW green hydrogen project in Egypt's Suez Governorate. The project's objective is to produce 800 000 tons of green ammonia annually for both domestic consumption and export. Collaborating entities include the Sovereign Fund of Egypt, the Egyptian Electricity Transmission, the New and Renewable Energy Authority, and the Suez Canal Economic Zone.

The hydrogen plant will be implemented in two 500 MW phases, a strategy designed to mitigate risks, capitalize on technological advancements, and reduce equipment costs. AMEA Power is actively engaging with European, Chinese, and Japanese companies to secure long-term purchasers for green ammonia. Simultaneously, discussions are ongoing with the Egyptian Hydrocarbon Corporation to allocate a portion of the green hydrogen output to support green industries in Egypt . Having conducted a feasibility study, AMEA Power anticipates reaching a final

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investment decision within the next two to three years. The initial phase of the project is set to commence operations in 2027.

Alfanar: Saudi Arabian construction company Alfanar has officially disclosed the signing of a Memorandum of Understanding with a consortium of key entities, including the General Authority of the Suez Canal Economic Zone, the Sovereign Fund of Egypt, the Egyptian Electricity Transmission Company, and the New and Renewable Energy Authority (NREA). This collaboration is aimed at establishing an ambitious Green Hydrogen facility in Sokhna, Egypt. Estimated to cost around $4 billion, the project will rely on renewable energy sources and is projected to achieve an annual production capacity of 100,000 tons of green hydrogen, in addition to an extra 500,000 tons of green ammonia.

Globeleq: Globeleq, a prominent independent power company in Africa, has signed a Memorandum of Understanding with the New and Renewable Energy Authority (NREA), the General Authority for Suez Canal Economic Zone (SCZONE), the Sovereign Fund of Egypt for Investment and Development (TSFE), and the Egyptian Electricity Transmission Company (EETC) to jointly develop a large-scale green hydrogen facility within the Suez Canal Economic Zone. Globeleq, as the lead developer and investor, will be responsible for developing, financing, building, owning, and operating the green hydrogen project. This initiative is planned to unfold in three phases, encompassing a total of 3.6 GW of electrolyzers and approximately 9 GW of solar photovoltaic (PV) and wind power generation. The initial phase will introduce a pilot project featuring a 100 MW electrolNational Hydrogen Commissionn producing green ammonia fertilizers. Additionally, the potential applications of green hydrogen for various purposes, including green fuels, will be explored in the medium and long term.

ReNew Power & Elsewedy Electric: Elsewedy Electric and ReNew Power Private Limited have partnered to sign a Framework Agreement with the Egyptian Government for the collaborative development, financing, construction, operation, and maintenance of a green hydrogen project along with its associated facilities. The agreement involves The Sovereign Fund of Egypt (TSFE) Infrastructure & Utilities Sub Fund, the New and Renewable Energy Authority (NREA), Egyptian Electricity Transmission Company (EETC), and The General Authority for Suez Canal Economic Zone. In alignment with Egypt's National Green Hydrogen Strategy introduced at COP27, the project aims to produce 220 000 tons of green hydrogen annually through various stages. A pilot electrolysis plant will initially generate 20,000 tons of green hydrogen annually, followed by subsequent phases increasing the annual output to a total of 220,000 tons. The pilot phase is anticipated to be operational by 2026.

Total Energies & Enara Capital: A memorandum of understanding was signed between a consortium comprising Total Energies and Enara Capital, a Small and Medium Enterprise (SME) investor focusing on Africa. This joint effort aims to construct a green ammonia plant within the Suez Canal Economic Zone (SCZone). In its initial phase, the plant will have the capacity to produce 300,000 tons of ammonia annually, with plans to subsequently raise the production to 1.5 million tons in the future.

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Fortescue Future Industries: During the 2022 United Nations Climate Change Conference (COP27), Fortescue Future Industries and Egypt entered into a significant framework agreement to collaborate on green hydrogen and renewable energy projects within Egypt. The framework agreement was signed by FFI and the Egyptian Government, in conjunction with key entities such as the New and Renewable Energy Authority (NREA), the General Authority for Suez Canal Economic Zone (SCZONE), the Egyptian Electricity Transmission Company (EETC), and The Sovereign Fund of Egypt for Investment and Development (TSFE). This partnership aims to explore projects with a potential capacity of 7,600 MW of renewable energy, with the possibility of generating 330 kilotons per annum of green hydrogen.

ACME Group: SCZONE has signed a framework agreement with Indian company ACME to initiate the construction of a green hydrogen project in Sokhna in early 2024. The agreement was formalized in New Delhi during a visit by a prominent SCZONE-led business delegation, aimed at highlighting investment prospects in Egypt. This follows an earlier memorandum of understanding in August 2022 between SCZONE and ACME Group, outlining plans for a green hydrogen production plant with an annual capacity of 2.2 million tons in Sokhna. The project, valued at $12 billion, will cover 4.5 million square meters and will begin by producing 100,000 tons.

4.1.4.5 Hydrogen supply and transportation scenarios

Port of Rotterdam: The port of Rotterdam has emerged as a potential destination for the export of Egypt's green hydrogen and ammonia. A partnership agreement could enable the joint export of hydrogen and ammonia to Rotterdam by 2025, enhancing transport capabilities along this route. Furthermore, this collaboration would contribute to the continued expansion of the chemical park in the region.

The Nordic Hydrogen Route Project in Finland and Sweden: The Nordic route will expand the hydrogen market by facilitating the import of ammonia and hydrogen from Egypt by southern and western European countries. These resources will be transported through an interconnected network of pipelines within Europe.

The Southern Gas Corridor Project in Azerbaijan: An additional pipeline could be linked to the existing natural gas pipeline from Azerbaijan to Egypt to transport hydrogen or a hydrogen-natural gas blend, expanding the hydrogen market to include more countries .

4.1.4.6 SWOT Analysis

<u>**Strengths:**</u>

- Abundant Renewable Energy Resources: Egypt benefits from approximately 11 hours of daily sunlight and vast desert areas suitable for solar and wind farms. These conditions make Egypt an optimal location for green hydrogen production, utilizing renewable energy to split water into hydrogen and oxygen.

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- Strategic Geographical Advantage: Positioned at the nexus of Africa, Europe, and Asia, Egypt offers a favorable location for exporting green hydrogen to these extensive markets. Additionally, its proximity to the Suez Canal, a major shipping route, may facilitate the cost-effective export of green hydrogen to other nations.
- International Collaborations: Egypt has the potential to establish collaborations with nations and companies possessing advanced expertise in green hydrogen technology. These partnerships could expedite the growth of Egypt's green hydrogen sector and provide access to cutting-edge technologies. Knowledge transfer from such collaborations could further boost Egypt's capabilities in this field.
- Governmental Commitment: The Egyptian government demonstrates a strong commitment to sustainable development and renewable energies. This commitment could lead to the introduction of policies and regulations designed to promote green hydrogen production, including incentives like tax breaks, subsidies, and investment encouragement.

Weaknesses:

- Limited Infrastructure: Egypt's renewable energy potential is promising, but its infrastructure for converting this energy into hydrogen is still in its nascent stages. This insufficiency may result in an inadequate number of solar and wind farms to generate the requisite electricity for green hydrogen production. Moreover, insufficient pipelines and storage facilities for hydrogen transport and storage could potentially hinder large-scale green hydrogen projects in Egypt.
- Required Investments: Establishing green hydrogen production facilities demands substantial capital investment. The costs associated with constructing solar and wind farms, electrolyzers, and pipelines are significant. Egypt may face challenges in securing the financial resources required for these projects, potentially deterring foreign investments in green hydrogen due to apprehensions about committing to projects in a developing nation with limited financial resources.
- Fossil Fuel Dependency: Egypt's reliance on fossil fuels presents a significant drawback in its pursuit of green hydrogen. This dependency exposes the country to fluctuating oil prices, geopolitical risks, and environmental concerns. Egypt needs to formulate an energy strategy focused on diversification and green hydrogen to mitigate these issues while promoting sustainability and minimizing economic disruptions.

Opportunities:

- Green Hydrogen Export: Europe and Asia represent two of the world's largest green hydrogen markets, characterized by rapid growth driven by carbon neutrality commitments. Egypt's abundant renewable energy resources, such as solar and wind power, can serve as a source for green hydrogen production. Its strategic

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location at the crossroads of Africa, Europe, and Asia positions Egypt favorably for exporting green hydrogen to these burgeoning markets.

- Economic Diversification: Egypt's economy currently heavily depends on traditional sectors, primarily oil and tourism. The development of the green hydrogen industry offers the potential to diversify the economy, reducing reliance on these traditional sectors. This industry can create new employment opportunities, fostering economic growth and positioning Egypt as a leader in the global energy transition.
- Development of Local Expertise: Egypt can make substantial investments in local skills training, research and development, collaborations between universities, industry, and research institutions, and the creation of an innovation-friendly environment. These initiatives can contribute to the development of local expertise in green hydrogen technology.

Threats:

- International Competition: The global green hydrogen market is in its early stages, featuring intense competition for market share. Egypt must compete with other nations boasting abundant renewable energy resources and strategic locations. Offering competitive prices for green hydrogen is crucial in this competitive landscape.
- Price Fluctuations: Green hydrogen prices are susceptible to volatility, influenced by fluctuations in energy prices, as well as production and transportation costs. Such fluctuations could affect projects profitability. For example, a drop in the price of natural gas may make blue hydrogen (hydrogen produced from natural gas with carbon capture and storage) more competitive against green hydrogen. Egypt must adapt to these potential market changes.

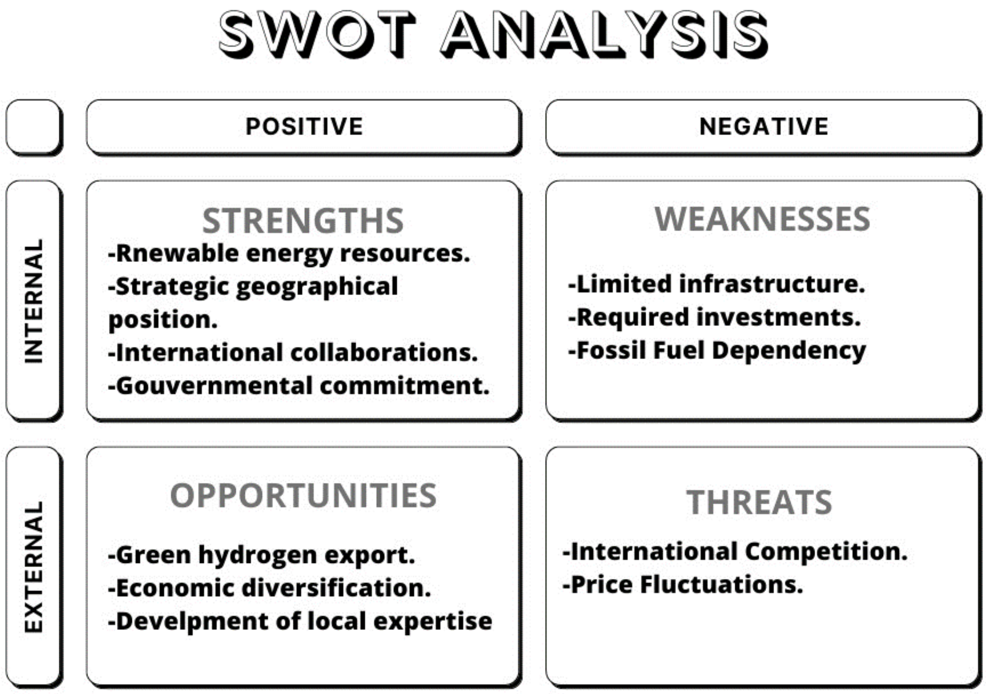

Figure 30: SWOT analysis for the Egyptian hydrogen context Figure 30:

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4.1.5 Mauritania Hydrogen Context and General overview

Mauritania, located in West Africa, boasts an advantageous geographical position well-suited for harnessing solar and wind energy to produce green hydrogen. The nation's wealth of sunlight, extensive sparsely populated terrains, consistent Atlantic Ocean winds, and access to water resources like the Senegal River collectively present a compelling opportunity for establishing a clean hydrogen-based economy. Nevertheless, realizing this potential hinge upon substantial investments in infrastructure, technology, and training, all while maintaining a balanced approach that carefully considers environmental and social implications. Mauritania's coastal climate is marked by robust and dependable winds, rendering it an area of great wind energy potential. The country's 754 kilometers of Atlantic coastline provide an ideal canvas for the establishment of substantial wind farms, a fact demonstrated by the successful operation of a 30 MW wind power plant in the capital city, Nouakchott. Mauritania holds significant potential in solar energy resources, with an estimated solar irradiance ranging from 2000 to 2300 kilowatt-hours per square meter annually. Mauritania's surface water resources are distributed across four distinct natural regions, encompassing the Senegal River Valley, the Mauritanides arc, maddened and “hodhs” area, and the Adrar region .

Table 27: The installed capacity of renewable energies in Mauritania

Renewable resources	Capacity
Solar energy	Not available
Wind energy	Not available
Hydropower	Not available
Total	170 MW
Integration percentage	19% (10% Solar and 9% Wind)

4.1.5.1 Hydrogen Perspective

In the year 2020, Mauritania set forth a comprehensive national strategy designed to revolutionize its energy sector. The ambitious objective of this strategy is to elevate the renewable energy component to an impressive 60% by the year 2030. Bolstered by its wealth of solar and wind resources, Mauritania stands as a promising contender in the realm of green hydrogen production. The government's unwavering commitment to nurturing a thriving green hydrogen sector was notably reaffirmed through a Memorandum of Understanding inked with British Petroleum “BP” during COP27. This partnership has the potential to yield an annual production capacity of 2 million tons of green hydrogen. Anticipations point to an escalating demand for green hydrogen, primarily driven by a collective global endeavour to decarbonize pivotal sectors, such as hydrogen and mineral production. Given Mauritania's substantial role as a producer of iron ore and copper, there lies an opportunity to cultivate a domestic market for green hydrogen, thus concurrently promoting the greening of the mining sector. In addition to the significant MoU with BP, Mauritania has two substantial green hydrogen projects currently in the pre-feasibility stages. These initiatives have

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garnered support from international developers, notably CWP Global and Chariot Ltd (in collaboration with Total Energies). Nonetheless, the green hydrogen sector confronts technical intricacies and uncertainties in cost competitiveness, elements that have the potential to temper its economic contribution to Mauritania. To optimize the benefits stemming from Mauritania's ongoing energy transition, the establishment of a green hydrogen sector necessitates bespoke institutional and regulatory frameworks. The utilization of the Extractive Industries Transparency Initiative (EITI) can fortify oversight of green hydrogen undertakings by promoting the disclosure of contracts, regulatory structures, and revenue streams. Mauritania is receiving invaluable support from international partners such as the CONNEX Support Unit and the European Union in shaping the essential legal and regulatory groundwork. Mauritania's overarching energy strategy encompasses the aspiration of evolving into a regional energy export hub while simultaneously establishing itself as a center for a low-carbon iron industry by the year 2040. The insights derived from this report, coupled with the financial models it presents, provide a substantial basis for informed deliberations as Mauritania navigates the intricate terrain of energy diversification. Through the adoption of the EITI's multi-stakeholder platform, the facilitation of discourse and vigilance becomes more attainable as Mauritania endeavours to adapt to the dynamic global energy landscape. Aligning the implementation of the EITI with national priorities is poised to further catalyse the potential of Mauritania's gas and green hydrogen sector.

4.1.5.2 Hydrogen Large-scale projects

Aman (CWP Global): In a significant collaborative effort, the Mauritanian government has engaged in a Memorandum of Understanding with CWP Global, a prominent renewable energy developer. This venture, with a staggering budget of $40 billion, is firmly directed towards the establishment of a green hydrogen production facility. The proposed project site spans a vast expanse, encompassing 8,500 square kilometers in the northern desert and coastal regions of Dakhlet Nouadhibou and Inchiri. At its core, Project Aman will harness the potent synergy of hybrid generators, ingeniously utilizing both wind and solar energy sources. The cumulative capacity generated by this dynamic duo stands at a remarkable 30 GW, with 18 GW attributed to wind power and an additional 12 GW stemming from solar sources. This colossal capacity will pave the way for an annual electricity generation of 110 TWh, thus setting the stage for the ambitious production targets of 1.7 Mt of green hydrogen and a remarkable 10 Mt of green ammonia. It is estimated that this monumental project could trigger an impressive surge in Mauritania's GDP, potentially surging by 50-60% by the year 2035.

Noor (Chariot Ltd in partnership with Total Energies): Following the successful completion of a pre-feasibility study, Chariot Ltd, a dynamic transitional energy group with a distinctive focus on the African continent, secured a significant agreement centred on green hydrogen collaboration with the Mauritanian Government in September 2021. This ambitious venture is anticipated to achieve a formidable capacity of 10 GW and is earmarked for realization by the year 2030. Project Noor's scope is expansive, spanning approximately 14,400 square kilometers, encompassing both

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onshore and offshore territories. Its unique approach harnesses the bountiful potential of solar and wind resources to drive the process of electrolysis for the generation of green hydrogen. Further enhancing the global significance of this endeavour, Chariot has entered a strategic partnership with the Port of Rotterdam, a pivotal agreement with the potential to facilitate the annual sale of 600,000 tons of green hydrogen. Rotterdam, in anticipation of the burgeoning demand within this emerging sector, has unveiled strategic plans to inaugurate a specialized terminal by 2026, solely devoted to the handling of this novel resource and its derivative products. This development aptly aligns with Europe's ambitious goal to augment its utilization of green hydrogen to a substantial 75 GW by the year 2035, with half of this capacity being sourced from international imports.

4.1.5.3 SWOT analysis

Strengths:

- Solar resources Abundance: Mauritania boasts an abundance of sunlight, an asset for efficient solar-powered electrolysis in green hydrogen production.
- Vast Desert Regions: The extensive desert areas within Mauritania offer significant potential for deploying dedicated solar infrastructure, further facilitating hydrogen production.
- Economic Diversification Prospects: Hydrogen industry development is an opportunity to diversify Mauritania's economy, which presently relies heavily on mining and the oil sector.
- Pioneering Large-Scale Projects: Mauritania is actively engaged in major initiatives, positioning the nation at the forefront of the green hydrogen landscape.

Weaknesses:

- Infrastructure Limitations: A formidable challenge lies in the need for substantial infrastructure development for hydrogen production, storage, and distribution, necessitating significant investments.
- Water Resource Constraints: Mauritania confronts challenges related to scarce water resources, essential for hydrogen production through electrolysis, which may potentially impede hydrogen production capabilities.
- Dependency on Extractive Industries: The country's existing reliance on extractive industries could pose complexities in transitioning to a hydrogen-based economy.

Opportunities:

- Rising Global Demand for Green Hydrogen: The escalating global demand for clean hydrogen opens doors to potential export opportunities for Mauritania.
- International Collaborations: Mauritania can establish collaborative partnerships with countries experienced in hydrogen production, expediting its indigenous industry growth.
- Local Expertise Development: The establishment of a hydrogen industry within Mauritania can stimulate the growth of technical competencies and specialized knowledge at the local level.

Threats:

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• International Competition: The competitive landscape in green hydrogen production is intensifying, with other countries also making substantial investments, potentially leading to global market competition.
• Technological and Financial Hurdles: The development of clean hydrogen technologies and the acquisition of requisite investments may present considerable challenges for Mauritania.
• Energy Price Fluctuations: Fluctuations in energy prices, including those pertinent to electricity required for hydrogen production, could impact the economic viability of the industry.
• Political and Regulatory Stability: The political stability and regulatory framework in Mauritania may significantly influence the development and attractiveness of investments in the hydrogen industry.
• Geographical Location Consideration: Mauritania's geographical positioning along the Atlantic coast of Africa, notably further from Europe compared to North African countries along the Mediterranean Sea, may entail higher shipping costs, potentially affecting the feasibility of exporting hydrogen from Mauritania to Europe.

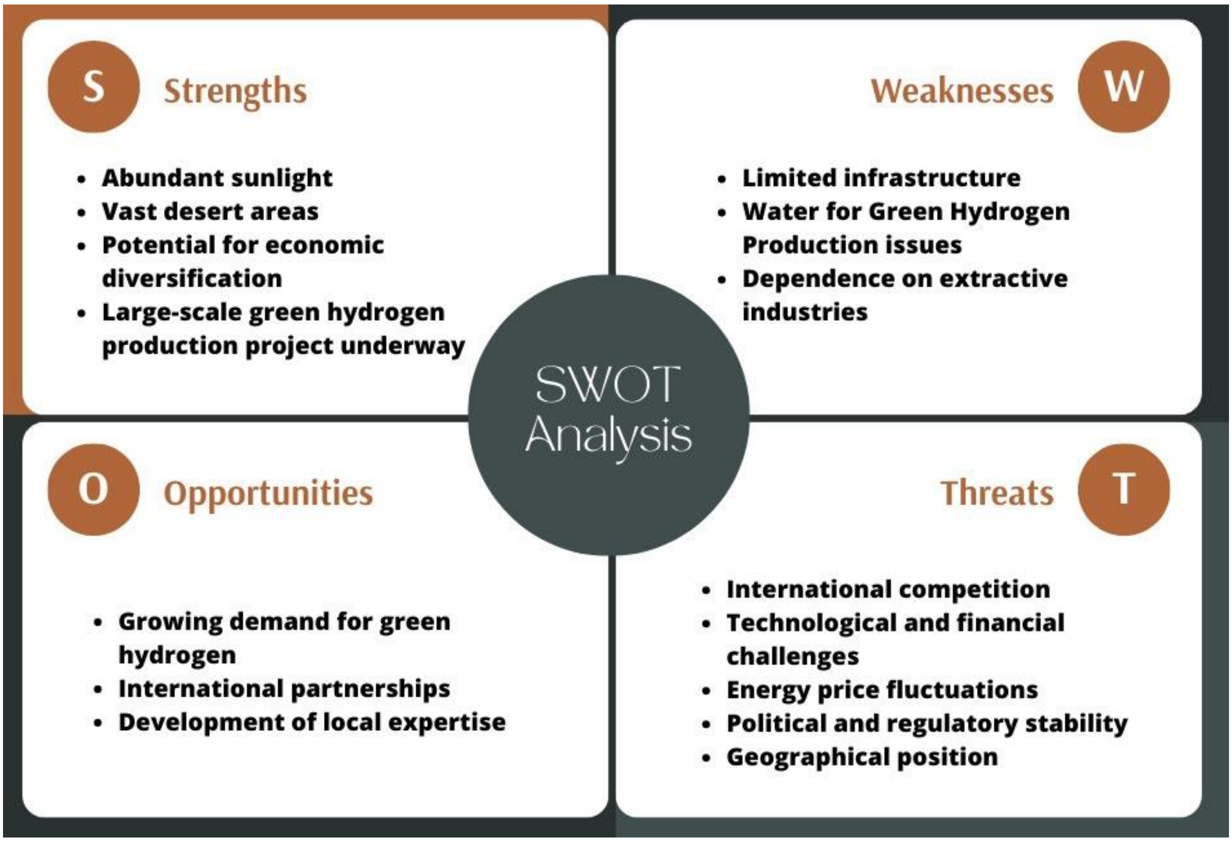

Figure 31: SWOT analysis for the Mauritanian hydrogen context

4.1.6 North African Countries overall analysis and comparison

According to information presented in the previous subchapters, in the next pages a comparison among the different North African countries is presented according to different technical and non-technical aspects.

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Renewable energy: The North African countries, distinct strengths and weaknesses concerning their renewable energy potentials and utilization. Morocco possesses several noteworthy strengths. The nation benefits from substantial and cost-effective photovoltaic and wind energy potential within its borders, particularly in proximity to the coastline. This geographical advantage facilitates water supply through seawater desalination, a critical resource for renewable energy projects. Morocco has also demonstrated its commitment to renewable energy with the successful implementation of large-scale operational projects. Furthermore, the country's strong economic growth further supports its capacity for renewable energy development. However, Morocco grapples with elevated greenhouse gas emissions, primarily emanating from coal-based power plants used for electricity generation.

Algeria is another country in the region with significant potential for both photovoltaic and wind energy. Favorable cost structures make these renewable sources attractive options. Nonetheless, Algeria faces challenges related to the limited adoption of renewable energy sources for electricity generation up to the present. Additionally, elevated greenhouse gas emissions are associated with electricity generation primarily relying on natural gas.

Tunisia shares characteristics with Algeria in terms of renewable energy potential and cost advantages in photovoltaic and wind energy. However, similar to Algeria, the adoption of renewable energy sources for electricity generation has been limited, contributing to elevated greenhouse gas emissions due to the reliance on natural gas.

Egypt stands out with substantial and cost-effective opportunities for photovoltaic and wind energy. The nation's geography, including the Nile River, offers favorable conditions for renewable energy projects. Egypt's economic growth is robust, and the country has established supportive frameworks for renewable energy, resulting in numerous developmental projects. Furthermore, advantageous sites along the Gulf of Suez are suitable for standalone hybrid photovoltaic and wind systems. Nevertheless, Egypt's market share for renewable energy sources in electricity generation remains constrained, and there are intentions to incorporate coal-fired generation into the national energy strategy, potentially conflicting with renewable energy goals.

Mauritania's strengths lie in its significant opportunities for cost-effective hybrid photovoltaic/wind systems. These systems are well-positioned near the coastline, allowing for water supply. However, access to energy and electricity remains restricted for a substantial portion of the population, with approximately 50% lacking access to electricity. Furthermore, there has been limited adoption of renewable energy sources, such as photovoltaic or wind energy, in the country. This indicates that there is untapped potential waiting to be harnessed.

In the context of the regional electricity capacity landscape, Morocco exhibits notable leadership by attaining an impressive 37.08% of its electricity capacity derived from renewable sources. This remarkable achievement can be attributed to the country's strategic approach of diversifying its energy portfolio across various renewable sectors, including solar, wind, and hydro infrastructure.

In contrast, Algeria and Tunisia are positioned at a less advanced stage, as their respective percentages of electricity capacity from renewables are relatively lower. This disparity highlights

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the pressing need for these nations to intensify their commitments to renewable energy sources, acknowledging the importance of advancing in this direction.

Meanwhile, Egypt demonstrates considerable promise with a renewable capacity of 20%. This reflects a burgeoning interest in the adoption of clean and sustainable energy solutions within the country, signifying potential for further growth in this sector.

Finally, Mauritania currently stands at a 19% renewable capacity, revealing room for substantial expansion in the realm of renewable energy. This underscores the urgency and importance of advancing renewable energy initiatives in Mauritania, recognizing the untapped potential for growth and development in this domain (table 27).

Table 27: Capacity of renewable Infrastructure Deployment and the Incorporation of Renewable Electricity in North African Nations

Countries	Solar Energy (MW)	Wind Energy (MW)	Hydropower (MW)	Total Energy (MW)	Integration percentage
Morocco	831	1 466	1 770	4 067	37.08%
Algeria	448	10	228	686	3%
Tunisia	166	244	62	472	8%
Egypt	1 724	1 643	2 832	6 199	20%
Mauritania	-	-	-	170	19%

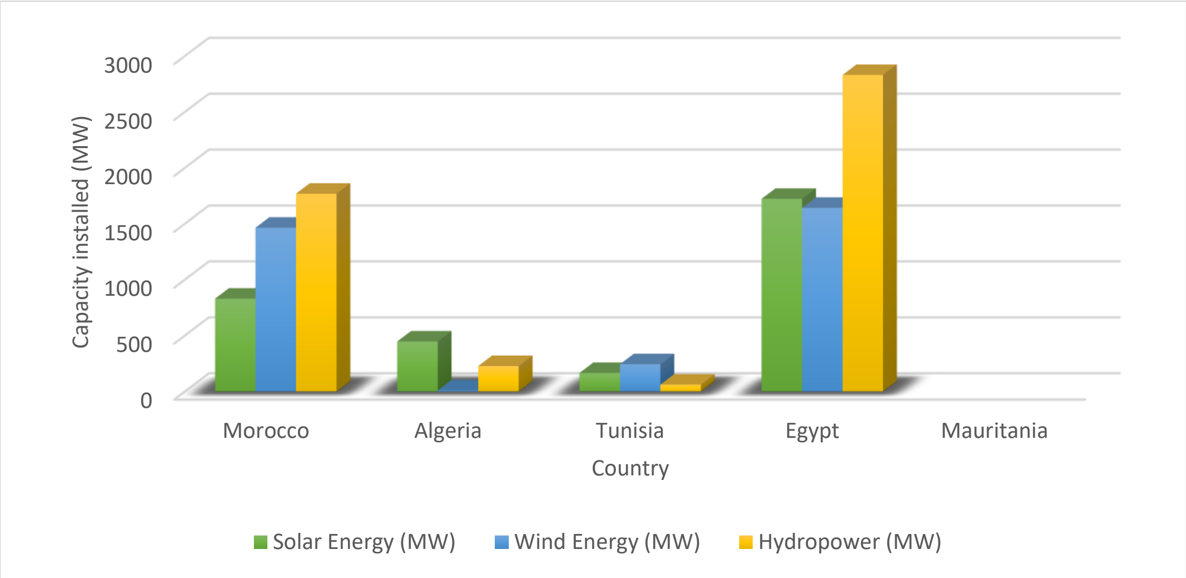

Figure 32: Breakdown of Renewable installation capacity in the North Africa countries

Within their geographical regions, Egypt and Morocco are notable leaders in renewable energy production capacity. Egypt has undertaken substantial investments in wind and solar energy initiatives, resulting in the establishment of numerous large-scale installations throughout the nation. Similarly, Morocco has taken proactive steps to advance its renewable energy sector, focusing on ambitious solar and wind projects.

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Projects on going: In North African countries, various agreements and projects are shaping the landscape of renewable energy. Morocco, a frontrunner in the region, has entered into agreements with several leader countries, including Germany, Portugal, Chile, the Netherlands, and the European Union. These collaborations have resulted in large-scale projects like the Hevo Ammonia Morocco Project and Total Energies Project. Beyond their extensive large-scale initiatives, Morocco has ventured into hydrogen research and development, recognizing the pivotal role that R&D can fulfil in advancing the hydrogen sector. Evidencing their dedication is the establishment of the GH2A research platform, underlining their faith in the substantial potential of research and development endeavours.

Algeria, although having fewer international agreements, is making strides with partnerships with Germany and AG. Their projects focus on experimental natural gas/hydrogen pipeline loops, solar energy storage for green hydrogen production, and green ammonia or methanol production.

Tunisia's agreements with Germany and the European Union have yet to materialize into large-scale or pilot projects. Still, they maintain cooperation in the "TuNur" initiative, showcasing their dedication to renewable energy development.

Egypt has made significant agreements with Germany and the EU, fostering an impressive 23 large-scale projects. Collaborations with Siemens, MAERSK, Belgian consortium DEME, and others have propelled Egypt's renewable energy sector forward, although small-scale and pilot projects remain currently absent.

Mauritania, while lacking private investors oriented international agreements (despite for some very recent ones with EU and Germany), is pushing for four large-scale projects such as Project Aman, Project Noor, Infinity Power & Conjunct Project, and Green Steel with ArcelorMittal. A single agreement with British Petroleum is driving progress in the country's renewable energy sector. These diverse efforts in the North African region underscore the growing importance of renewable energy in the global transition towards sustainable and clean energy sources.

In the context of hydrogen production and related initiatives, Morocco and Egypt have firmly positioned themselves as the most dynamic and proactive nations within the North African region. These two countries have taken substantial strides, with a plethora of large-scale projects that involve collaboration with numerous leading companies and organizations. The intensity of their commitment to the hydrogen sector is palpable, reflecting their unwavering dedication to renewable energy advancement and the pursuit of a sustainable future.

Morocco has emerged as a notable player in this landscape, primarily due to its diversified approach. Besides embarking on large-scale projects, the country has invested significantly in research and development endeavours pertaining to hydrogen technology. This focus on innovation and knowledge creation underscores Morocco's commitment not only to the immediate application of hydrogen in its energy sector but also to the long-term advancement and sustainability of the hydrogen industry. While Egypt shares Morocco's enthusiasm for large-scale production, it distinguishes itself by its rapid pace and ambitious approach. Egypt's commitment to renewable

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energy has attracted a wide array of international industry leaders and investors, creating a robust and dynamic ecosystem of hydrogen-related projects.
Mauritania, on the other hand, exhibits a somewhat more measured pace compared to its regional counterparts but is nonetheless making steady progress in the realm of hydrogen. It is actively engaged in the development of green hydrogen and has several significant projects in the pipeline.
Algeria and Tunisia, in contrast, present a more modest contribution to the regional hydrogen landscape. Their involvement in large-scale hydrogen initiatives is less pronounced, reflecting a lower degree of activity in this domain. Despite this, both countries have recognized the significance of renewable energy and are gradually exploring their potential in the hydrogen sector.
Partnership: In the context of green hydrogen initiatives, the North African landscape exhibits varying degrees of engagement and involvement among its nations, with each country charting its own distinct course in the renewable energy and hydrogen sectors. Morocco, a standout participant, is notable for its comprehensive approach, characterized by a multitude of agreements with leading countries, representing a rich tapestry of international collaborations. These partnerships span across a wide spectrum of projects, encompassing both large and small-scale endeavors, coupled with a strong focus on research and development. This multifaceted engagement underscores Morocco's unwavering commitment and robust diversification in the field of green hydrogen.
In stark contrast, Algeria takes a more reserved stance, with only a single agreement listed, particularly in conjunction with Germany. The country primarily focuses its efforts on smaller-scale projects, reflecting a less diversified portfolio of partners and initiatives. This may indicate a lower level of engagement within the sphere of green hydrogen in Algeria.
Tunisia, while exhibiting a slightly more elevated level of activity than Algeria, still falls behind the vigor displayed by Morocco. The country engages in two agreements, one with Germany and another with the European Union, but lacks large-scale projects. With the exception of the TuNur cooperation, there is a noticeable absence of major initiatives, indicating a relatively lower degree of engagement in this field compared to other countries in the region.
Egypt, on the other hand, stands out for its substantial activity in large-scale projects, demonstrated by its involvement in a multitude of international partnerships. Egypt, through two agreements with Germany and the European Union, has positioned itself as a regional powerhouse in renewable energy initiatives. However, it is intriguing to note that the country does not appear to emphasize research and development or development projects, potentially suggesting a primary focus on energy production initiatives.
Mauritania, while not featuring agreements with leading nations, is indeed an active participant in the large-scale project arena. The presence of a production development project within its portfolio highlights a burgeoning interest in renewable energy and the hydrogen sector.
The North African countries showcase diverse approaches and levels of commitment to green hydrogen projects, ranging from the comprehensive engagement of Morocco to the more reserved stances of Algeria and Tunisia, with Egypt's predominant focus on energy production initiatives, and Mauritania's increasing involvement in large-scale projects. Each country's unique trajectory

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reflects its individual strategy in contributing to the regional and global transition towards cleaner, sustainable energy solutions.

Politics: Morocco, for instance, demonstrates an impressive dedication to green hydrogen by launching energy and hydrogen pilot projects and engaging in collaborative endeavors with leading countries and corporations. Compared to other countries in the region, Morocco excels in performance quality. However, it faces challenges due to regulatory limitations, which may necessitate further development to support its green hydrogen aspirations.

Algeria, characterized by a strong political interest in green hydrogen as a diversification strategy beyond natural gas, portrays potential in the field. Despite this, the nation grapples with regulatory standards that exhibit significant deficiencies. Moreover, its level of political stability is notably low, which may impact the feasibility of long-term projects.

Tunisia exhibits heightened political enthusiasm regarding green hydrogen, marking its commitment to sustainability. The country has also established trade collaborations with the European Union (EU) and Germany, furthering its position in the sector. However, Tunisia experiences a notable lack of political stability and regulatory constraints, indicating areas that require improvement to harness its green hydrogen potential fully.

Egypt, on the other hand, outshines its neighboring nations in the region, boasting the most extensive array of collaborations with prominent countries and corporations. Its involvement in green hydrogen projects is substantial, reflecting its commitment to sustainable energy solutions. Nevertheless, significant infrastructure is under military ownership and operation, potentially posing challenges for international funding organizations and the engagement of private companies.

Mauritania places a strong political emphasis on green hydrogen and has initiated significant initial projects in this sector. However, its regulatory framework is fragile and necessitates further development to support a burgeoning green hydrogen industry. Mauritania also faces limitations or challenges when it comes to participating in various stages or aspects of the hydrogen industry that contribute to its economic development.

These distinct attributes within the North African region paint a dynamic landscape of green hydrogen endeavors, each country charting its unique course toward sustainability and renewable energy solutions. Their strengths offer promising prospects, while their weaknesses underscore areas for improvement in fostering a cleaner, more sustainable future.

Regulatory: In the evolving landscape of green hydrogen production across North African countries, the establishment of comprehensive legal and regulatory frameworks plays a pivotal role. Here, we examine the regulatory progress and initiatives in Morocco, Algeria, Tunisia, Egypt, and Mauritania.

Morocco, known for its burgeoning green hydrogen projects, presently grapples with the absence of a comprehensive regulatory regime tailored to address hydrogen-related issues. This regulatory gap underscores the need for further legal development to accommodate and govern the emerging green hydrogen industry within the nation.

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Algeria, while expressing political interest in green hydrogen as a diversification strategy beyond natural gas, currently lacks any specific laws or regulations related to hydrogen. The absence of a legal framework reflects the need for regulatory measures that can support and guide the country's journey into sustainable hydrogen production.

Tunisia, with a growing interest in green hydrogen, is yet to establish a specific regulatory framework for this sector. The absence of defined regulations points to a requirement for legal development to provide clarity and guidance in the emerging field of green hydrogen within the country.

In contrast, Egypt has taken substantial steps to foster green hydrogen initiatives. On May 17, 2023, the Egyptian Cabinet approved a new bill aimed at providing incentives for projects related to green hydrogen and its derivatives. This legislation serves the purpose of encouraging environmentally friendly endeavors and is applicable to projects involved in the production of green hydrogen and its derivatives, subject to the condition that agreements are concluded within five years from the law's enactment.

Mauritania, while demonstrating strong political emphasis on green hydrogen, is actively developing the necessary legal and regulatory framework. Collaborating with international partners like the CONNEX Support Unit and the European Union, the Mauritanian government is working to establish the framework that will underpin the country's foray into the green hydrogen industry.

These regulatory updates and initiatives across the North African region reflect the diverse approaches and challenges faced by each nation as they navigate the intricate terrain of green hydrogen production. The progress made and regulatory frameworks put in place highlight the commitment of these countries to sustainable and environmentally responsible energy solutions. As the green hydrogen sector continues to evolve, the development of comprehensive legal and regulatory frameworks will remain a critical factor in shaping the future in the region.

Hydrogen Roadmaps & Strategies: Morocco has been initiative-taking in laying the foundation for its green hydrogen journey. In 2021, the Moroccan Ministry of Energy, Mines, and Environment initiated a roadmap under the National Hydrogen Commission. This strategic roadmap serves as a guiding framework for Morocco's pursuit of green hydrogen, outlining key objectives and milestones to be achieved.

Algeria, with its rich renewable energy potential and ambitions for economic development, is gearing up for its green hydrogen roadmap launch in 2023. The primary goals are to bolster renewable energy capacity, facilitate cleaner energy exports, and drive economic growth. This roadmap is poised to shape Algeria's energy landscape and contribute to the nation's sustainable future.

Tunisia, cognizant of the global green hydrogen market taking shape, embarked on the development of its national strategy for green hydrogen at the outset of 2022. This strategy is slated for completion by 2024 and comes with a distinctive focus on prioritizing the export of green hydrogen, positioning Tunisia as a key player in the international green energy market.

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Egypt, a regional leader in the green hydrogen race, is diligently unveiling its roadmap by the close of 2023. The Egyptian government is in the final stages of crafting a comprehensive national green hydrogen production strategy. Importantly, this strategy incorporates a governance structure aligned with international best practices, ensuring economic viability and investor appeal.

Mauritania, while in the initial stages of its green hydrogen journey, is actively engaged in the formulation of a roadmap for the development of green hydrogen. This roadmap will serve as a strategic blueprint, guiding the nation's efforts to harness the potential of green hydrogen for economic growth and sustainability.

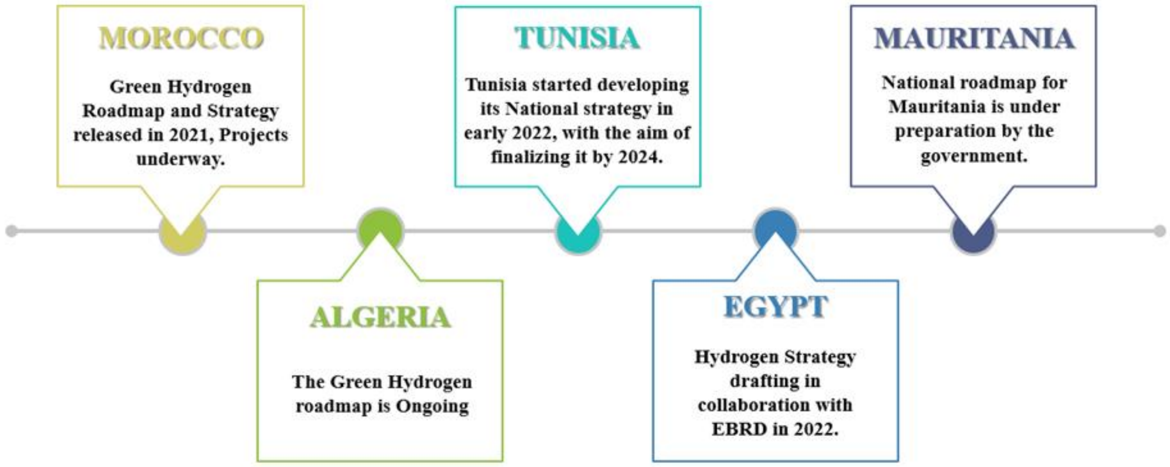

Figure 33: Green Hydrogen strategies & Roadmaps situation in North Africa

Interconnections and infrastructures: The energy connections between Europe and North African nations have historically been strong. In 2019, North Africa played a significant role in supplying Europe with energy resources, accounting for approximately 13% of Europe's gas and 10% of its oil consumption. In return, Europe was a substantial recipient of North Africa's oil and gas exports, constituting more than 60% of these exports.

The existing energy infrastructure facilitates this connection, with established gas transportation systems linking North Africa to Europe. These pipelines, which run from Algeria to Europe through routes via Italy and Spain, are responsible for transporting a substantial volume of gas, amounting to over 63.5 billion cubic meters annually.

Looking ahead, there are plans to adapt this well-established infrastructure to transport hydrogen from North Africa to Europe between 2030 and 2035. Initially, the focus will be on producing hydrogen from natural gas, commonly referred to as "blue hydrogen." As technology and renewable energy sources progress, the long-term goal is to introduce green hydrogen, generated from abundant solar and wind resources.

In addition to the existing infrastructure, new hydrogen pipelines are under consideration, connecting Egypt and Greece to Europe. The "South-Nordstream" project is a noteworthy initiative in this regard, requiring a substantial investment of 16.5 b€. Once operational, it has the potential to transport an impressive 7.6 million tons of hydrogen annually, with a competitive cost estimated

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at €0.005 per kWh or €0.2 per kg H_2. These developments signify the evolving landscape of energy transportation between North Africa and Europe, with a growing emphasis on cleaner and more sustainable energy sources. When considering the geographical positioning of these North African countries in relation to potential hydrogen transportation, various strengths and weaknesses emerge.

Morocco currently serves as a transit country within the existing pipeline infrastructure on its way to Spain. This positioning grants Morocco a strategic advantage in facilitating the transportation of hydrogen. However, there is also room for improvement, as it is currently reliant on these transit arrangements, which may present limitations in the future.

Algeria is looking into repurposing its extensive natural gas pipeline infrastructure that currently leads to Italy and Spain for the transportation of hydrogen. While this offers a strong foundation for hydrogen export, there is a potential challenge in transitioning from the existing natural gas business model to a focus on green hydrogen. Striking the right balance between these two energy sources is crucial.

Tunisia also plays a role in the transit of energy resources, notably relying on Algeria for its transportation infrastructure. The existing pipeline structure, directed towards Italy, passes through Tunisia, making it a significant player in the potential hydrogen transportation network. However, dependence on a single source could pose challenges in diversifying energy transportation routes.

Egypt stands out with several strengths in terms of its geographical positioning. Positioned along prospective trade routes facilitated by the Suez Canal, Egypt has the potential to establish additional hydrogen transportation infrastructure services. Moreover, existing infrastructure designed for ammonia imports can be repurposed for the export of green ammonia. Nevertheless, Egypt faces a challenge in the lack of pipeline connectivity for linking to European demand hubs, which is vital for successful hydrogen export.

Mauritania faces unique geographical circumstances. While it offers strengths such as a large geographical distance from the European Union compared to other North African countries, potentially providing a unique position for energy export, it currently lacks established connections with its neighbouring North African nations. Building these interlinkages will be essential for enhancing its role in the regional hydrogen landscape.

Over the coming decades, the significant expansion and enhancement of electricity grid infrastructure will be imperative, particularly to facilitate the transmission of electricity from regions rich in solar and wind resources to meet the growing demand in urban and rural areas. Currently, there are two existing interconnections between Spain and Morocco, representing Europe's sole electricity links with the African continent, boasting a combined technical capacity of 700 MW. This forms the backbone of energy trade between the two continents.

Spain and Morocco have recently solidified their intentions to further bolster this energy connection through a memorandum of understanding (MoU), setting the stage for the construction of an electrical interconnector that will physically link these two nations. The assessment and planning

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for this ambitious project will be jointly conducted by two key players: the Spanish electricity grid operator, “Red Eléctrica de España” (REE), and its Moroccan counterpart, “ONEE”. This interconnector is anticipated to possess a technical capacity of 700 MW and is scheduled for commissioning before 2026. In terms of the commercial exchange capacity, which must be viewed as a holistic entity, it is set to reach an impressive 1 400 MW, offering ample potential for substantial energy trade between the two countries.

Within each of these North African nations, three distinct categories of internal connections have been identified: the first comprises presently operational transmission lines, the second encompasses projects that are either currently under construction or slated to commence between 2025 and 2030, and the third pertains to potential projects, which include existing ones that could be expanded considering new energy generation scenarios. This tripartite classification underscores the evolution and growth of energy connectivity within the region.

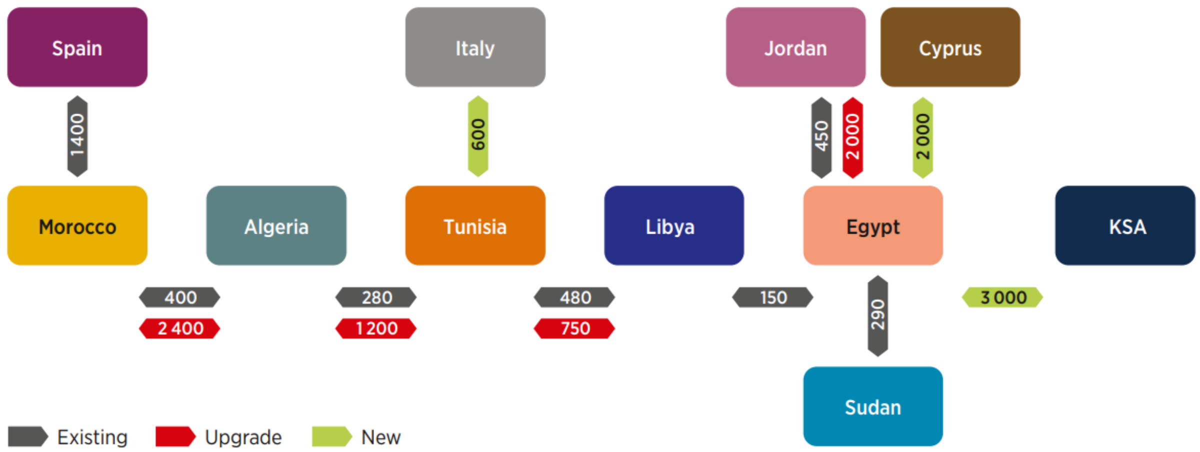

Figure 34: Existing and planned electrical interconnection capacity in North Africa

Detailed maps in Figure 34 provide a comprehensive overview of the current and projected interconnection capacity among North African nations, as well as the links between North African countries and other global regions. This visual representation paints a clear picture of the intricate network of energy transmission within the region and its connections beyond its borders.

It's important to note that, except for Mauritania, all North African countries have already established interconnections. However, it's also crucial to address a stability concern when attempting to synchronously connect the Libya-Egypt-Jordan-Syria region with the Tunisia-Algeria-Morocco cluster and integrate these with the European Network of Transmission System Operators (ENTSO-E). This challenge underscores the complexity and importance of seamless cross-border energy synchronization and grid reliability in the pursuit of a sustainable and interconnected energy future.

4.1.7 North African Countries overall analysis and comparison

The North African region boasts immense potential for green hydrogen production, primarily attributed to its abundant renewable resources, specifically solar and wind energy. A

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comprehensive study conducted across the five countries in the region reveals notable variations in the maturity of their respective hydrogen sectors, providing a nuanced perspective of their evolving positions in the green hydrogen landscape.
At the forefront of the region's green hydrogen endeavours is Morocco, which has already established a national strategy and is actively engaged in both production and research projects. This proactive stance sets Morocco apart as a trailblazer in the domain of green hydrogen.
Egypt, on the other hand, finds itself in the launch phase of its green hydrogen journey, actively formulating its strategy and negotiating cooperation projects to propel its efforts forward. The country's strategic geographical location, which includes the Suez Canal, holds the promise of facilitating hydrogen trade and strengthening Egypt's presence in the global hydrogen market.
Mauritania is positioned in the development phase, marking its entry into the green hydrogen arena with investment plans for infrastructure and the formulation of relevant policies. This phase signifies the country's commitment to a sustainable energy transition and its recognition of the role green hydrogen can play in this transition.
Tunisia, meanwhile, is situated in the planning phase, where a burgeoning strategy is evolving, and potential partnerships are being considered to establish a robust foundation for its green hydrogen endeavours. The country's collaboration with Germany and the European Union demonstrates its intent to make strides in this innovative field.
Algeria is in the initiation phase, marked by the inception of a national strategy. However, regulations specific to green hydrogen have yet to be fully defined. Algeria's substantial experience in the energy sector, particularly in natural gas, provides a valuable foundation upon which to build its green hydrogen future.
The varying degrees of maturity in these North African countries' hydrogen sectors are influenced by a multitude of factors, including their respective energy policies, public and private sector investments, and international partnerships. This diversity is a testament to

the evolving nature of the green hydrogen landscape and underscores the importance of context-specific approaches tailored to the unique circumstances and potential of each nation.

Green hydrogen represents an emerging and transformative technology with vast potential for the North African region. As Europe intensifies its efforts to reduce its reliance on fossil fuels and transition toward cleaner energy sources, there is an exceptional opportunity for North African countries to become major players in green hydrogen production and export. The European market provides a promising destination for green hydrogen, given its commitment to sustainable energy solutions.
To fully realize this potential, it is imperative that the countries in the North African region continue to invest in their hydrogen sectors, strengthening their policies and fostering international partnerships that are conducive to the growth of green hydrogen. This collaborative and forward-

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looking approach will not only secure a sustainable energy future for the region but also position North African nations as influential contributors to the global green hydrogen landscape.

Lastly, considering the proximity between North Africa and Europe and the existence of electric grid infrastructure too connecting EU and North Africa, it is of paramount importance:

1) to evaluate when to proceed with "Renewable Energy" produced in North Africa via an export of "electrons" or "molecula", also considering recent investments of some EU countries on HVDC and the planning of Southern EU hydrogen backbone.
2) To evaluate the possibility to decarbonize via green hydrogen installation the production of carbon/energy intensive products (e.g. steel, refineries, fertilizers...) at local level via electrolysis.

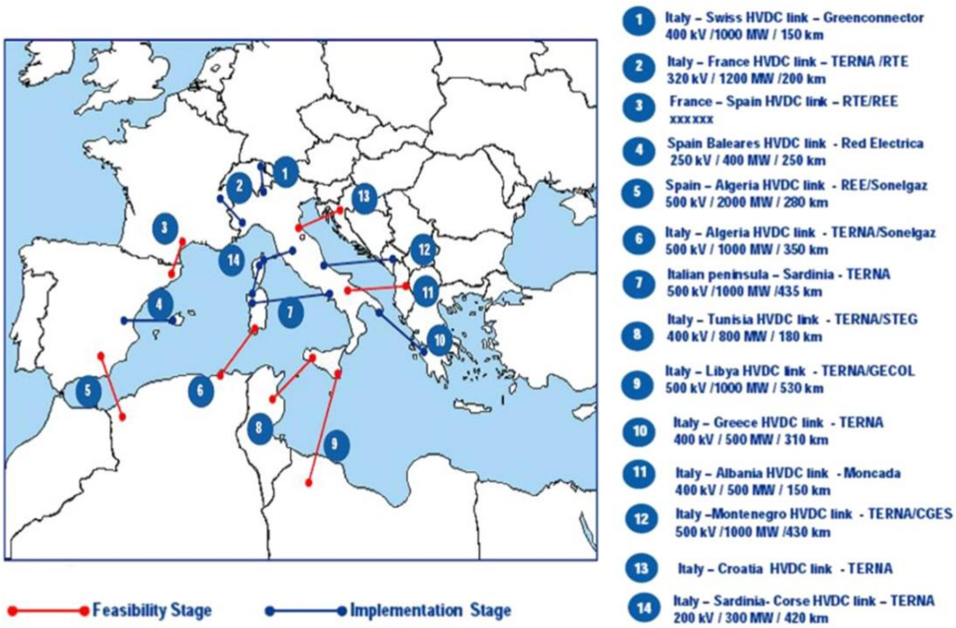

Figure 35: Potential HVDC electrical interconnection capacity in North Africa (up to 2018 plans)

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4.2 Western Africa Potential Assessment

The region under analysis in this chapter (prepared by JULICH) includes all the countries along the Western Africa coast from Senegal to Nigeria, as well as three landlocked countries, i.e., Mali, Burkina Faso, and Niger. All the 14 countries under analysis are (current or suspended) members of the Economic Community of West African States (ECOWAS).

4.2.1 Overview of national strategies, projects, and international initiatives

The assessment of the Western African region started with a research of ongoing projects, national hydrogen plans and roadmaps, as well as international agreements and relations regarding green hydrogen. We found that none of the countries had adopted yet a national hydrogen plan or roadmap. Similarly, no large hydrogen project was found to be under development. However, in the context of international relations, several initiatives were identified:

- **WASCAL**, namely the West African Science Service Centre on Climate Change and Adapted Land Use, an institution mainly funded by the Federal Republic of Germany and comprising 11 ECOWAS countries (Benin, Burkina Faso, Cape Verde, Ivory Coast, Gambia, Ghana, Mali, Niger, Nigeria, Senegal, and Togo). WASCAL offers capacity building, in particular the International Master's Programme in Energy and Green Hydrogen. Moreover, it works on the implementation of pilot projects and the development of the ECOWAS Green Hydrogen Policy and Strategy.
- **H2Uppp** a project implemented by GIZ, which, among other countries in other regions of the world, involves Nigeria. Its main aim is the identification and support of H2 projects, as well as the analysis of market potential and business models.
- **H2-Diplo** another project implemented by GIZ, involving Nigeria, as well as other countries highly dependent on fossil fuel export. The project aims at strengthening bilateral cooperation at diplomatic level and overcoming political and macroeconomic challenges involved in the reconversion of fossil fuel export economies.
- **PV2H** and **BIO2H**, two projects within the WASCAL framework. The projects aim at studying the technical feasibility of large-scale production of hydrogen in Burkina Faso through PV electricity and bioenergy, respectively.
- **HyAfrica** a subproject within the framework of the LEAP-RE project funded by the EU. HyAfrica aims at assessing the natural hydrogen resources in several African regions, including the Lacs prefecture in Togo. While the focus is on natural hydrogen, the complementarity with green hydrogen production is also part of the expected results.

4.2.2 Assessment of technical, socioeconomic, and political potential for green hydrogen production and export

The assessment of the region was primarily conducted by means of the results of the H2 Atlas, a tool that was developed within the Forschungszentrum Jülich following the work of the H2 Atlas

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project. The H2 Atlas Tool provides a set of multidimensional and spatially granular results, which includes the assessment of:

- Technical potential in terms of renewable electricity and H2 production.
- Sustainable yield of groundwater resources.
- Potential for local socioeconomic impact in terms of increase in electricity access and employment opportunities.

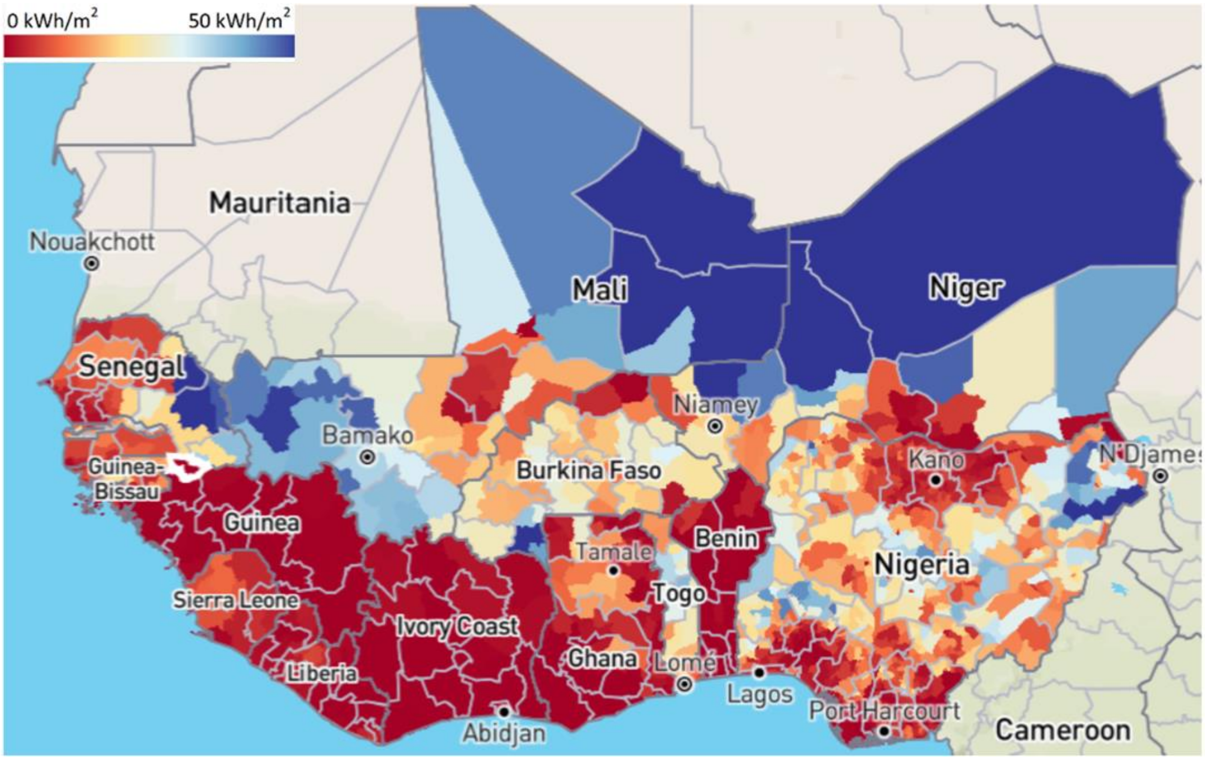

Figure 36: Annual green hydrogen production potential per unit of area

The H2 technical potential is calculated based on the available eligible land and the available potential for renewable electricity generation deriving from wind and solar energy, whereas potential water constraints are not considered. Regarding sustainable yield of groundwater resources different scenarios are available: in this assessment we considered the most conservative scenario. Finally, given that local benefits are a priority of this assessment, the socioeconomic indicator is used for a first assessment of potential local impacts in terms of employment and potential demand. Low electricity access, population density, poverty rate and unemployment rates are main drivers pushing up georeferenced socioeconomic indicator scores. The prioritization of local demand is particularly important for the region, as solar and wind resources are less optimal for exports, while low energy access and high population density offers large untapped potential in terms of local demand.

Moreover, H2 Atlas Tool also provides a set of national framework indicators covering:

- National energy sector framework and policies.
- National export and transport infrastructure.

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- National eco-political and regulatory frameworks.

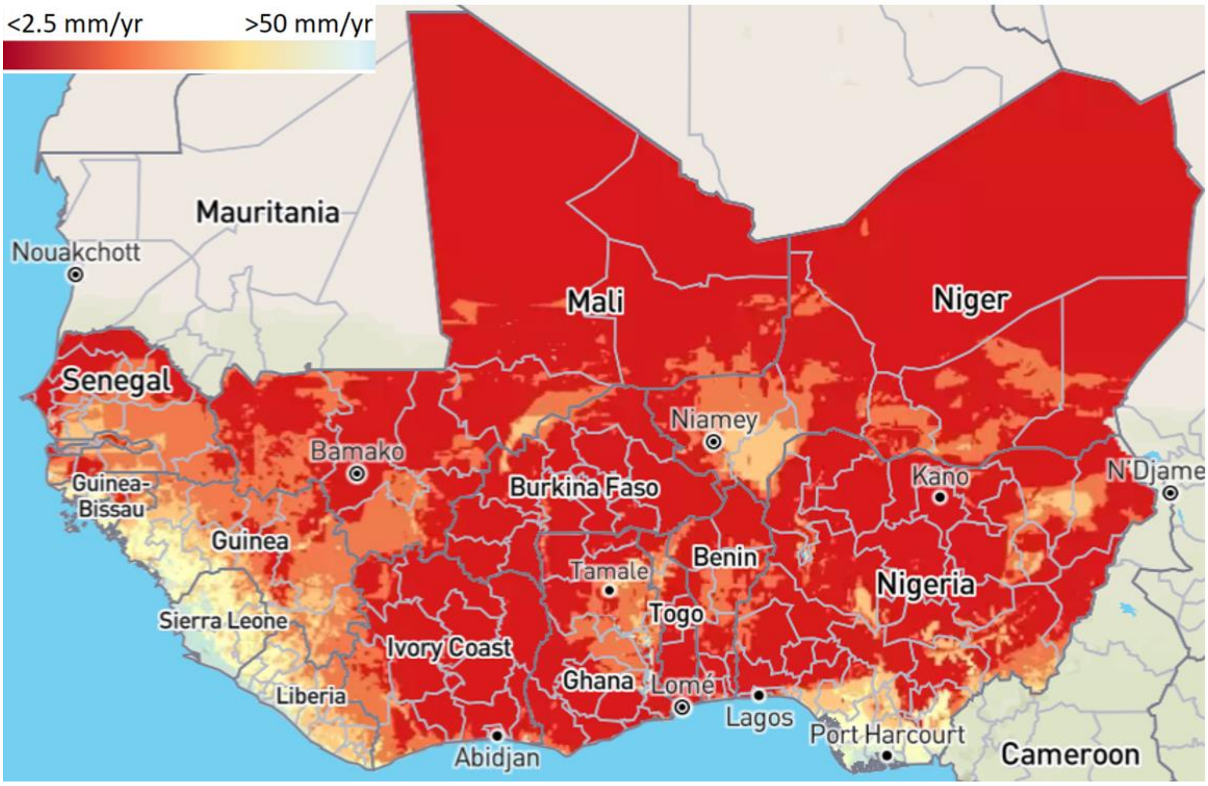

Figure 37: Sustainable yield of groundwater resources

These framework indicators provide an assessment of the political and regulatory environment (also in terms of sustainability-related policies), energy sector characteristics, as well as export and transport infrastructure. Such framework indicators aim to reflect the socioeconomic and political feasibility of and readiness for green hydrogen production and exports.

The input data from the H2 Atlas Tool were integrated with additional data and evaluations from other sources, namely:

- Socioeconomic potential from PtX Atlas, an indicator covering a broad range of economic, societal, political, and technological dimensions. The use of this indicator serves as a crosscheck of the national framework indicators of H2 Atlas.
- Per capita electricity generation from renewable electricity sources (RES) derived
- An assessment of port infrastructure from a study of PwC

Fig.36 shows the maximum annual hydrogen production potential per area, in subnational regions. High potential for H2 production can be found in regions of the landlocked countries Mali, Burkina Faso, and Niger, but also in interior regions of Senegal, Togo and Nigeria. Groundwater resources are however scant throughout most of interior regions, as shown in Fig. 37, whereas relatively abundant groundwater resources are found in the coastal regions of Guinea, in Sierra Leone, in Liberia and in southeastern coastal regions of Nigeria. Therefore, for large-scale green hydrogen production, desalination seems to be the most viable option throughout most of the region.

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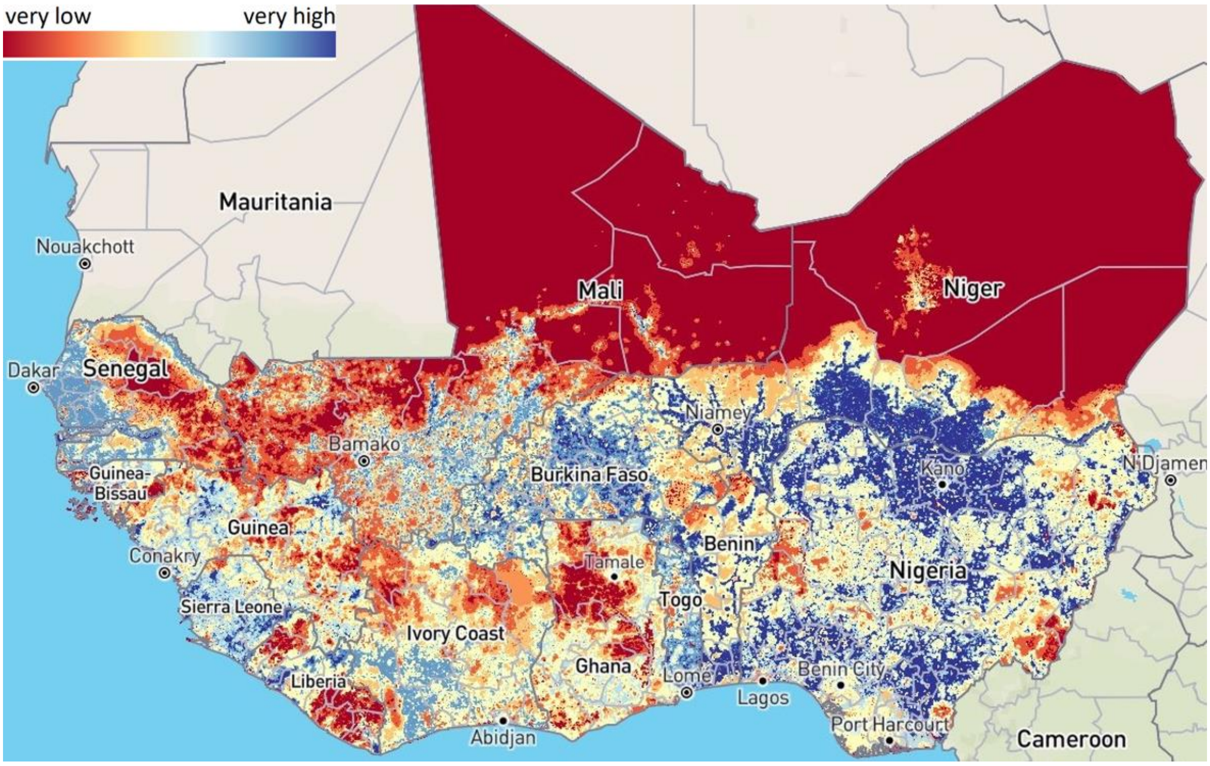

Figure 38: Potential local socioeconomic impact deriving from green hydrogen production

Fig. 38 shows the potential for local socioeconomic impact, which is a priority in the context of Western Africa. Many of the areas with high production potential (i.e., northern regions of Mali and Niger, Southwestern Mali, and eastern areas of Senegal) have a low socioeconomic potential, mostly due to their low population density. Large areas with high socioeconomic potential can be observed in coastal regions of Senegal, in Sierra Leone, in most of Burkina Faso, in Togo, Southwestern Niger, as well as in large parts of Nigeria. However, also in regions with a medium level of socioeconomic potential significant benefits may be expected, following the increase in available energy and economic opportunities deriving from a green hydrogen industry.

Finally, we analyzed the framework conditions, which determine the socioeconomic and political feasibility of and readiness for a green hydrogen economy. Beside technical potential, aspects such as institutional stability, security, risk of conflict, political-regulatory framework in terms of sustainability, business environment, readiness of energy and transport infrastructure, are crucial, especially from the perspective of potential green hydrogen investors and off-takers. Table 28 provides an overview of the three-tier score of the three framework indicators analysed by JULICH Researchers. In comparative terms (scores are normalized within the region), three countries perform well in all the three categories, namely, Senegal, Ivory Coast and Ghana. As these multidimensional indicators are affected by many assumptions regarding aggregation, normalization, and weighting, JULICH conducted a robustness check using the socioeconomic potential: according to this alternative indicator, Ghana achieves the highest score followed by Ivory Coast, Senegal and Togo. Another factor affecting green hydrogen production readiness, is the current level of generation of renewable electricity generation per capita (RES kWh pc.). Table 28

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reports this value for the year 2021, where Ghana stands out with 234 kWh per capita, followed by Guinea with 197 kWh per capita. However, such levels of generation are negligible, considering that production of H2 should derive from significant surplus of RES electricity. Moreover, most of generation derives from hydropower. In this regard, Table 28 also reports only the electricity generated through solar and wind energy, where Senegal achieves the highest value with merely 22.6 kWh per capita. While some countries appear to have more experience than other countries with solar or wind energy (mostly with the first than the latter), massive additional deployment of solar and wind energy power plants, as well as its related capacity building, will be needed across the whole region. Finally, a key factor affecting the potential for export of H2 (or its derivatives) is the presence of major ports. The study of PwC evaluated, the potential for throughput expansion, hub attractiveness and port performance: in this regard Abidjan (in Ivory Coast), Tema (in Ghana) and Lagos-Apapa (in Nigeria) are the ports obtaining the best results in the region.

Table 28 – National framework indicators for green H2 feasibility and readiness (based on [6,8,9,10,11])

Country	Energy sector framework	Exp.&Transp. infrastract.	Eco-political framework	Socioecon. potential	RES gen. (kWh pc.)	Solar and wind gen. (kWh pc.)	Main port
Senegal	3	3	3	2.76	26.5	22.6	Dakar
Gambia	1	2	3	2.42	2.3	2.3	Banjul
Guinea-Bissau	1	1	1	2.24	1.0	1.0	Kamsar
Guinea	1	1	1	2.4	197.1	1.7	Conakry
Mali	2	1	1	2.63	85.6	4.3	Landlocked
Sierra Leone	1	1	2	2.48	29.0	0.7	Freetown
Liberia	1	1	1	2.47	25.4	0.8	Monrovia
Ivory Coast	3	3	3	2.88	95.8	0.2	Abidjan
Burkina Faso	1	3	3	2.32	10.6	4.4	Landlocked
Ghana	3	3	3	3.09	234.2	4.5	Tema
Togo	1	1	2	2.74	18.3	8.4	Lomé
Benin	1	1	3	2.65	0.2	0.2	Cotonou
Niger	1	1	2	2.51	1.8	1.8	Landlocked
Nigeria	3	3	1	2.50	43.7	0.5	Lagos-Apapa

4.2.3 Conclusions

A broad interest in green hydrogen can be observed in all ECOWAS countries, as, in the context of international relations and cooperation, the potential for a green hydrogen economy is being explored through multiple initiatives.

From a technical perspective, Western Africa shows significant potential for green hydrogen production despite some major challenges. High renewable energy potential tends to be located in interior regions with scarce groundwater resources. However, good levels of production potential can also be found in locations with better groundwater resources and/or closer to the coast: for the latter, desalination represents an opportunity for large-scale production facilities. From a socioeconomic perspective, large potential for positive socioeconomic impacts can be observed in large areas of the region: the benefits to the local population in terms of local demand and employment opportunities are the priority in the context of Western Africa. Finally, regarding

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socioeconomic and political feasibility and readiness, national framework indicators were considered. In this regard, countries such as Ghana and Ivory Coast appeared to benefit from the best framework conditions.

After this first assessment (that for this specific area is interesting to be compared with UNIGE assessment presented in Chapter 2), which included technical, socioeconomic, and political aspects, we concluded that a large area, which include Ghana and part of its neighbors, offers the largest potential in terms of feasible production, local demand, and export. Ghana has a moderate level of technical production, performs best in terms of national framework indicators and infrastructure readiness, and has a port with considerable potential for integration into international hydrogen trade. Moreover, through the collaboration with neighboring Togo and Burkina Faso, the area of interest could be expanded to include additional significant potential in terms of production and socioeconomic impact.

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4.3 Central-Eastern Africa Potential Assessment

Focusing specifically on East Africa – more specifically Kenya, Ethiopia, Uganda, the Democratic Republic of Congo, and Tanzania — this chapter (Developed by STRATH) will delve into how JUST GREEN AFRH2ICA project initiative can be instrumental in shaping the region's energy landscape. It will explore the unique opportunities and challenges these countries face in the transition towards a hydrogen-based economy, and how their collaboration with European counterparts can foster a sustainable and equitable energy future.

The chapter is structure in different sub-chapters as follow:

§4.3.1: Overview of the Green Hydrogen Opportunities Landscape in East Africa - providing a comprehensive overview of the green hydrogen landscape, emphasising the key renewable energy sources such as geothermal, wind, solar, and hydro power that underpin the potential for green hydrogen production in East Africa. This section will explore how these resources can be harnessed effectively to create a sustainable energy future.

§4.3.2 Country Specific Opportunities and Challenges Analysis - Following the general overview, the report will delve into detailed analyses of each East African country included in the study – Kenya, Ethiopia, Uganda, the Democratic Republic of Congo, and Tanzania. This section will highlight the unique opportunities presented by each country in terms of their renewable energy resources and potential for green hydrogen production. Alongside these opportunities, this section of the report will also address the specific political, policy and infrastructure challenges that may impede the development of green hydrogen initiatives in each nation.

§4.3.3 Conclusions and recommendations - The final section will synthesise the findings from the previous sections, drawing conclusions on the overall potential and challenges of implementing green hydrogen strategies in East Africa. It will also provide recommendations for policymakers, industry stakeholders, and international partners to overcome barriers and leverage opportunities for the successful development of a green hydrogen economy in the region.

Therefore, through this structure, the report aims to provide a thorough and advanced understanding of the green hydrogen landscape in East Africa, offering insights into both the vast potential and the significant challenges that must be addressed to realize a sustainable and equitable energy future.

4.3.1 Overview of the Renewable Energy Opportunities Landscape in East Africa

This section of the report aims to provide a comprehensive overview of the green hydrogen landscape in East Africa. It will delve into the region's vast pool of renewable energy sources, exploring how they can be effectively harnessed to create a sustainable energy future. Through this exploration, the report will highlight the immense opportunities that green hydrogen presents for East Africa, not only to meet the growing energy demand but also as a catalyst for economic growth, social development, and environmental stewardship. It is crucial to recognise that the successful implementation of green hydrogen initiatives in East Africa could set a precedent for

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other regions, demonstrating the viability and transformative potential of renewable energy in the global fight against climate change.

As the world deals with the dual challenges of climate change and energy security, the focus on sustainable and renewable energy sources has become more critical than ever. East Africa, a region marked by its diverse and abundant natural resources, stands at the forefront of this transformative journey. With a expanding population and a pressing need for sustainable development, the potential of green hydrogen as a cornerstone of the region's energy future cannot be exaggerated. Green hydrogen, produced through the electrolysis of water using renewable energy sources, provides an encouraging opportunity in the global pursuit of carbon neutrality. Unlike conventional hydrogen production, which often relies on fossil fuels, green hydrogen offers a pathway to decarbonise various sectors, including transportation, industry, and power generation. In East Africa, the unique confluence of geothermal, wind, solar, and hydro power resources offer abundant grounds for the development of a green hydrogen economy. These renewable energy sources are not only abundant in the region but are also increasingly cost-competitive and technologically accessible.

Nonetheless, the drive to the harnessing of green hydrogen in East Africa is not without its challenges. Issues such as infrastructural needs, technological advancement, investment, and policy frameworks must be meticulously navigated. Additionally, with nearly 50% of Africa's population lacking access to reliable energy, the imperative to develop energy projects that can enhance energy accessibility through solutions that are both sustainable and inclusive is paramount.

4.3.1.1 Renewable Energy Sources in East Africa

The development of renewable energy in East Africa is much more than just a quest for energy sufficiency. It can a catalyst for socio-economic growth, creating jobs, stimulating local economies, and fostering the emergence of new industries and services. It is also a step toward environmental sustainability, reducing the region's carbon footprint and contributing to global efforts in combating climate change. The renewable energy landscape in East Africa is a mosaic of opportunities and promises. It is not just about meeting the growing energy demands of the region but about forging a path that leads to socio-economic prosperity and environmental stewardship. This path, though challenging, is one filled with hope and potential, signifying a brighter, greener future for East Africa.

The renewable energy landscape in East Africa, with its rich mix of geothermal, wind, solar, and hydro power, offers a promising pathway toward a sustainable and energy-secure future. Effective harnessing of these resources requires a comprehensive approach encompassing investment, policy support, and technological innovation. The development of these renewable sources promises not only to meet the growing energy needs of the region but also to stimulate socio-economic growth and environmental sustainability.

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East Africa's renewable energy landscape consists of vast utilised and untapped resources, spanning across countries Kenya, Ethiopia, Uganda, Tanzania, and the Democratic Republic of Congo. Each of these countries has its own unique set of renewable energy assets and potentials, a reflection of the diverse geographical and climatic conditions in the region. From the geothermal resources of Kenya and Ethiopia, the hydropower dominance in Ethiopia and Uganda – and potential in the DRC – the region is making efforts in harnessing its renewable resources. However, alongside these developments lies a vast array of untapped renewable energy sources, including wind, solar, geothermal and biomass, which present further opportunities for sustainable growth and energy security (Sawadogo, W., Reboita, M.S., Faye, A. *et al*). This part delves into the current state of renewable energy exploitation in East Africa, highlighting both the achievements and the yet-to-be-explored potential that could reshape the region's energy landscape, support a prosperous green hydrogen sector and contribute significantly to global efforts in combating climate change. The segment below reviews the landscape for geothermal, wind, hydro and solar in East Africa.

Central to East Africa's renewable landscape is geothermal energy. The Great Rift Valley, a geological fault-line that runs through East Africa offers immense geothermal potential, particularly in countries Kenya and Ethiopia (Ndyambuki *et al*, 2021). This source of energy, when effectively harnessed, provides a steady and reliable power supply, an essential cornerstone for any energy strategy (Coscun, Kaygusuz & Kaygusuz, 2021). Complementing geothermal energy is the encouraging potential of wind power. The highlands and coastal areas of East Africa are ideal locations for wind farms. These farms, with the right investment, can significantly contribute to the region's energy mix, offering a clean and renewable power source that harmonises with the environment. Not to be overlooked is the power of the sun. East Africa, with its abundant sunlight, is perfectly poised to harness solar energy. This is especially transformative in rural and remote areas, where traditional grid connectivity poses challenges. In addition, hydro power also plays a vital role in the region's energy landscape. The numerous rivers and lakes in East Africa can support hydroelectric power generation. While hydro power has been a traditional energy source in the region, there still exists vast, untapped potential, particularly in the realm of small to medium-sized hydro projects – as well as the opportunities for mega-projects, for example in the Democratic Republic of Congo, Uganda, and Ethiopia.

Geothermal Energy

East Africa's Rift Valley is a hotspot for geothermal energy. This region, particularly in Kenya and Ethiopia, possesses an estimated geothermal potential exceeding 15,000 MW (Renewable Energy Institute, 2023). Kenya's pioneering ventures into geothermal energy, notably at the Olkaria and Eburru fields, have established it as a leader in geothermal production in Africa and among the top global producers. These geothermal plants have become integral to Kenya's energy mix,

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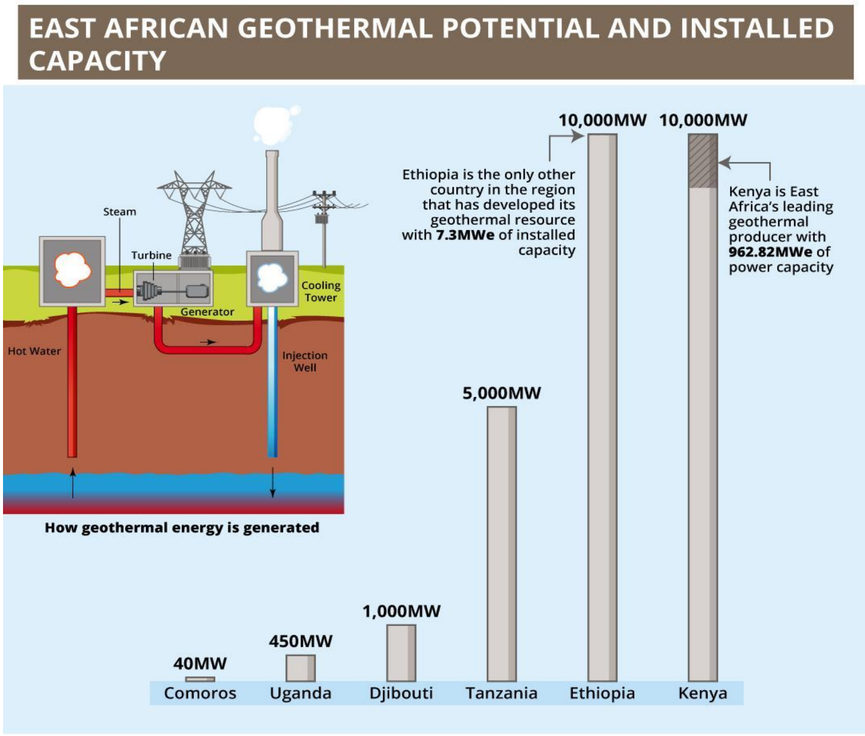
contributing significantly to the national grid and mitigating the country's reliance on less reliable and environmentally unfriendly energy sources like hydroelectric power, which is susceptible to climate-induced droughts (Kenya Energy Sector Overview, 2023). The development of geothermal energy in East Africa aligns with the region's goals for sustainable and resilient energy systems, as it offers a reliable and constant power source, unlike the intermittency associated with solar and wind energy (Green Energy Africa Report, 2023). Further, geothermal energy's potential for expansion is underscored by the ongoing exploration and technological advancements, suggesting that countries like Ethiopia and Djibouti could significantly scale up their geothermal output, given their geological similarities with Kenya (Geothermal Expansion in East Africa, 2024). Despite these strides, geothermal energy is under-exploited, with scope considerable increases in generation as indicated in Figure 39.



Source: Energy For Growth Hub

MUSTARD **INSIGHTS**

Figure 39: East Africa Geothermal Energy Potential and Installed Capacity

The exploration of geothermal energy development in Kenya and Ethiopia offers an insightful window into the diverse and dynamic nature of renewable energy landscapes in East Africa. Geothermal energy, a sustainable and reliable source of power, has become increasingly significant in the region, particularly given its rich geothermal potential thanks to the East African Rift System, as indicated above. This analysis delves into how Kenya and Ethiopia, two countries at different stages of geothermal development, are harnessing this resource to meet their energy needs, contribute to their economic growth, and align with global sustainability goals.

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Kenya, with a history of geothermal development dating back to the 1950s, has emerged as a global leader in this sector. It presents a compelling case study of how geothermal energy can be effectively integrated into a national energy strategy, driving substantial contributions to the country's total energy production. The Kenyan experience also highlights the challenges and opportunities inherent in developing and scaling up geothermal energy within a developing country context. Conversely, Ethiopia's geothermal sector is in a nascent stage but is characterised by ambitious plans for expansion and development. This points to a transformative phase in Ethiopia's energy sector, underpinned by large-scale investments and international collaborations. Ethiopia's approach reflects the broader aspirations and challenges faced by countries seeking to tap into their renewable energy resources to foster sustainable development.
The comparative analysis of these two countries' approaches to geothermal energy development provides valuable insights into the broader themes of regional cooperation, sustainable development, and the challenges and opportunities in harnessing renewable energy resources in the developing world. This analysis aims to synthesize the key aspects of geothermal energy development in Kenya and Ethiopia, drawing from various reports and studies, to present a nuanced understanding of their individual and collective impacts on the regional energy landscape.

Several reports and papers on geothermal energy in Kenya and Ethiopia offer a comprehensive view of how each country is addressing and developing this renewable energy source, each with its distinct challenges and potential.

With respect to Kenya for instance, a Reuters' report titled *Kenya steps up as global geothermal powerhouse* highlights the country's status as a leading global user of geothermal energy. It emphasises Kenya's ambitious plans to expand its geothermal capacity, which is part of a broader commitment to sustainable energy goals. This expansion is not just a domestic venture, as illustrated by the Science News article *How Kenya is helping its neighbours develop geothermal energy*. Kenya's expertise in geothermal energy is not only propelling its own growth but also aiding neighbouring countries, underlining the potential of East Africa in generating significant electricity from geothermal sources. The International Energy Agency's *Kenya Energy Outlook – Analysis* provides a detailed overview of Kenya's energy landscape, particularly its renewable energy initiatives. It places a special emphasis on the geothermal sector, showcasing Kenya's efforts in harnessing this resource. Similarly, ESI Africa's report *Kenya leads the way in tapping into geothermal energy potential* discusses the current and projected role of geothermal power in Kenya's energy mix. It underscores Kenya's leadership in expanding geothermal power plants and its potential to influence energy development across Africa. The International Monetary Fund's report *Kenya Taps the Earth's Heat* explores Kenya's renewable energy priorities since the 1990s, highlighting progress in geothermal energy, including the development of one of the largest geothermal plants globally, the Olkaria VI project.

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In Ethiopia, the study *Geothermal energy resources in Ethiopia: Status review and insights* reviewed the country's geothermal energy resources, emphasising their significant potential to contribute to power generation capacity and address electricity access challenges. The IEA's *Ethiopia Energy Outlook – Analysis* presented key energy indicators, including Ethiopia's plans for geothermal energy development as part of a broader energy strategy. This analysis provided insights into the future role of geothermal energy in Ethiopia's energy mix. PV Magazine's report *Ethiopia's renewable energy sector hit by range of issues* discussed the challenges and developments in Ethiopia's renewable energy sector, including geothermal energy. It shed light on the broader context of renewable energy initiatives in the country. The Multilateral Investment Guarantee Agency's article *MIGA Increases Support for Geothermal Power Plant in Ethiopia* highlighted the international investment and support for Ethiopia's geothermal power plant development, reflecting the growing recognition of geothermal energy's potential in the country. The scholarly article *Overview of Geothermal Resources Utilization in Ethiopia* (Benti *et al*, 2023) provide a detailed view of the opportunities and challenges in utilizing geothermal resources in Ethiopia.

Together, these reports and papers provide insights into how Kenya and Ethiopia are developing their geothermal energy sectors. Kenya's advanced stage of development and contribution to regional energy strategies is contrasted with Ethiopia's emerging but ambitious geothermal initiatives, each reflecting their unique contexts and stages of development in renewable energy. The key themes emerging from these reports are:

1. Rapid development in Kenya: Kenya is recognised as a global leader in geothermal energy. The country's journey, which began in the 1950s, has led to it becoming the seventh largest geothermal energy producer globally. A significant portion of Kenya's energy mix is derived from geothermal sources, and it continues to expand its capacity. Kenya's leadership is also demonstrated through its influence in aiding neighbouring countries to develop their geothermal capacities, underscoring its regional importance in renewable energy.
2. Ethiopia's emerging geothermal sector: Whilst Ethiopia started its geothermal production later than Kenya, it has ambitious plans for the future. With a goal to significantly increase its geothermal capacity, Ethiopia is positioning for a major transformation in its energy sector. The country's plans include a vast investment in clean energy projects, thus signalling a strong commitment to diversifying its energy sources and enhancing overall energy capacity.
3. Challenges and potential in East Africa: Both countries benefit from the geothermal potential offered by the East African Rift System. However, they also face challenges such as high initial investment costs and the need for specialised expertise. The development of geothermal energy in this region is an indicator of the potential in contributing significantly to renewable energy goals and regional power generation.
4. Sustainable development and climate resilience: Geothermal energy in Kenya and Ethiopia is not only about electricity generation but also about sustainable development and resilience to

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climate change. The continuous and reliable nature of geothermal energy, as well as its low carbon footprint, positions it as a key player in the transition to sustainable and resilient energy systems.

5. Regional cooperation and knowledge transfer: Kenya's experience and advancements in the geothermal sector are aiding its neighbouring countries, including Ethiopia. This cooperation highlights the importance of knowledge transfer and regional collaboration in exploiting geothermal resources, which could be a model for other regions with similar geological features.

These reports consequently collectively emphasise the significant role of geothermal energy in the renewable energy landscape of Kenya and Ethiopia. They highlight the rapid development and leadership of Kenya in this sector and the emerging potential of Ethiopia, along with the broader themes of regional collaboration, sustainable development, and the challenges and opportunities in harnessing this renewable energy source.

The comparative analysis of Kenya and Ethiopia's geothermal sectors reveal the contrasts and synergies. Kenya's mature geothermal sector, with its substantial contribution to the energy mix and regional influence, offers a model for leveraging existing strengths for further growth and regional support. Ethiopia's emerging sector, focused on large-scale investment and rapid expansion, underscores the potential for significant growth in renewable energy even for countries starting from a lower baseline. The challenges faced by both countries, including significant investment requirements and the need for specialised expertise, are common in the path towards sustainable energy development. The broader implications of these developmental trajectories in Kenya and Ethiopia are significant for the region. Kenya's established geothermal energy sector showcases how such resources can contribute to national energy strategies and regional development initiatives. Ethiopia's ambitions, supported by international partnerships, highlight the potential for growth and development in renewable energy sectors. Together, these narratives from Kenya and Ethiopia illustrate the dynamic nature of energy transition in the developing world, where resource availability, strategic investment, and regional cooperation are key to shaping sustainable and resilient energy futures.

Consequently, the exploration of geothermal energy development in Kenya and Ethiopia underscores the significant role this renewable resource can play in shaping the energy futures of developing nations. Kenya's established geothermal sector serves as an indicator of success, demonstrating how sustained efforts, strategic investments, and regional cooperation can lead to substantial advancements in renewable energy utilization. Ethiopia's emerging geothermal sector, with its ambitious expansion plans and international support, represents the potential for significant growth and transformation in renewable energy landscapes. The contrast between Kenya's mature geothermal development and Ethiopia's nascent but ambitious initiatives are indicative of the diverse stages of renewable energy adoption across different national contexts. Kenya's experience provides valuable lessons in harnessing geothermal resources, while Ethiopia's

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progress highlights the challenges and opportunities faced by countries at the threshold of significant renewable energy development.

The narratives of both countries also reflect a broader regional trend towards sustainable and resilient energy systems, emphasising the importance of renewable energy sources in meeting global climate goals and ensuring energy security. The collaborative efforts in geothermal energy development, particularly Kenya's role in supporting neighbouring countries, underline the potential for regional partnerships in advancing sustainable energy initiatives. Overall, the development of geothermal energy in Kenya and Ethiopia is not just about energy generation; it is about a pathway to sustainable development, economic growth, and environmental stewardship. As the world increasingly looks towards cleaner and more sustainable energy sources, the experiences of these two East African countries re geothermal offer valuable insights for how other regions with similar renewable energy potentials can cooperate.

Wind Energy

On wind energy East Africa, whilst Kenya is making significant investments, the region – particularly Ethiopia and Tanzania – is recognised for the substantial yet untapped wind energy potential. The Lake Turkana area in Kenya and the Ethiopian highlands are characterised by high wind speeds, making them prime locations for wind farm development. The successful implementation of Kenya's Lake Turkana Wind Power project, Africa's largest wind farm, stands as indication to the region's potential in harnessing wind energy (Lake Turkana Wind Power Case Study, 2023). In Ethiopia, projects like the Ashegoda and Adama wind farms have started to tap into this potential, though there remains room for substantial growth and investment (Ethiopian Wind Energy Report, 2023). The wind energy sector in East Africa is undergoing a significant transformation and growth, as detailed in a series of reports focusing on countries like Ethiopia, Uganda, Tanzania, and the Democratic Republic of Congo (DRC). These reports, of which the contents are summerised and analysed herein, provide a comprehensive view of the current state and future prospects of wind energy in the region, highlighting unique opportunities, challenges, and strategic directions being pursued by each country. The summary of these reports offers insights into how each country is leveraging its renewable resources, particularly wind power, to meet its energy needs and contribute to sustainable development. The analysis further delves into the broader implications of these developments, considering economic, social, environmental, and policy aspects. This holistic view encapsulates the dynamic and multifaceted nature of the wind energy landscape in East Africa, reflecting a region on the cusp of significant renewable energy advancements.

The wind energy landscapes in various East African countries, as detailed in recent reports and studies, present a dynamic and promising outlook for renewable energy development in the region:

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1. Ethiopia: *The Wind Project Development Roadmap* report underscores Ethiopia's substantial wind potential and the country's collaborative efforts with Denmark to expand wind energy. With a current installed capacity of 324 MW and plans for an additional 1,000 MW, Ethiopia is preparing to significantly enhance its renewable energy mix, focusing on public-private partnerships and policy frameworks to accelerate this growth.
2. Uganda: According to the *Executive summary – Uganda 2023* by the International Energy Agency, Uganda is aiming to diversify its energy sources beyond its current heavy reliance on hydropower. With an ambitious national energy policy, the country is focusing on expanding its renewable energy capacity to address its energy needs and future growth. Nonetheless, Uganda's policy directions are very limited in providing any pathways for wind energy development.
3. Tanzania: Tanzania's renewable energy sector, as of 2020, has begun to include wind power with its first wind farm. The country's diverse renewable resources, coupled with areas identified with sufficient wind speeds for grid-scale generation, indicate a budding interest and potential growth in wind energy.
4. Democratic Republic of Congo: The *Renewable Riches* study highlights the DRC's significant wind and solar potential, estimated at 85GW, which could greatly surpass the output of traditional energy sources and address the country's chronic power shortages. This potential can position the DRC to become a key player in the renewable energy landscape in Africa, not only meeting its own energy needs, but in exporting clean energy to other countries. .

These reports collectively illustrate a region trending towards growth in renewable energy with wind energy playing a role in the energy mix. Each country, with its unique resources and strategies, can contribute to a broader narrative of embracing renewable energy for sustainable development and energy security in East Africa. For instance, Ethiopia's significant investment in wind energy, as outlined in its *Wind Project Development Roadmap* indicates a strategic approach to diversifying its energy mix, highlighting the importance of robust policy frameworks and private sector engagement. Tanzania, initiating its first wind farm, signals a growing recognition of wind power's viability in the regional energy mix.

Challenges and opportunities are central themes across these reports. Uganda's focus, as reflected in the *Executive summary – Uganda 2023* (IEA) remains on expanding its overall renewable energy portfolio, but with an emphasis on solar. This nonetheless is still indicative a broader strategy to transition from traditional energy sources. The DRC's considerable wind potential and desperate lack energy access situation as pointed out in the *Renewable Riches* study, suggests an opportunity to leapfrog traditional energy development paths, despite infrastructural and economic constraints.

The transition to wind energy in East Africa carries significant economic and social implications. This shift promises not just economic growth and job creation but also improved energy security. For countries like Ethiopia and Tanzania, embracing wind energy as part of the energy mix is a means to meet the demands of rapid urbanisation and economic development. Meanwhile, in Uganda and the DRC, expanding energy access is pivotal in reducing energy poverty and enhancing living standards, particularly in rural and underserved areas. Environmental benefits and climate

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resilience are also accruing as key considerations. A shift towards wind energy aligns with global efforts to combat climate change and enhances the region's climate resilience. This is particularly pertinent for countries like Uganda, where reducing reliance on hydropower mitigates risks associated with climate-induced water variability.

Supportive policies and investments emerge as recurring themes across these reports. Creating favourable regulatory environments and encouraging public-private partnerships are critical for the development of wind energy. The collaboration between Ethiopia and Denmark in developing the wind energy roadmap illustrates the benefits of international partnerships and knowledge sharing, providing technical expertise, financial resources, and policy guidance essential for emerging renewable energy markets in East Africa.

These reports therefore show a region with immense potential and a willingness to embrace wind energy. However, realising this potential requires navigating a complex landscape of economic, technical, and policy challenges, with a strong focus on sustainable and inclusive development strategies.

The perspectives and analyses derived from the reports on wind energy landscapes in East Africa reveal several key themes and strategic considerations:

1. **Diverse Potential Across Countries**: Each country in East Africa has its unique renewable energy potential, with varying degrees of development and focus on wind energy. Ethiopia's significant investment in wind energy, highlighted in the "Wind Project Development Roadmap," showcases a strategic approach to diversifying its energy mix. Tanzania's initiation of its first wind farm signals a growing recognition of wind power's viability. Uganda's focus, as per the "Executive summary – Uganda 2023," remains on expanding its overall renewable energy portfolio, with a current emphasis on solar energy. The DRC's considerable wind and solar potential, as shown in the "Renewable Riches" study, indicates an opportunity to leapfrog traditional energy development paths.
2. **Challenges and Opportunities**: The reports collectively underline both the challenges and opportunities in harnessing wind energy. For instance, Ethiopia's roadmap emphasizes the need for robust policy and private sector engagement to realize its wind potential. In Uganda and Tanzania, the challenge lies in transitioning from traditional energy sources and building the necessary infrastructure for renewable energy integration. The DRC faces the challenge of leveraging its vast potential amidst infrastructural and economic constraints.
3. **Economic and Social Implications**: The transition to wind and other renewable energies in these countries has significant economic and social implications. Increased renewable energy capacity can drive economic growth, create jobs, and improve energy security. For countries like Ethiopia and Tanzania, this transition can also aid in meeting growing energy demands due to rapid urbanization and economic development. In Uganda and the DRC, expanding renewable energy access can significantly reduce energy poverty and improve living standards, especially in rural and underserved areas.

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4. **Environmental Benefits and Climate Resilience**: A shift towards wind energy aligns with global efforts to combat climate change. For East African countries, this not only contributes to global emission reduction goals but also enhances climate resilience. Reducing reliance on hydropower, especially in countries like Uganda, can mitigate risks associated with climate-induced water variability.

5. **Policy and Investment Focus**: A recurring theme in these reports is the importance of supportive policies and investments. Creating favorable regulatory environments, encouraging public-private partnerships, and securing investments are crucial for the development of wind energy. Ethiopia's focus on policy frameworks and Tanzania's exploration of new renewable projects are examples of this approach.

6. **Regional Collaboration and Knowledge Sharing**: The collaboration between Ethiopia and Denmark in developing the wind energy roadmap illustrates the benefits of international partnerships and knowledge sharing. Such collaborations can provide technical expertise, financial resources, and policy guidance, essential for emerging renewable energy markets in East Africa.

In conclusion, these reports paint a picture of a region with immense potential and willingness to embrace renewable energy, particularly wind power. However, realizing this potential requires navigating economic, technical, and policy challenges, with a strong focus on sustainable and inclusive development strategies.

Accordingly, the wind energy landscape in East Africa, as depicted in the above reports from characterises a region at a pivotal moment in its wind energy development. The countries are increasingly recognising the importance of renewable energy sources, particularly wind power, to meet their growing energy demands, drive economic growth, and address environmental concerns. Despite facing unique challenges, including the need for robust policy frameworks, infrastructure development, and investment, the region shows a promising trajectory towards a more sustainable and resilient energy future. The collaborative efforts, policy initiatives, and strategic investments highlighted in these reports are not only pivotal for the energy sector's growth in East Africa but also contribute significantly to the global agenda of sustainable development and climate change mitigation.

Solar Power

The equatorial location of East Africa endows it with abundant solar resources, making solar power a rapidly growing sector in the region. Countries like Kenya, Tanzania, Uganda, and Rwanda have embarked on significant solar energy projects to meet their increasing energy needs while reducing their carbon footprint. The Garissa Solar Plant in Kenya, one of the largest in the region, exemplifies the strides made in harnessing solar energy (Kenya Solar Energy Development Report, 2023). Additionally, Tanzania's rural electrification initiative has seen the installation of numerous solar-

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powered mini-grids, reflecting the government's commitment to sustainable energy solutions (Tanzania Solar Energy Policy, 2023).
The future of solar power in East Africa is promising, given the decreasing costs of photovoltaic (PV) technology and the versatility of solar installations. This scalability, from small-scale rooftop systems to large solar farms, makes solar power a flexible option for various applications (Photovoltaic Technology Advancements, 2024). Moreover, solar energy has a critical role in electrifying rural areas, thereby enhancing the quality of life and economic opportunities in these communities (Rural Solar Electrification Study, 2023).

A comprehensive examination of the solar energy landscape in East Africa reveals a multifaceted and evolving sector, marked by both promising opportunities and notable challenges. As countries like Kenya, Ethiopia, and the Democratic Republic of the Congo (DRC). increasingly turn towards renewable energy sources, the potential of solar energy to transform the regional energy paradigm is becoming ever more apparent. This section explores the intricate dynamics of the solar energy sector in East Africa, exploring key themes and insights drawn from a range of reports and analyses. It aims to shed light on the current state of solar energy development in the region, highlighting the interplay of policy, financing, infrastructure, and market dynamics that shape the sector's progress. As East Africa stands at a critical juncture in its energy transitions, understanding these underlying factors is crucial for charting a path towards a sustainable and energy-secure future.

The landscape of solar energy in East Africa has been explained in detail in a series of reports. These reports contribute unique insights into the development, challenges, and policy landscape of solar energy in this region. The Energise Africa and Power for All report *Report Identifying Reforms to End Energy Poverty in Ethiopia* lays bare the significant policy and financial barriers impeding investment in that country's off-grid solar market. By contrasting Ethiopia's market dynamics with those of its regional neighbours, including the DRC, Kenya, Rwanda and Tanzania as well as Nigeria and Zimbabwe, the report underscores the urgency of adopting long-term reforms and more favourable policy environments to address energy poverty. It advocates for financial systems that can catalyse investment in solar energy, indicating a strategic shift towards renewable energy as a cornerstone of Ethiopia's energy future.
In the context of the DRC, the Power Africa's *Power Africa in Democratic Republic of the Congo Report* highlighted the intricate web of opportunities and challenges that define the country's solar energy sector. Despite being endowed with abundant potential for solar energy (as well as hydro and wind), the DRC contends with infrastructural inefficiencies, regulatory hurdles, and financial barriers evidenced through high taxes, VAT, and import duties. Collectively, these stymie the growth of solar energy access. The report suggests that enhancing governance and regulatory frameworks could unlock considerable opportunities for solar energy investment and development in the DRC.

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Kenya's solar energy narrative, as detailed in the Power Africa's *Power Africa in Kenya* report, positions the country as a renewable energy catalyst in sub-Saharan Africa. Factors such as an engaged private sector, Kenya Power's credibility and rich renewable resources have set the groundwork for solar energy advancement. Yet, the sector is not without its challenges, including aging infrastructure, high losses, and procurement complexities. Interestingly, the report points to an imbalance in energy planning, necessitated by lower-than-anticipated demand growth, which underscores the importance of strategic and informed energy sector management.

IRENA's regional perspectives focus primarily geothermal development, though the report also provides critical insights applicable to solar energy. The report advocates for transparent and predictable administrative procedures to attract developers and investors in solar energy. It emphasises the transformative potential of solar energy in addressing broader socio-economic challenges when supported by innovative financing and robust public awareness campaigns. Similarly, *Africa Energy Outlook 2022* (IEA) situates the solar energy discourse within the larger African energy crisis. It discusses Africa's vast, yet underutilised, solar potential and the pivotal role solar PV can play as the continent's most cost-effective energy source. The report connects the dots between addressing energy sector challenges and mitigating broader socio-economic issues such as extreme poverty and food insecurity, which can be exacerbated by global crises, for example the COVID-19 pandemic.

These reports collectively paint a picture of a region at the edging towards a solar energy transformation, hindered yet hopeful. They underscore a shared narrative across where the immense potential for solar energy is often entangled with policy, financial, and infrastructural challenges. A comparative analysis of these countries reveals common themes: the necessity of policy reform, the importance of innovative financing, and the potential impact of solar energy on broader economic and social development. Addressing these systemic issues is portrayed as not just beneficial but essential for the sustainable growth of the solar energy sector in East Africa.

In conclusion, it can be highlighted that East Africa is rich in solar energy potential, offering a vast, untapped resource that could change the energy landscape. This natural advantage is coupled with a growing market demand for electricity, especially in off-grid and remote areas, indicating a growing market for solar solutions. The potential for innovative financing models, including pay-as-you-go systems and green bonds can provide avenues to mobilise capital for solar projects. Such financial innovations can make solar energy more accessible and affordable. Additionally, there is a noticeable policy shift towards renewables across the region, with governments increasingly recognizing the importance of sustainable energy sources. This shift is further bolstered by international support and partnerships, as seen by the involvement of agencies like Power Africa, offering both financial and technical assistance to enhance the sector's growth prospects.

However, these opportunities are tempered by substantial challenges. Policy and regulatory barriers, particularly in Ethiopia and the DRC, are identified as major obstacles to solar energy

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investment. Inconsistent policies, bureaucratic hurdles, and the absence of clear regulatory frameworks deter investors and impede project development. Financial constraints are also significant, with high upfront costs and perceived investment risks limiting the flow of capital into the sector. The region's solar industry is further challenged by infrastructural and technical limitations. Aging infrastructure, high technical losses, and inadequate distribution networks, particularly in Kenya can significantly hamper the effective distribution and utilisation of solar energy. Moreover, the region faces a skills and knowledge gap in the solar energy sector, with a lack of trained professionals and technical expertise hindering the efficient deployment and maintenance of solar systems. Market dynamics and demand forecasting also pose challenges; inaccurate predictions can lead to imbalances in energy planning and underutilisation of resources. Addressing these challenges is crucial for the sustainable growth of the solar energy sector in East Africa. Policy reform is needed to create more conducive environments for solar energy investments. Improving financial mechanisms through innovative financing and fostering public-private partnerships are essential to meet the capital requirements of the sector. Investment in infrastructure development and capacity building is vital to bridge the skills gap and ensure the efficient implementation and maintenance of solar energy systems.

Thus the solar energy sector in East Africa is at a crossroads; the alignment of opportunities with strategic solutions to existing challenges will dictate its success. Leveraging the region's natural solar potential, coupled with policy reform, financial innovation, and infrastructure development, can unlock a future where solar energy plays a pivotal role in sustainable development. The key themes emerging from the reports on solar energy in East Africa, particularly focusing on countries like Ethiopia, the Democratic Republic of the Congo (DRC), and Kenya, encompass a range of interconnected issues that highlight both the potential and the challenges of the solar energy sector in the region. These themes include:

1. Policy and regulatory frameworks: A recurring theme across the reports is the need for robust, clear, and supportive policy and regulatory environments. The reports consistently highlight how bureaucratic hurdles, policy inconsistencies, and lack of clear regulatory frameworks impede investment and growth in the solar sector. Establishing policies that are conducive to renewable energy investment and development is crucial for the sector's advancement.
2. Financing and investment: Access to financing emerges as a critical theme. The reports discuss the challenges related to securing investment for solar projects, including high upfront costs and perceived risks. They also point to the potential of innovative financing models, such as PAYGO systems, to make solar energy more accessible and to drive investment in the sector.
3. Infrastructure and technical capacity: The need for improved infrastructure and technical capacity is a prominent theme. Issues like aging infrastructure, high technical losses, and inadequate distribution networks are noted as significant barriers to the efficient distribution and utilization of solar energy. Additionally, there is a need for enhanced technical skills and knowledge in the sector, pointing to the importance of capacity building and training.

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4. Market dynamics and demand forecasting: Understanding the market dynamics and effectively predicting energy demand are highlighted as key for sustainable solar energy development. The reports suggest that accurate demand forecasting is essential for balanced energy planning and for ensuring that investments in solar energy align with actual market needs.
5. Solar energy resources potential: The reports continually emphasise the vast potential of solar energy resources in East Africa. This theme underscores the region's natural advantage and the untapped potential for solar energy to significantly contribute to the energy mix.
6. Socio-economic impact and sustainability: The impact of solar energy on broader socio-economic development is also a recurring theme. The reports link the development of the solar sector to potential improvements in living standards, reduction in energy poverty, and contributions to sustainable development goals.
7. International support and collaboration: The role of international support and collaboration in developing the solar energy sector in East Africa is also a key theme. External assistance from international agencies and partnerships is seen as pivotal in providing both financial and technical support, enhancing the growth prospects of the sector.

Taken holistically, these themes provide the setting a region with immense potential for solar energy development yet facing significant hurdles. Addressing these challenges through strategic policy interventions, financial innovation, infrastructure development, and international collaboration is key to unlocking the full potential of solar energy in East Africa.

Hydro Power

Hydroelectric power has been a traditional energy source in East Africa, with major rivers offering vast potential for hydroelectric generation. Ethiopia's ambitious Grand Ethiopian Renaissance Dam (GERD) project, upon completion, is poised to become Africa's largest hydroelectric power plant and is a cornerstone of Ethiopia's energy strategy (GERD Development Report, 2023). In the Democratic Republic of Congo, the proposed Grand Inga Dam, with the potential to be the world's largest hydro project, could significantly alter the continent's energy dynamics (Congo Hydroelectric Potential Assessment, 2023).

Despite its potential, hydroelectric power faces challenges, including environmental and social impacts. Moreover, the threat of climate change, with its impact on rainfall patterns, poses risks to the reliability of hydroelectric power generation (African Hydroelectric Climate Risk Analysis, 2024). Despite these challenges, hydro power remains a vital component of the region's energy mix, providing a substantial and renewable power source to support base-load energy demands (East African Hydro Power Policy Review, 2023).

4.3.2 Country Specific Opportunities and Challenges Analysis

This section provides review and analysis of green hydrogen sector development in East Africa, specifically in Kenya, Ethiopia, Uganda, the Democratic Republic of Congo (DRC), Tanzania, and

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Rwanda. It entails a multifaceted scrutiny of this promising sector and navigates various dimensions – contextualising green hydrogen within the global renewable energy transition, probing into the specific opportunities, challenges, and risks of green hydrogen development in each of these countries, and then presenting a detailed perspective on the potential impacts and implications for the region.

The global shift towards renewable energy, driven by the urgent need to address climate change and reduce dependency on fossil fuels, has brought to the fore the significance of green hydrogen. Produced through the electrolysis of water using renewable energy sources, green hydrogen stands out as a sustainable and carbon-neutral energy solution. Its potential to revolutionise energy systems, contribute to climate change mitigation, and drive economic growth is particularly relevant in the context of East Africa, a region with vast renewable energy resources – as illustrated in the preceding section – and unique socio-economic dynamics. For East Africa, the examination and opportunity of green hydrogen is not just a question of adopting a new energy source but a transformative opportunity that aligns with the region's goals of enhancing energy security, fostering sustainable development, and actively participating in the global green economy. Each country in the region that is examined here – Kenya, Ethiopia, Uganda, DRC, Tanzania, and Rwanda – exhibits unique sets of circumstances that shape their approach to and potential benefits from green hydrogen.

In Kenya, the established geothermal and wind energy sectors provide a strong base for green hydrogen development, posing opportunities for economic growth and regional energy collaboration. Ethiopia, with its vast hydroelectric potential, could leverage green hydrogen for industrial growth and energy export. Uganda's rich solar energy potential makes it a prime candidate for green hydrogen initiatives, particularly in rural electrification. The DRC's immense hydroelectric capacity positions it as a potential green hydrogen powerhouse, albeit challenged by political and infrastructural issues. Tanzania's diverse renewable resources present an opportunity for economic diversification and regional energy leadership. Rwanda, with its commitment to sustainability, could integrate green hydrogen into its innovative and technology-driven development plans.

However, the drive to establish a robust green hydrogen sector is laden with challenges. These range from high initial investment costs, technological complexities, and infrastructural requirements to the need for skilled workforce development and effective resource management. Moreover, each country faces distinctive risks, including market volatility, policy uncertainties, environmental impacts, and geopolitical dynamics, which must be carefully navigated to realise the full potential of green hydrogen.

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Consequently, the following review and assessment of the landscape provides an ample view of the green hydrogen sector in East Africa, highlighting its potential as a game-changer in the region's energy landscape. It underscores the need for strategic planning, regional cooperation, and international partnerships to overcome the challenges and mitigate the risks associated with this promising yet complex sector. The development of green hydrogen in East Africa is thus not merely an energy policy decision but a strategic opportunity that could reshape the region's economic, environmental, and social future.

For regions like East Africa, the emergence of green hydrogen as a key sector supported by their vast renewable energy resources portends transformation. It aligns with global efforts to shift away from fossil fuels, offering a pathway to energy independence and economic development, while also contributing to the global fight against climate change.

4.3.2.1 The East African Context: Geopolitical and Economic Landscape

The transition towards renewable energy and the integration of green hydrogen into the global energy mix is not only a technical challenge but also a significant geopolitical and economic opportunity. This is especially true for East Africa. This transition has the potential to alter the energy landscape profoundly, and East African countries can position to play a critical role. To fully understand this transformation, it is essential to contextualise it within the broader East African region and then dive into the specifics of key countries under review: Kenya, Ethiopia, Uganda, the Democratic Republic of Congo (DRC), Tanzania, and Rwanda.

East Africa is a region characterised by its diverse geography, climate, and economic structures. It is at a critical juncture in its energy development. The region's economies are predominantly agrarian, with a significant portion of the population engaged in subsistence farming. However, there is a growing shift towards industrialisation and urbanisation, which is driving an increased demand for energy. Historically, East Africa's energy supply has been dominated by biomass (such as wood and charcoal) and fossil fuels, with only a limited contribution from renewable sources. This reliance on traditional energy sources has had environmental and health implications, while the lack of reliable and widespread electricity access remains a significant barrier to economic development. The introduction of green hydrogen technology into this context offers a promising alternative. It aligns with the region's goals of increasing energy security, reducing environmental impact, and fostering economic growth. Green hydrogen could provide a clean, reliable, and sustainable energy source for both urban and rural areas, potentially transforming the region's energy landscape, whilst marking the region as a key player in the global energy space.

At this purpose a brief recap of the potential opportunities to be offered to each country of the area is presented in the following sections.

Kenya: A pioneer in geothermal and wind energy

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Kenya stands out in East Africa for its substantial investments in renewable energy, particularly geothermal and wind power. The country is home to the Olkaria Geothermal Plant, one of the largest geothermal power stations in the world. Kenya's Rift Valley region, with its significant geothermal potential, has been a focal point for renewable energy development. Additionally, Kenya's Lake Turkana Wind Power project, which is Africa's largest wind power project, exemplifies the country's commitment to diversifying its energy mix. The integration of green hydrogen production in Kenya could leverage these existing renewable energy infrastructures. By using excess renewable electricity for hydrogen production, Kenya could enhance its energy storage capabilities and potentially become an exporter of green hydrogen, stimulating economic growth and regional energy collaboration.

Furthermore, a relevant type and number of local off-takers and stakeholders have been identified in order to develop a domestic Kenyan hydrogen market (Figure below), that would be helpful to identify Kenya project use cases to be presented in D1.3.

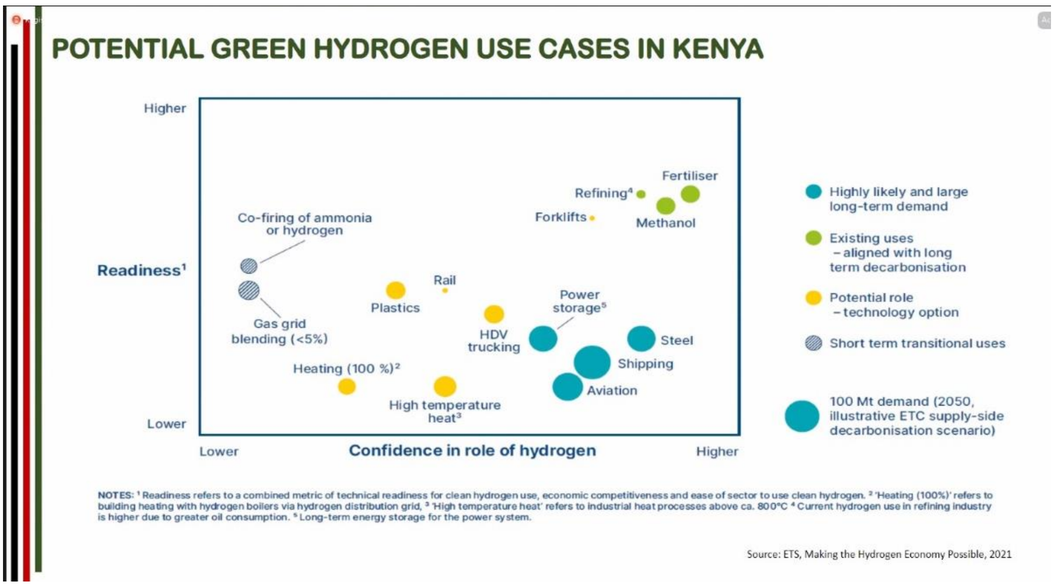

Figure 40: Kenyan potential end-users

Ethiopia: Harnessing hydroelectric and wind resources

Ethiopia is another key player in East Africa's renewable energy landscape, with a particular emphasis on hydroelectric power. The Grand Ethiopian Renaissance Dam (GERD), upon completion, will be the largest hydroelectric power plant in Africa. This significant hydroelectric capacity, coupled with the country's wind energy potential, positions Ethiopia as a potential hub for green hydrogen production. Ethiopia's transition to green hydrogen could provide a sustainable solution to its growing energy needs, particularly in light of its ambitious plans for industrialization. Green hydrogen production could also offer a pathway for Ethiopia to engage in international energy markets, particularly in exporting hydrogen to European and Asian markets.

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Uganda: Solar and biomass energy potential

Uganda's energy sector is characterised by a high reliance on biomass and a growing interest in solar energy. The country's equatorial location provides it with significant solar energy potential, which is yet to be fully tapped. Integrating green hydrogen production into Uganda's energy strategy could provide a solution to its energy access challenges, particularly in rural areas. The development of green hydrogen infrastructure in Uganda could also stimulate local industries, create jobs, and attract foreign investment. Additionally, it could help the country reduce its greenhouse gas emissions and contribute to global climate change mitigation efforts.

Democratic Republic of Congo: Vast hydroelectric potential

The DRC holds some of the world's most significant hydroelectric power potential, primarily due to the Congo River. This potential remains largely untapped, but its development could transform the DRC into a major player in the renewable energy sector, including green hydrogen production. The DRC's vast hydroelectric resources could provide the necessary energy for large-scale electrolysis, making the country a potential powerhouse in green hydrogen production. This development could have far-reaching implications for the DRC's economy and energy security, as well as for regional energy markets.

Tanzania: Emerging renewable energy initiatives

Tanzania's renewable energy sector is in its nascent stages, with several initiatives underway to harness the country's solar, wind, and geothermal resources. The development of green hydrogen in Tanzania could accelerate the country's renewable energy adoption and provide a clean energy source for its growing industrial sector. Investing in green hydrogen technology could also help Tanzania meet its increasing energy demands while reducing its dependence on imported fossil fuels. Furthermore, it could position Tanzania as a leader in renewable energy in East Africa.

Rwanda: A Commitment to Sustainable Development

Rwanda's vision for its energy sector is closely tied to its broader goals of sustainable development and environmental conservation. The country has made significant strides in increasing its renewable energy capacity, particularly through solar power. The integration of green hydrogen technology into Rwanda's energy strategy could further enhance its commitment to sustainability. It could provide a clean and reliable energy source, support the country's economic development, and contribute to its ambitious climate goals.

In summary therefore, the integration of green hydrogen into the energy mix of East Africa can represent a significant opportunity for the region. Each country – Kenya, Ethiopia, Uganda, the DRC, Tanzania, and Rwanda – has unique resources and challenges that green hydrogen technology could address. The development of green hydrogen in these countries could lead to increased energy security, economic growth, and a significant contribution to global efforts to combat climate change. The potential of green hydrogen in East Africa is not just a matter of energy policy; it is a strategic opportunity that could reshape the region's economic and environmental future.

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4.3.2.2 Opportunities, Risks and Challenges in the Green Hydrogen Sector per each country

In the following a summary matrix of opportunities, challenges, and risks is presented.

KENYA

Kenya	Opportunities	**Geothermal and Wind Energy Resources:** Kenya's significant geothermal and wind energy resources offer a strong foundation for green hydrogen production.
		Established Renewable Energy Sector: The presence of established renewable energy projects, like the Lake Turkana Wind Power project, provides a platform for integrating green hydrogen technologies.
		Strategic Location: Kenya's strategic location could facilitate the export of green hydrogen to neighbouring countries and beyond.
		Government Support: The Kenyan government's commitment to renewable energy could accelerate the development of the green hydrogen sector.
	Challenges	**High Capital Expenditure:** The initial investment required for setting up green hydrogen production facilities is substantial.
		Technological Barriers: Kenya must overcome technological barriers, including the need for advanced electrolysers and infrastructure for hydrogen storage and distribution.
		Market Development: Developing a domestic and international market for green hydrogen requires strategic planning and partnerships.
		Skilled Workforce: There is a need for skilled personnel trained in green hydrogen technologies.
	Risks	**Market Volatility:** The nascent nature of the green hydrogen market poses risks related to price and demand fluctuations.
		Infrastructure Reliability: Dependence on renewable energy sources could pose risks in terms of consistency and reliability of power supply for hydrogen production.
		Policy Continuity: Changes in government policies or priorities could impact the development of the green hydrogen sector.

ETHIOPIA

Ethiopia	Opportunitie s	**Hydroelectric Power Potential:** Ethiopia's massive hydroelectric power potential, exemplified by the GERD, is a significant asset for green hydrogen production.
		Energy Export Potential: Ethiopia could become a major exporter of green hydrogen, bolstering its economy.

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		Industrial Growth: Green hydrogen can fuel Ethiopia's burgeoning industrial sector, reducing reliance on fossil fuels.
	Challenges	**Resource Management:** Efficiently managing water resources for both hydroelectric power and green hydrogen production is critical.
		Infrastructure Needs: Building the necessary infrastructure for hydrogen production and distribution is a major challenge.
		Technological Expertise: Developing local expertise in green hydrogen technology is essential.
	Risks	**Geopolitical Tensions:** The use of shared water resources for hydroelectric power and hydrogen production could exacerbate regional tensions.
		Economic Stability: Fluctuations in the global economy could impact funding and investment in green hydrogen projects.
		Climate Variability: Changes in rainfall patterns could affect hydroelectric power generation, impacting hydrogen production.

DEMOCRATIC REPUBLIC OF CONGO

Democratic Republic of Congo	Opportunities	**Hydroelectric Power Capacity:** The DRC's potential in hydroelectric power is a massive asset for hydrogen production.
		Mineral Resources: The availability of mineral resources like cobalt, essential for renewable energy technologies, can facilitate green hydrogen development.
		Export Opportunities: The DRC could become a key exporter of green hydrogen in Africa and globally.
	Challenges	**Political Stability:** Political instability and governance issues could hinder the development of the green hydrogen sector.
		Infrastructure Development: Building the necessary infrastructure in a vast and geographically diverse country is challenging.
		Economic Diversification: Diversifying the economy to include green hydrogen production requires strategic planning and implementation.
	Risks	**Investment Security:** Political and economic instability can deter potential investors.
		Environmental Sustainability: Managing environmental impacts of large-scale hydroelectric projects for hydrogen production is essential.
		Resource Management: Efficiently managing the Congo River's resources for multiple purposes, including hydrogen production, is critical.

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UGANDA

Uganda	Opportunities	**Solar Energy Potential:** Uganda's significant solar energy potential is ideal for green hydrogen production.
		Rural Electrification: Green hydrogen could be a solution for electrifying remote areas.
		Agricultural Sector Growth: Hydrogen can be used to produce green fertilisers, supporting the agricultural sector.
	Challenges	**Lack of Infrastructure:** The absence of existing infrastructure for hydrogen production and distribution is a major hurdle.
		Investment Requirements: Securing investment for green hydrogen projects is challenging.
		Public Awareness and Acceptance: Raising awareness and gaining public acceptance for green hydrogen as an energy source is necessary.
	Risks	**Resource Allocation:** Balancing the allocation of resources between traditional energy needs and green hydrogen development is tricky.
		Market Dependence: Dependence on external markets for technology and expertise poses risks.
		Environmental Impact: Ensuring that hydrogen production does not adversely affect Uganda's rich biodiversity is crucial.

TANZANIA

Tanzania	Opportunities	**Diverse Renewable Resources:** Tanzania's diverse renewable resources, including solar, wind, and hydro, provide a solid base for green hydrogen production.
		Economic Diversification: Green hydrogen can contribute to diversifying Tanzania's economy.
		Regional Energy Hub: Tanzania could position itself as a regional hub for green hydrogen production and distribution.
	Challenges	**Renewable Energy Integration:** Integrating existing renewable energy sources with green hydrogen production facilities is complex.
		Funding and Investment: Securing adequate funding and investment is a major challenge.
		Regulatory Framework: Developing a comprehensive regulatory framework for the green hydrogen sector is needed.
	Risks	**Technological Dependency:** Dependency on foreign technology for green hydrogen production poses risks.
		Market Fluctuations: Exposure to global market fluctuations in the energy sector can impact the viability of green hydrogen projects.
		Resource Allocation: Balancing resource allocation between traditional energy sources and green hydrogen development is a risk.

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RWANDA

Rwanda	Opportunities	**Commitment to Sustainability:** Rwanda's strong commitment to sustainability and environmental conservation aligns with green hydrogen development.
		Strategic Partnerships: Rwanda's ability to forge strategic partnerships can facilitate technology transfer and investment in green hydrogen.
		Innovation and Technology: Rwanda's focus on innovation can drive the development of the green hydrogen sector.
	Challenges	**Limited Energy Resources:** Rwanda's limited energy resources necessitate careful planning in green hydrogen development.
		Infrastructure and Technology: Developing the necessary infrastructure and technology for hydrogen production is a challenge.
		Economic Scale: Rwanda's small economic scale may limit the extent of green hydrogen projects.
	Risks	**Economic Viability:** Ensuring the economic viability of green hydrogen projects in a small economy is a risk.
		Technology Importation: Reliance on imported technology for green hydrogen production poses risks.
		Environmental Impact: Managing the environmental impact of renewable energy projects for hydrogen production is crucial.

The development of the green hydrogen sector in each of these East African countries therefore offers unique opportunities for economic growth, energy security, and environmental sustainability. However, it also presents significant challenges related to infrastructure, technology, investment, and market development. The risks associated with market volatility, geopolitical dynamics, and environmental impacts further complicate the scenario. Addressing these challenges and mitigating these risks will be crucial for the successful development of the green hydrogen sector in Kenya, Ethiopia, Uganda, the DRC, Tanzania, and Rwanda. Strategic planning, regional cooperation, and international partnerships will be key in harnessing the full potential of green hydrogen in East Africa.

4.3.2.3 Current Installed Electricity Capacity vs Potential

An overview of electricity generation capabilities in East Africa is essential for evaluating the feasibility, planning, economic viability, environmental impact, and regional cooperation aspects of developing a green hydrogen sector in the region. Outlining electricity generation capacity, both current and potential, is crucial for assessing the development landscape of the green hydrogen sector in East Africa for several reasons. In the next pages, an overview in this sense is presented per each country.

Generally speaking, in East Africa, the development landscape of the green hydrogen sector will be heavily influenced by the region's collective electricity generation capabilities, both in terms of

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current installed capacity and potential capacity. This holistic regional approach is essential in understanding how East Africa, as a cohesive unit, can leverage its energy resources for sustainable green hydrogen production. The region has seen a significant growth in its installed electricity capacity, with countries like Kenya, Ethiopia, Tanzania, and Rwanda actively expanding their energy infrastructure. Kenya, for instance, has increased its capacity to approximately 3,300 MW as of mid-2022, with a notable focus on renewable energy sources such as geothermal and hydroelectric power. Similarly, Ethiopia, with a capacity of around 5,200 MW, plans to expand its coverage to a larger segment of its population, tapping into its abundant renewable resources like hydro, wind, and solar. Tanzania and Rwanda are also on similar paths, with ambitious plans to increase their respective capacities and diversify their energy mixes.

Collectively, these efforts indicate a strong regional commitment to enhancing renewable energy capacities. This is particularly relevant for green hydrogen production, which requires substantial amounts of electricity, preferably from renewable sources. East Africa's concerted move towards renewable energy not only addresses immediate electricity needs but also sets the stage for sustainable green hydrogen production. The region's potential, particularly in hydroelectric power as seen in Ethiopia and the Democratic Republic of Congo (DRC), along with geothermal energy in Kenya and solar and wind potentials across the region, present vast opportunities for green hydrogen initiatives.

The region's renewable energy surplus is another critical aspect. The gap between the current electricity generation capacity and the potential capacity suggests that East Africa could generate surplus renewable energy, which is essential for green hydrogen production. For instance, Ethiopia's and Kenya's ambitious plans to significantly increase their power generation capacities, if realised, could provide the necessary surplus energy for hydrogen production.

Infrastructure development across the region will also plays a crucial role. By leveraging the existing and potential renewable energy sites, East Africa can strategically plan and develop the necessary infrastructure for hydrogen production, storage, and transportation. This includes the integration of renewable energy sources into the grid and the establishment of facilities specifically for green hydrogen. Economic viability, driven by the cost of electricity, especially from renewable sources, is another factor influenced by the regional energy landscape. The transition towards renewable energy in East Africa could lead to more competitive electricity pricing, which in turn would impact the economic feasibility of green hydrogen production.

Policy-making and investment decisions in the region can also be informed by this collective energy landscape. Understanding the potential for renewable energy expansion across East Africa can guide policy frameworks and financial models to support the green hydrogen industry. Additionally, the environmental impact of green hydrogen production is a critical consideration. The region's

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focus on renewable energy aligns with sustainable hydrogen production, contributing to global efforts to reduce carbon emissions. Finally, the regional approach emphasises the importance of cooperation and grid stability. East Africa's energy landscape involves cross-border energy trade and regional grid connections. A collective understanding of the overall capacity and potential within the region facilitates cooperative efforts in green hydrogen production and ensures grid stability, especially when integrating large-scale renewable energy sources.

Therefore, East Africa's expanding and diversifying energy resources creates a conducive environment for the development of the green hydrogen sector. The region's focus on renewable energy, potential for surplus generation, infrastructure planning, economic considerations, policy frameworks, environmental sustainability, and regional cooperation are all pivotal in shaping a robust and sustainable green hydrogen industry.

The quest for the development of the green hydrogen sector in East Africa, encompassing shows a region at the could be on the verge of a significant energy transformation. This assessment demonstrates that East Africa holds immense potential to become a frontrunner in the global green hydrogen arena, leveraging its abundant renewable energy resources and unique geographical and economic landscapes. The region's abundant and diverse renewable energy sources, including hydroelectric, geothermal, solar, and wind energy, provide a solid foundation for the sustainable production of green hydrogen. Countries such as Kenya, with its advanced geothermal and wind energy sectors, and Ethiopia, with its vast hydroelectric potential, are positioned to lead this transformation. Others, such as Uganda, the DRC, Tanzania, and Rwanda, each with their distinct renewable energy profiles, present unique opportunities, and challenges in integrating green hydrogen into their energy mix.

Kenya

As of 2019, Kenya's effective installed (grid-connected) electricity capacity was 2,651 MWs (MW), with peak demand reaching 1,912 MW, increasing to 3300MW by mid-2022. The country's grid network extends about 300,000 kilometres in circuit length, serving over 9.1 million customers and giving access to over 75% of the country's population across all 47 counties. The electricity supply in Kenya is predominantly generated from renewable sources, with the majority coming from geothermal power and hydroelectricity. The breakdown of the generation capacity by source as of October 2019 was as follows:

- Hydroelectricity: 826 MW (29.3%)
- Fossil Fuels (including gas, diesel, and emergency power): 720 MW (25.54%)
- Geothermal: 891.8 MW (29.4%)
- Bagasse Cogeneration: 28 MW (0.99%)
- Wind: 435.5 MW (11.88%)

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- Solar: 55 MW (1.77%)
- Others: 32 MW (1.14%)
- Total: 2,819 MW

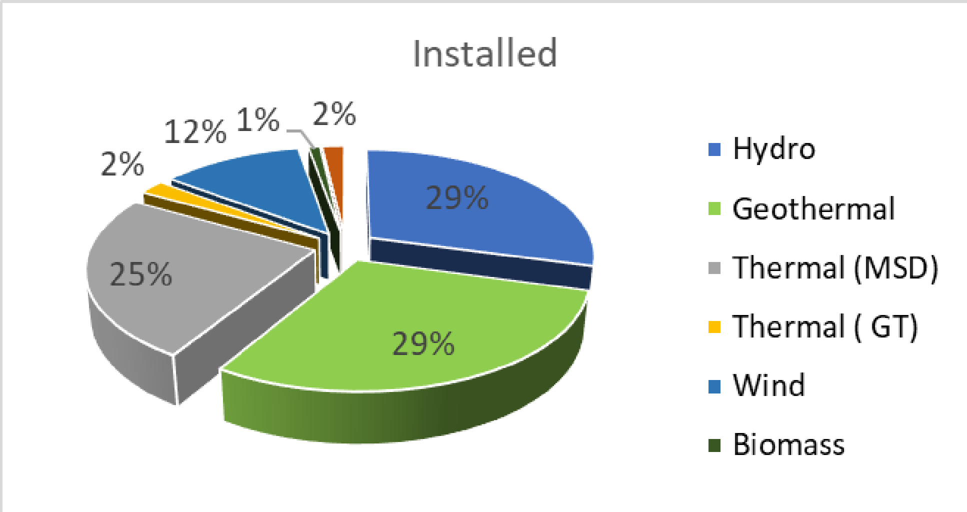

Figure 41: Kenya electricity mix (Cleantech Africa) - Kenya

The Kenya Electricity Generating Company PLC (KenGen) has an installed generation capacity of 1,904 MW, of which over 86% is drawn from green sources, namely hydro, geothermal, and wind. The rest is generated from fossil fuels at thermal power plants. Kenya's total installed capacity, including independent power producers, is now around 3,000 MW.

"KenGen" aims to double Kenya's installed generation capacity to 6,000 MW within the next 10 years. This expansion will be driven largely by tapping into the vast potential of geothermal energy in the Rift Valley region, estimated to be about 10,000 MW of clean and renewable energy. "KenGen" plans to deploy up to 2,000 MW from geothermal and hydro sources as baseload power to stabilize the country's energy sources.

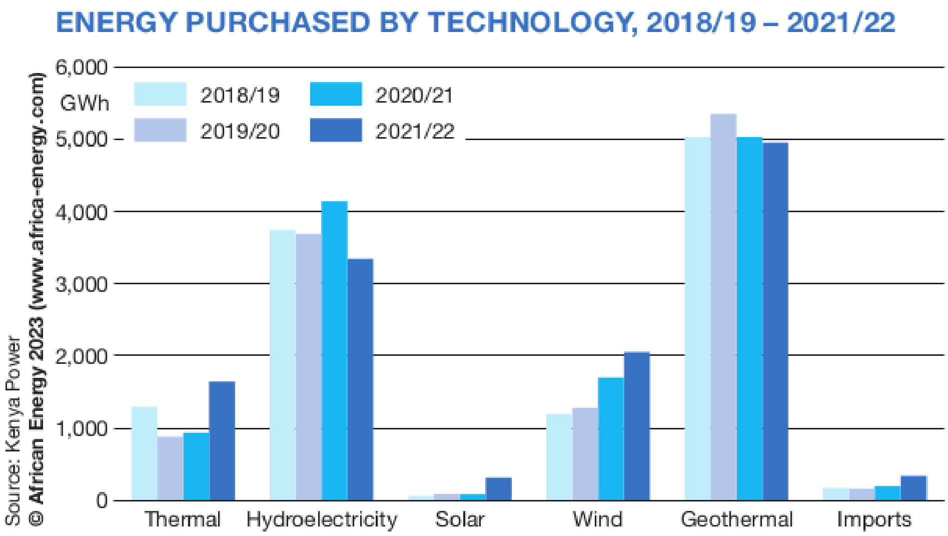

Figure 42: Kenya electricity mix and RES growth in the last years (Kenya Power)

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Kenya is recognised for its leadership in renewable energy uptake in Africa. The country is well on its way to meeting its goal of transitioning to 100% clean energy by 2030, with over 80% of its electricity currently generated from renewable sources. The country has installed over 170 MW of generation potential from solar power as of 2022, with a significant amount added to its grid in 2021 alone. A report by the World Economic Forum commends Kenya for making significant progress towards energy transition by improving its regulatory environment and infrastructure. In the broader context, Sub-Saharan Africa, including Kenya, is leading the world in the uptake and investment in renewable energy, with the continent holding 60% of the world's renewable energy assets, including solar, wind, geothermal, and hydropower. This demonstrates the region's potential and commitment to a greener and more sustainable energy future, contributing to the global fight against the climate crisis.

Ethiopia

As of May 2023, Ethiopia's electricity generation capacity was reported to be about 5,200 MWs (MW). The Ethiopian Electric Power (EEP) indicated plans to increase the country's electric power supply coverage to 96% of the population. The EEP's strategy involves generating power from various renewable energy sources including water, wind, solar, and underground steam to meet the growing demand.

In terms of potential electricity generation capacity, Ethiopia has an abundance of renewable energy resources and the potential to generate over 60,000 MW from hydroelectric, wind, solar, and geothermal sources. The country's rapid GDP growth has led to steadily increasing demand for electricity. Despite this potential, Ethiopia is currently experiencing energy shortages and load shedding as it serves a population of over 110 million and tries to meet a growing electricity demand, which is forecast to grow by approximately 30% per year. There are plans to significantly increase the power generation capacity to 17,000 MW in 10 years.

The energy mix in Ethiopia is heavily dominated by hydropower, accounting for approximately 90% of the installed generation capacity. The remaining generation capacity includes about 8% from wind and 2% from thermal sources. The dependence on hydropower is prone to disruptions by drought, prompting efforts to diversify the generation mix with solar, wind, and geothermal sources for a more climate-resilient power system. Key projects include the Grand Ethiopia Renaissance Dam (GERD) with a projected installed capacity of 5,150 MW and the Koysha Hydo Power dam with a capacity of 2,170 MW. As of 2020, the breakdown of Ethiopia's electricity generation sources was as follows:

- Hydropower: 95.8%
- Wind: 3.8%
- Biomass and waste: 0.3%

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- Solar: 0.1%
- Fossil fuels, nuclear, tide, wave, and geothermal: 0%

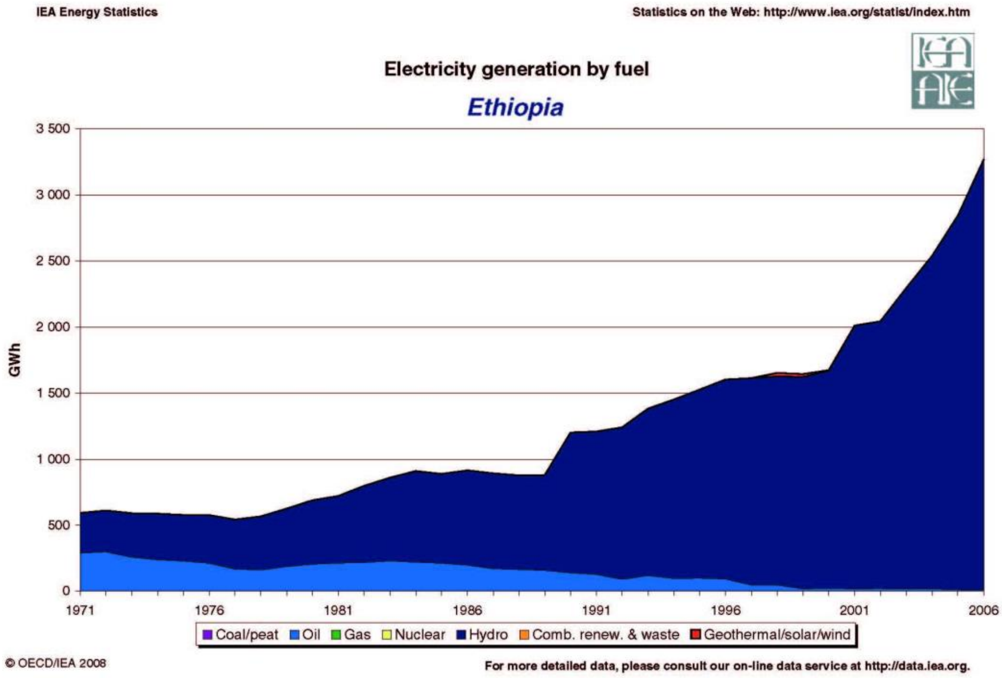

Figure 43: Ethiopia electricity generation by fuel (Global Energy Network Institute – GENI (2023)

This data indicates a strong reliance on renewable energy sources, particularly hydropower, for electricity generation in Ethiopia.

As per the most recent data, Ethiopia's electricity grid network has expanded to cover nearly 60 percent of towns and villages, significantly progressing in its electrification program over the past decade. However, more than half the population still lacks access to reliable electricity, particularly in deep-rural areas which rely on biomass and kerosene. This is particularly notable given that Ethiopia has the third largest energy access deficit in Sub-Saharan Africa. Regarding the size of Ethiopia's power supply system, it consists of a publicly owned and operated interconnected system. In addition to the main power supply system, Ethiopia also has small operational off-grid self-contained systems supplied by diesel generators and hybrid solar-diesel with a total installed capacity of 21.8 MW as of 2021.

Democratic Republic of Congo

Data available in 2020 indicate that the Democratic Republic of the Congo (DRC) had an installed electricity generation capacity of approximately 2.919 million kW. The energy mix in the DRC is highly dominated by hydroelectric power, which accounts for 99.6% of the total installed capacity. Other minor contributors to the energy mix include biomass and waste (0.3%), solar (0.1%), and

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fossil fuels (0.1%). The country does not use wind or geothermal sources in its current energy mix .

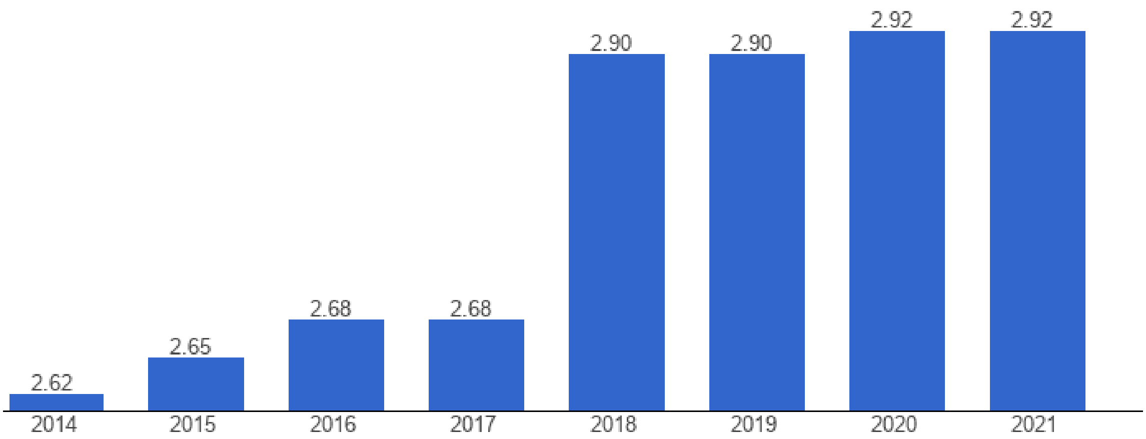

Figure 44: DRC Electricity Capacity in TW - The GlobalEconomy.com (2022)

Regarding the potential electricity generation capacity, the DRC has significant potential, particularly in hydroelectric power. The country can potentially generate over 100,000 MW of electric power from hydroelectric sources. The Inga Dam on the Congo River is a key component of this potential, with the capacity to generate 40,000 to 45,000 MW of electric power, which would be sufficient to supply the electricity needs of the entire Southern Africa region. However, this potential remains largely untapped due to ongoing uncertainties in the political arena and a resulting lack of interest from investors.

It's important to note that while the DRC has immense and varied energy potential, including non-renewable resources like oil, natural gas, and uranium, as well as renewable sources like hydroelectric, biomass, solar, and geothermal power, the actual access to electricity is quite limited. Only 19% of the DRC's population of 108 million has access to electricity, with a higher percentage in urban areas (41%) compared to rural areas (1%). This lack of access to modern electricity services has significant implications for the health, education, and income-generating potential of millions of Congolese people. Most power generation development in the country is directed and funded by mining companies for their operations.

Tanzania

Tanzania's electricity sector is currently marked by a diverse energy mix and ambitious plans for expansion. The country's installed capacity as of 2021 was reported to be between 1,605.86 MW and 1,900 MW. The primary sources of electricity are natural gas (48%), hydropower (31%), and petrol (18%), with smaller contributions from solar and biofuels. Notably, approximately 80% of the electricity is derived from renewable sources.

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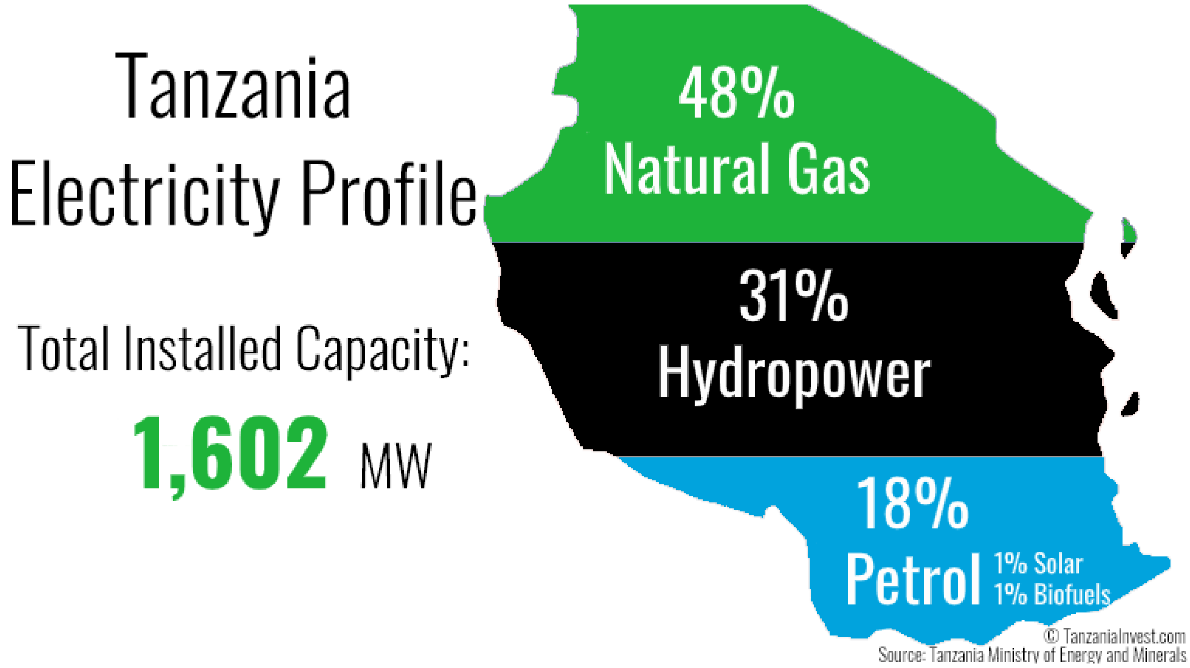

Figure 45: Tanzania Electricity Capacity Mix – Tanzania Invest (2020)

To meet rising demand which is expected to quadruple by 2025, Tanzania aims to increase its installed capacity to 10 GW by 2025 and to nearly double its electrification rate by 2033. The government's strategy emphasises a significant shift towards renewable energy, targeting the integration of over 6,000 MW of green energy into the national grid. This includes the Julius Nyerere Hydropower Project, which alone is expected to contribute 2,100 MW. Other hydropower projects, such as Ruhudji and Rumakali, are slated to add 358 MW and 222 MW, respectively. Furthermore, Tanzania is exploring solar energy with a target of 700 MW and is venturing into wind energy. This expansive green energy roadmap is set to position Tanzania as a leading renewable power generator in Africa, alongside South Africa and Morocco.

Rwanda

Data from December 2022 indicate Rwanda's national installed generation capacity totalled approximately 276.068 MWs, with plans to expand this capacity to 556 MW by 2024. The current installed generation capacity is somewhat variably reported, with one source stating 216 MW, another indicating 276.068 MW, and a third mentioning 332.6 MW. The country has ambitions to achieve universal electricity access (100%) by 2023/24, with specific targets for on-grid and off-grid connections.

Rwanda's potential electricity generation capacity is set to significantly increase in the near future. The government has set ambitious targets to achieve 512 MW of installed power generation capacity by 2023/24, which is a substantial increase from the current levels. This expansion plan is part of the National Strategy for Transformation (NST1), aiming for 100% electricity access for all Rwandans by 2024. Thus, whilst Rwanda is actively working to expand its electricity generation

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capacity, with a focus on increasing the share of renewable energy sources. The goal to more than double the current capacity within a short time frame highlights the country's commitment to enhancing its energy infrastructure and accessibility.

4.3.2.3 The Legal, Regulatory and Policy Landscape

In this comprehensive assessment, this section will dive into the intricacies of governance in developing the green hydrogen sector in East Africa. The discussion is multifaceted, covering the policy, legal, regulatory frameworks, and the role of regional power pools in shaping the green hydrogen landscape. Each aspect is critically analysed to understand the current state, challenges, and opportunities in these countries, providing a holistic view of the green hydrogen sector's potential in the region.

This section begins by an assessment of the policy landscape, examining how national energy and climate policies can either directly or indirectly impact the development of green hydrogen. This is followed by an exploration of the legal frameworks, highlighting the need for specific legislation tailored to the unique requirements of the green hydrogen sector. The regulatory environments are then scrutinised, focusing on how current energy regulations can be enhanced to better support green hydrogen initiatives.

Furthermore, the role of power pools, particularly the Eastern Africa Power Pool (EAPP) and the Southern African Power Pool (SAPP), is evaluated to understand how regional electricity market integration can facilitate the growth of the green hydrogen industry. Finally, based on these analyses, a set of recommendations is proposed, aimed at guiding policymakers, stakeholders, and investors in effectively nurturing the green hydrogen sector in East Africa. These recommendations address the gaps and leverage the synergies in the existing frameworks, aiming to propel the region towards a sustainable and economically viable green hydrogen future.

In Kenya, the government's commitment to renewable energy is evident in its Vision 2030 and the previous administration's Big Four Agenda. The country has made significant strides in renewable energy, especially in geothermal and wind power. This creates a conducive environment for green hydrogen production. Ethiopia's abundance in hydropower and wind energy potential positions it as a potential leader in green hydrogen production. The country's Growth and Transformation Plan (GTP) outlines its ambition in renewable energy development. However, the specific focus on green hydrogen is still developing. The Democratic Republic of Congo holds a significant potential for green hydrogen production, primarily due to its vast hydropower resources, especially the Congo River. Nevertheless, the country faces challenges in political instability and infrastructural inadequacies, which could hinder the development of a green hydrogen sector.

Uganda, with its focus on solar and hydroelectric power, has shown limited specific focus on green hydrogen so far, but the potential remains untapped. Tanzania's potential in solar and wind energy,

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which could be leveraged for green hydrogen production, is an integral part of the country's development visions that emphasise industrialisation. This industrial drive could integrate green hydrogen initiatives. Rwanda, known for its strategic focus on becoming a regional technology hub and investments in renewable energy, also stands as a potential player in the green hydrogen sector.

Despite these potentials, specific policies for green hydrogen are limited or in the early stages in these countries. However, all these countries have some form of renewable energy policy or strategy, therefore laying a foundational framework for green hydrogen development. They also have policies around environmental protection, foreign investment, and industrial development that indirectly impact the green hydrogen sector.

The primary challenges in the development of green hydrogen in East Africa include a lack of adequate infrastructure for production, storage, and transportation of hydrogen. In countries like the DRC, political instability poses a significant risk to investments. Additionally, limited local expertise and technology for green hydrogen production are hurdles that these countries face. High initial investment costs and lack of financing options also emerge as major barriers.

Nevertheless, there are considerable opportunities in this sector. International partnerships could provide both technical and financial support, essential for the nascent green hydrogen industry in these countries. Regional integration, particularly through the East African Community (EAC), could facilitate a regional approach to green hydrogen development, leveraging shared resources and markets. The global demand for green hydrogen presents significant export opportunities for these countries, provided they can develop the necessary infrastructure and policy framework.

It is anticipated that as the focus increases, specific policies and regulatory frameworks for green hydrogen will emerge as part of broader renewable energy and industrial policies in these countries. Kenya, which is trail blazer in the region has already launched its green hydrogen development roadmap and strategy, and has also released through its regulator, EPRA, green hydrogen sector development guidelines. Technological advancements, driven by regional partnerships and international collaborations, are likely to be a key feature of the sector's development. As global interest in green hydrogen grows, East African countries could see increased foreign investment, which would be crucial for the sector's growth. Additionally, the development of local expertise and infrastructure for green hydrogen production is anticipated, which would be crucial for these countries to fully leverage their green hydrogen potential.

Therefore, whilst the development of the green hydrogen sector in East Africa is at a nascent stage, the potential and opportunities it presents are significant. The varying degrees of readiness and potential across Kenya, Ethiopia, DRC, Uganda, Tanzania, and Rwanda reflect the broader regional

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dynamics and challenges. However, with targeted policies, regional cooperation, technological advancements, and capacity building, these countries could significantly contribute to the global green hydrogen market, while advancing their own sustainable development and energy security goals.

4.3.2.4 Country per country policy frameworks

In examining the policy frameworks relating to the development of the green hydrogen sector in East Africa, particularly in Kenya, Ethiopia, Democratic Republic of Congo (DRC), Uganda, Tanzania, and Rwanda, it is crucial to understand the unique context of each country and the regional dynamics. This assessment dives into the intricacies of the policy environment that shapes the prospects and challenges of green hydrogen development in these nations.

Kenya

Kenya recently approved its own hydrogen strategy in July 2023. Kenya's approach to green hydrogen is embedded within its broader renewable energy and economic development policies. The country's Vision 2030 and the Big Four Agenda, which emphasise industrialisation, affordable housing, universal healthcare, and food security, provide a strategic framework that implicitly supports the development of renewable energy sources, including green hydrogen. Kenya has made significant strides in renewable energy, particularly in geothermal and wind power, creating an enabling environment for green hydrogen production. The Kenyan government has been proactive in creating a policy environment that encourages renewable energy investments. This is evident in the Renewable Energy Feed-in Tariff (FiT) policy, which offers attractive tariffs for renewable energy generation. However, specific policies targeting green hydrogen are still in their infancy. The government needs to develop a comprehensive policy that addresses the production, storage, distribution, and use of green hydrogen, ensuring that it aligns with the country's broader energy and economic objectives.

There will be a further discussion in the next section which will examine the recently launched Kenya Green Hydrogen Strategy and Roadmap as well as the Green Hydrogen Development Guidelines. Furthermore, it is relevant to highlight that to make Kenyan Green Hydrogen transition many and various stakeholders should be involved as presented in Figure below.

Figure 46: Kenya hydrogen stakeholders

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Ethiopia

Ethiopia's policy framework for green hydrogen is guided by its Growth and Transformation Plan (GTP), which outlines the country's ambition in renewable energy development. Ethiopia's significant hydropower and wind energy resources position it well for green hydrogen production. The country's Climate-Resilient Green Economy (CRGE) strategy, which aims to build a carbon-neutral economy by 2025, provides a conducive backdrop for green hydrogen initiatives.

However, Ethiopia's policy framework for green hydrogen is not developed. While the GTP and CRGE create a favourable macro-environment, specific policies that address the intricacies of green hydrogen production and use are needed. These policies should focus on incentivising investments in hydrogen technology, establishing regulatory standards for hydrogen production and use, and fostering public-private partnerships.

Democratic Republic of Congo (DRC)

The DRC's potential in green hydrogen largely hinges on its vast hydropower resources, particularly the Congo River. However, the country's political instability and infrastructural challenges pose significant hurdles to the development of a comprehensive policy framework for green hydrogen. While the DRC has immense potential for renewable energy, the lack of a stable and conducive policy environment impedes significant progress in this sector.

For the DRC, establishing a stable political and economic environment is a prerequisite for developing a robust green hydrogen policy. The government needs to work towards political stability and infrastructural development to attract investments in the green hydrogen sector. Additionally, policies that address the specific needs of the green hydrogen industry, including regulatory frameworks for production and distribution, are critical.

Uganda

Uganda's focus on solar and hydroelectric power provides a foundation for the development of green hydrogen, but the country has yet to develop specific policies targeting this sector. Uganda's Renewable Energy Policy, established to promote the use of renewable energy sources, could serve as a starting point for integrating green hydrogen initiatives. However, to effectively harness green hydrogen potential, Uganda needs to develop policies that specifically address the unique requirements of the hydrogen sector. This includes creating incentives for green hydrogen production, establishing standards and regulations for hydrogen use, and promoting research and development in hydrogen technologies.

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Tanzania

Tanzania's potential in solar and wind energy, which could be leveraged for green hydrogen production, aligns with the country's development visions that emphasise industrialisation. The government's focus on industrial development through policies such as the Tanzania Development Vision 2025 provides a strategic framework that could support green hydrogen initiatives.

However, Tanzania needs to formulate specific policies that cater to the development of the green hydrogen sector. This includes creating a regulatory framework that addresses the production, storage, and distribution of hydrogen, as well as incentives for investment in hydrogen technologies. Additionally, integrating green hydrogen initiatives into the country's industrialization and energy policies would be crucial.

Rwanda

Rwanda's strategic focus on becoming a regional technology hub and its investments in renewable energy make it a potential player in the green hydrogen sector. Rwanda's Vision 2050 and the National Strategy for Transformation (NST1) outline the country's long-term development goals, which include sustainable energy development.

Rwanda can capitalise on its strategic goals by developing specific policies for green hydrogen. This includes creating a regulatory framework for hydrogen production and use, incentivizing investment in hydrogen technology, and integrating green hydrogen into the country's broader energy and economic policies.

4.3.2.5 Country per country legal and regulatory framework

The development of the green hydrogen sector in East Africa is not only a matter of policy but also significantly influenced by the legal frameworks in place in Kenya, Ethiopia, Democratic Republic of Congo (DRC), Uganda, Tanzania, and Rwanda. This exploration, expanding to over 1000 words, delves into the legal intricacies that shape the prospects and challenges of green hydrogen development in these nations, focusing on legislation, regulatory mechanisms, and legal reforms.

Kenya

Kenya's legal framework for renewable energy, which implicitly encompasses green hydrogen, is primarily governed by the Energy Act of 2019. This act consolidates laws relating to energy, providing a structured approach to energy resource development, including renewables. It establishes the Energy and Petroleum Regulatory Authority (EPRA), which oversees energy regulation, including licensing, tariff-setting, and enforcing standards.

While the act provides a comprehensive framework for energy regulation, specific legal provisions for green hydrogen are still nascent. The Kenyan government must consider amending existing laws or introducing new legislation that directly addresses green hydrogen. This legal framework

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should cover aspects like safety standards, environmental impacts, and the regulatory requirements for green hydrogen production and distribution. Additionally, there's a need for legal provisions that facilitate public-private partnerships and foreign investment in this sector.

In Kenya, the regulatory framework for green hydrogen is an extension of its broader energy regulation, chiefly managed by the Energy and Petroleum Regulatory Authority (EPRA). The EPRA, established under the Energy Act of 2019, is responsible for overseeing energy regulations, which include licensing, enforcing standards, and tariff-setting. However, specific regulatory guidelines for green hydrogen are underdeveloped.

To foster the growth of the green hydrogen sector, Kenya needs to develop regulations that specifically address the production, storage, and distribution of hydrogen. This includes establishing regulatory standards for hydrogen safety, environmental impact assessments, and mechanisms for integrating green hydrogen into the national grid. Moreover, regulations that facilitate public-private partnerships and ease foreign direct investment in this sector are crucial.

Ethiopia

Ethiopia's legal framework for green hydrogen is indirectly influenced by its general energy and environmental laws. The country's commitment to a Climate-Resilient Green Economy (CRGE) is reflected in various legislative instruments. However, specific legal frameworks dedicated to green hydrogen are yet to be developed.

The Ethiopian government could benefit from enacting legislation that specifically addresses green hydrogen. This could include laws that define the regulatory landscape for hydrogen production, storage, and transportation. In addition, creating legal incentives for green hydrogen investments and establishing a clear legal path for public-private partnerships in this field would be pivotal for the sector's growth.

Ethiopia’s regulatory landscape for green hydrogen is influenced by its general energy regulations, which primarily focus on traditional energy sources. The Ethiopian Energy Authority (EEA) oversees the regulation of the energy sector, but specific regulatory provisions for green hydrogen are not yet in place.

Ethiopia needs to advance its regulatory framework to specifically include green hydrogen. This advancement would involve setting up regulatory standards for the production and utilization of hydrogen, ensuring compliance with environmental and safety norms, and establishing clear guidelines for investment and technology transfer in the green hydrogen sector.

Democratic Republic of Congo (DRC)

In the DRC, the legal framework for energy is complex and often challenged by the country’s political and infrastructural issues. The DRC’s Hydrocarbons Code and the Electricity Sector Regulation Law provide some legal basis for energy management, but they are not directly tailored to renewable energy, let alone green hydrogen.

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Given the DRC's vast potential for hydropower-based green hydrogen, there is a significant opportunity for legal reform. The government needs to establish legal structures that specifically cater to renewable energy, particularly green hydrogen. This includes laws that govern the production, distribution, and export of green hydrogen, as well as legal mechanisms that ensure the stability and security of investments in this sector.

The DRC's regulatory framework for energy is complicated by the country's broader political and infrastructural challenges. The existing energy regulations, governed by the Hydrocarbons Code and the Electricity Sector Regulation Law, lack specific focus on renewable energy, including green hydrogen.

To capitalize on its hydropower potential for green hydrogen, the DRC must reform its regulatory framework. This involves establishing regulations that specifically cater to renewable energy, particularly green hydrogen. The focus should be on creating a stable and transparent regulatory environment that can attract and secure investments in green hydrogen production and infrastructure.

Uganda

Uganda's legal framework for renewable energy is guided by the Electricity Act 1999 and the Renewable Energy Policy of 2007. These legal instruments lay the groundwork for renewable energy development but lack specific provisions for green hydrogen.

To harness the potential of green hydrogen, Uganda would need to introduce specific legal frameworks that cater to the unique characteristics of hydrogen as an energy source. This includes legal standards for hydrogen production, use, and safety, as well as legal incentives to attract investment in this sector.

Uganda's regulatory framework for renewable energy is primarily guided by the Electricity Regulatory Authority (ERA). While the ERA oversees the regulation of the electricity sector, including renewable energy, specific regulations for green hydrogen are lacking.

Uganda should focus on developing regulations that address the unique aspects of green hydrogen. This includes regulatory guidelines for the safe production and storage of hydrogen, environmental compliance, and standards for hydrogen-powered transport and infrastructure. Additionally, regulations that incentivize investment in the green hydrogen sector would be pivotal for its growth.

Tanzania

Tanzania's legal framework for energy is governed by the Electricity Act of 2008 and the Renewable Energy Act. While these acts provide a general legal structure for energy development, specific legal provisions for green hydrogen are absent. The Tanzanian government could advance its green hydrogen sector by enacting legal reforms that specifically address hydrogen energy. This could involve legal provisions for the licensing and regulation of hydrogen production facilities,

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legal standards for storage and transportation of hydrogen, and legal mechanisms to promote both local and foreign investment in the hydrogen sector.

Tanzania's regulatory framework for energy, governed by the Tanzania Electric Supply Company (TANESCO) and the Energy and Water Utilities Regulatory Authority (EWURA), is primarily focused on electricity supply and water utilities. Specific regulatory provisions for green hydrogen within this framework are yet to be developed.

To support the growth of the green hydrogen sector, Tanzania needs to introduce regulatory reforms that specifically cater to hydrogen energy. This includes establishing standards for hydrogen production, storage, and distribution, as well as regulatory incentives for investments in hydrogen technologies and infrastructure.

Rwanda

Rwanda's legal approach to renewable energy, as part of its broader aim to become a regional technology hub, is progressive. The country's legal framework for energy is outlined in the Law on Renewable Energy, which promotes renewable energy sources. However, like its East African counterparts, Rwanda lacks specific legal provisions for green hydrogen.

Rwanda could enhance its legal framework by incorporating specific regulations and standards for green hydrogen. This should include legal guidelines for production, environmental compliance, safety standards, and investment facilitation in the green hydrogen sector.

In Rwanda, the regulatory environment for renewable energy is progressive and is overseen by the Rwanda Utilities Regulatory Authority (RURA). However, like other East African nations, specific regulatory frameworks for green hydrogen are not yet fully established.

Rwanda could enhance its regulatory framework by incorporating regulations specific to green hydrogen. This would involve setting standards for production, storage, and use, along with guidelines for environmental and safety compliance. Regulations to facilitate investment in the green hydrogen sector would also be essential.

Regional Legal Cooperation

For effective development of the green hydrogen sector, regional legal cooperation in East Africa is essential. The East African Community (EAC) can play a crucial role in harmonizing legal frameworks across member states. This cooperation could involve the development of a regional legal framework for green hydrogen, addressing cross-border issues, standardization of regulations, and joint legal mechanisms for investment and technology transfer.

The EAC's involvement could ensure that legal frameworks across these countries are not only aligned but also conducive to regional green hydrogen projects. This would facilitate easier movement of technology, expertise, and funding across borders, fostering a cohesive regional green hydrogen market.

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In summary, the development of a robust green hydrogen sector in East Africa is contingent on the establishment of specific, comprehensive, and coherent legal frameworks in each country and across the region. These frameworks should address the unique needs of the green hydrogen sector, providing clear legal guidelines for production, distribution, and use, while ensuring environmental compliance and safety. Legal reforms in each country, coupled with regional legal cooperation, will be fundamental in creating a conducive environment for investment, technological advancement, and the sustainable development of the green hydrogen sector in East Africa.

4.3.3 Conclusions

In conclusion, the development of the green hydrogen sector in East Africa, encompassing Kenya, Ethiopia, Democratic Republic of Congo, Uganda, Tanzania, and Rwanda, stands at a pivotal juncture. The region possesses significant potential for green hydrogen production, primarily due to its abundant renewable energy resources. However, the realization of this potential is contingent upon the establishment and harmonization of comprehensive policy, legal, and regulatory frameworks across these nations. Each country exhibits unique challenges and opportunities, necessitating tailored approaches within a collaborative regional context.

The assessment reveals that while there are foundational policy and legal structures in place for energy and environmental management, specific focus on green hydrogen is still evolving. Strengthening these frameworks to explicitly encompass green hydrogen is crucial. This includes enacting dedicated legislation, establishing clear regulatory guidelines, and leveraging the synergies offered by regional power pools like the EAPP and SAPP for infrastructure development and energy integration.

The proposed recommendations highlight the importance of targeted actions in policy development, legal reforms, regulatory enhancements, and regional cooperation. By addressing these areas, East Africa can not only advance its green hydrogen sector but also contribute significantly to global sustainability efforts. Furthermore, this development can spur economic growth, energy security, and regional integration, positioning East Africa as a key player in the global green hydrogen landscape.

Ultimately, the successful development of the green hydrogen sector in East Africa requires a concerted effort from governments, regional bodies, industry stakeholders, and international partners. By embracing innovation, fostering partnerships, and prioritizing sustainable practices, East Africa can harness the full potential of green hydrogen, paving the way for a cleaner, more resilient energy future.

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4.4 Southern Africa Potential Assessment

4.4.1 Overview of the Green Hydrogen potential and Initiatives in South Africa

In South Africa, to effectively incorporate renewable energy sources into the energy grid, it's essential to have reliable energy storage technologies. The country is actively advancing hydrogen and fuel-cell technologies through the 15-year Hydrogen South Africa RDI Programme. These environmentally friendly technologies play a crucial role in supporting the integration of renewable energy and managing energy demand efficiently. Hydrogen is a key element in South Africa's efforts to reduce emissions gradually, following a "peak, plateau, decline" trajectory. Additionally, hydrogen fuel cells are being considered for essential infrastructure and public buildings, and there's a growing focus on decarbonizing transportation by introducing hydrogen-powered electric vehicles. The ambitious decarbonization efforts encompass multiple sectors, including heavy-duty trucks, shipping, aviation, and rail, as well as energy-intensive industries such as iron and steel, chemicals, mining, refineries, and cement. These efforts aim to establish a thriving export market for green hydrogen and green ammonia. Simultaneously, there's a focus on enhancing the power sector and making buildings more environmentally friendly. This comprehensive approach also involves the development of a manufacturing sector for hydrogen-related products and components, along with training programs for Technical Vocational Education and Training (TVET) college students. The transition from grey to blue to green hydrogen is a pivotal part of this transformative endeavour. Figure shows a roadmap, government reports and policies that support green hydrogen.

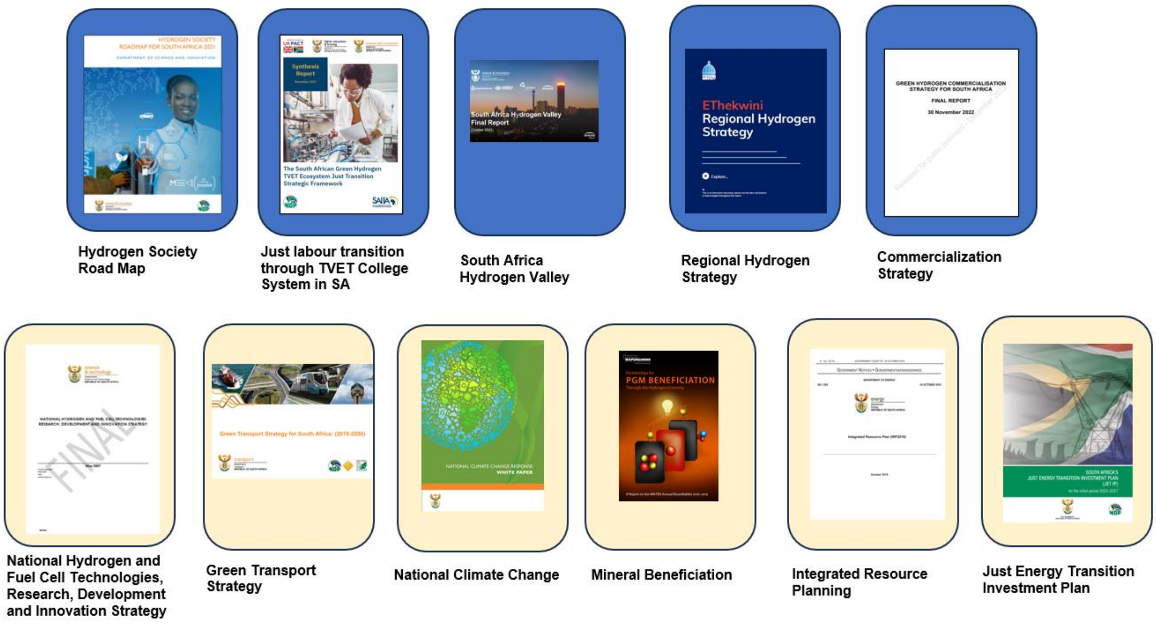

Figure 47: Roadmaps, policies and government reports linked to hydrogen in South Africa

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4.4.2 Hydrogen Valleys and other relevant implementation projects in South Africa

In this section some relevant green hydrogen projects already conceptualized or realized are presented showing the strategic potential of hydrogen in the country. All these projects can be supportive each other also to promote the development of a domestic H2 market. These projects have been deeply analysed by NWU and JUST GREEN AFRH2ICA consortium also to identify South African use cases to be modelled in WP2 to be presented in D1.3,

South African Hydrogen valley

The concept of a "hydrogen valley" refers to a strategically planned, interconnected hydrogen ecosystem that spans from Mokopane, a mining area for platinum group metals, all the way to Johannesburg and finally concluding in Durban. This idea was initially put forward in 2020, and throughout 2021, several studies were conducted to assess its feasibility. The aim is to decarbonize medium to heavy-duty trucks via national roads (N1 and N3). Some of the hard-to-abate industries (e.g., Iron and steel, oil refining) within the Johannesburg hub and Durban or Richards Bay hubs will also be decarbonized. The valley is set to extend over a distance of roughly 835 kilometres, offering significant employment and investment prospects. This aligns with the broader strategy of reducing reliance on coal.

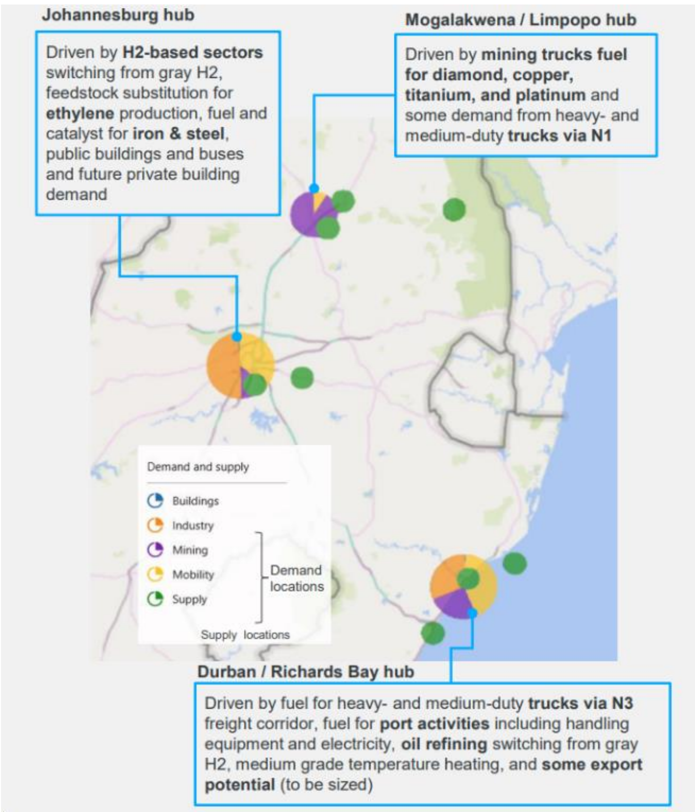

Figure 48: Archetype of Hydrogen Valley in South Africa

As part of the Hydrogen Valley project, Anglo-American, one of the world's leading mining companies, has taken a significant step towards reducing carbon emissions and improving air quality in mining operations by developing a hydrogen-powered mining haul truck. The mining haul

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truck, a 290-tonne vehicle, is equipped with a hydrogen fuel cell system that generates electricity to power the electric motors of the vehicle. The proof-of-concept and demonstration facilities are located in Mogalakwena Anglo Platinum mine in Limpopo, South Africa. The haul truck system uses multiple fuel cells that deliver up to 800kW of power each, combining to provide a total of 2MW of power. The 1.2MWh battery pack is designed to store energy and work alongside the fuel cells to power the haul truck. This innovative combination of hydrogen fuel cells and batteries allows for more efficient energy management, reduced emissions, and increased operational flexibility. To produce hydrogen, 7 MW alkaline water electrolysers are utilized, which are accompanied by compressors, cooling units, and composite storage tanks. These components work together to supply the hydrogen to the dispensing unit, enabling the efficient refuelling of the truck.

Figure 49: Mining factor retrofitted to hydrogen fuelled power train and local alkaline electrolysers

"Prieska" Power Reserve in the Northern Cape

The "Prieska" Power Reserve is a hybrid energy storage system located in the Northern Cape province of South Africa. The system consists of a battery storage system and a hydrogen fuel cell system. The battery storage system is used to store excess renewable energy generated from wind and solar power, while the hydrogen fuel cell system provides backup power during periods of low renewable energy generation or high demand. The "Prieska" Power Reserve aims to provide reliable and sustainable power to the local community and support the integration of renewable energy sources into the grid. The system can also be used for remote off-grid applications and as a backup power supply for critical infrastructure.

Boegoebaai in the Northern Cape (Sasol and Northern Cape government)

Boegoebaai is a proposed green hydrogen project in the Northern Cape province of South Africa, a collaboration between Sasol, a South African energy and chemicals company, and the Northern Cape government. The project aims to produce green hydrogen from renewable energy sources and use it for local industrial and transportation applications. The project will involve the construction of a green hydrogen production facility, which will use renewable energy sources such as wind and solar power to produce hydrogen through electrolysis. The green hydrogen will then be transported to local industries and transportation companies via pipelines or trucks. The project aims to reduce carbon emissions and support the development of a regional hydrogen economy.

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Sasolburg Green Hydrogen project, located in the Free State

The Sasolburg Green Hydrogen project is a proposed green hydrogen production plant located in the Free State province of South Africa. The project aims to produce green hydrogen from renewable energy sources, including solar and wind power, and use it for various applications, such as transportation and industrial processes. The project will involve the construction of a green hydrogen production facility, which will use renewable energy sources to produce hydrogen through electrolysis. The green hydrogen will then be used as a feedstock for various applications, such as fuel for hydrogen fuel cell vehicles and industrial processes. The project aims to support the transition to a low-carbon economy and reduce greenhouse gas emissions.

HIVE Energy –green ammonia plant in the Coeca Special Economic Zone

HIVE Energy is a UK-based renewable energy company that is planning to build a green ammonia production plant in the Coega Special Economic Zone in South Africa. The plant aims to produce green ammonia from renewable energy sources and use it as a low-carbon alternative to traditional ammonia production processes. The plant will use renewable energy sources, such as solar and wind power, to produce hydrogen through electrolysis. The hydrogen will then be combined with nitrogen to produce green ammonia, which can be used as a fertilizer or as a fuel for hydrogen fuel cell vehicles. The project aims to support the development of a regional hydrogen economy.

Southern Corridor: Namibian green hydrogen project

This project represents the initial phase in the government's plan to establish a substantial green hydrogen industry across multiple regions in Namibia. Its purpose is to promote economic growth within Namibia and contribute to global decarbonization objectives as well as exports. The project is designed to progress in stages, with the ultimate goal of producing 350,000 metric tons of green hydrogen annually. This production will rely on around 7 GWs of renewable energy generation capacity and approximately 3 GWs of electrolysis capacity.

Sadhana bay green hydrogen

Saldanha Bay is well-positioned to meet the needs of its existing customers with this innovative net-zero product, and Freeport Saldanha can play a pivotal role as a catalyst in this endeavour. The availability of cost-effective and environmentally friendly renewable energy is a crucial element in ensuring the economic viability of green hydrogen. Saldanha Bay's suitability for green hydrogen production is highlighted by its extensive potential for renewable energy generation. The region enjoys a consistent and robust supply of wind, making it an ideal site for wind power production, in addition to ample solar resources. Leveraging these renewable sources, Saldanha Bay has the capacity to power large-scale electrolysis plants for the production of green hydrogen and exports.

4.4.2 South Africa SWOT Analysis

Strengths

Geographical position: South Africa is blessed with abundant solar resources and strong and consistent winds in the western cape, making it an ideal location for the development of renewable energy technologies, including green hydrogen production. The country has a favourable geographic location for exporting green hydrogen to other regions, such as Europe and Asia. Due

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to its strategic geographical location, the country is well-positioned as a hub to access markets in sub-Saharan Africa. The country serves as a gateway to the rest of the continent in many respects. The African Continental Free Trade Area (AfCFTA) Agreement became effective on May 30, 2019, and 30 African countries have ratified it thus far. South Africa, as a member of the AU, has given its endorsement to the AfCFTA. The free trade zone is of great economic significance to both South Africa and the African continent, as it will create a market of more than 1 billion people with a GDP exceeding US$2.6 trillion (South African Revenue Services, 2021).

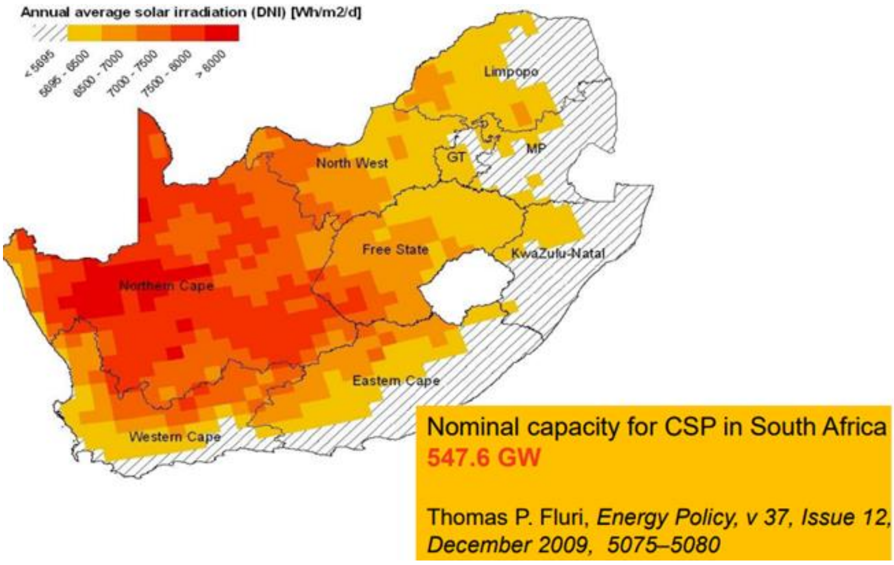

Figure 50: Solar Irradiation in South Africa

Mineral resources: South Africa has nearly 80% of the world PGMs (platinum group metals), which crucial component of green hydrogen technology. Platinum is used as a catalyst in the electrolysis process that produces green hydrogen, and South Africa is the world's leading producer of platinum, giving the country a significant advantage in the global green hydrogen market.

Figure 51: South African Mineral reserves

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Research institutions: South Africa has a strong research and development infrastructure that supports the development of renewable energy technologies, including green hydrogen. The country has several leading research institutions, including the Council for Scientific and Industrial Research (CSIR), MINTEK and Hydrogen South Africa.

Open market investment: South Africa has a business-friendly environment that attracts foreign investment, including investment in the energy sector. The country has several incentives to attract foreign investment, including tax breaks, subsidies, and a range of other incentives aimed at encouraging investment in green hydrogen technology. For example, the 12I Tax Incentive has been crafted to support both Greenfield and Brownfield investments. This incentive scheme encourages businesses to invest in new projects and expand existing ones. The Capital Projects Feasibility Programme (CPFP) offers a cost-sharing grant to support the cost of feasibility studies aimed at boosting local exports and increasing demand for South African capital goods and services. The Critical Infrastructure Programme (CIP) is aimed at driving investment growth in line with the National Industrial Policy Framework (NIPF) and Industrial Policy Action Plan (IPAP). The CIP aims to lower business costs by supporting infrastructure development, thus enticing more investments.

Weaknesses

The development of a green hydrogen industry in South Africa is faced with several challenges that require attention. One of the most significant challenges is the lack of infrastructure for green hydrogen production and distribution, which would require significant investment. Moreover, there is competition from other regions with established green hydrogen industries, such as Europe and Australia. Additionally, there is limited public awareness and education on the benefits of green hydrogen, which could impact demand. The bureaucratic processes for approval of new energy solutions are slow and complex, which creates uncertainty for investors. Policy uncertainty, corruption, and load-shedding also pose significant risks that could scare investors away. Commercializing and implementing proven scientific research is a challenge that also needs attention. There is a lack of skilled labor in the country, which constrains the development of the industry. Finally, slow economic growth adds to the challenges of the development of the green hydrogen industry in South Africa. These challenges need to be addressed through policy reforms, public awareness campaigns, investment in infrastructure, and the development of a skilled workforce to promote the growth of the green hydrogen industry in South Africa.

Opportunities

There is a growing global demand for green hydrogen as a clean energy source, which provides an opportunity for South Africa to tap into the global market. Additionally, potential partnerships with international companies and investors interested in investing in green hydrogen production in South Africa can bring much-needed investment and expertise to the industry. This, in turn, presents opportunities for job creation and economic growth in the country. The possibility of using green hydrogen to address energy access challenges in rural and remote areas of South Africa is another opportunity that can help drive the growth of the industry. With proper investment in infrastructure

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and the development of a skilled workforce, the green hydrogen industry in South Africa can help address energy access challenges, especially in underserved communities. Overall, the development of a green hydrogen industry presents significant opportunities for South Africa to contribute to the global clean energy transition while driving economic growth and job creation in the country.

Threats

The green hydrogen industry in South Africa is facing threats that could impede its growth potential. Emerging competitors, with international companies recruiting scarce skills in the country, pose a significant challenge to the industry. Public resistance to renewable energy projects, including green hydrogen, is another challenge that could limit the growth of the industry. Political instability and regulatory uncertainty in South Africa could discourage foreign investments, while the resistance from traditional energy producers could also hinder the development of the industry.

4.4.3 Identifying key green-H2 stakeholders in South Africa

Government departments and agencies

Department of Mineral Resources and Energy (DMRE): As the government body responsible for energy policies and regulations, DMRE plays a crucial role in setting the framework for green hydrogen development in South Africa. Their support and regulatory guidance are essential for promoting the growth of the sector and ensuring that projects align with the country's overall energy strategy.

Industrial Development Corporation is a national development finance institution that provides financing to entrepreneurs and businesses engaged in competitive industries, including green hydrogen. As a financial stakeholder, the IDC plays a key role in supporting the growth and development of the green hydrogen sector by providing funding and financial assistance to eligible projects and businesses.

Department of Trade, Industry and Competition (DTIC) is a government department responsible for promoting economic development, including the development of new industries such as green hydrogen. The DTIC can play a critical role in creating a favourable business environment for green hydrogen projects by providing incentives, supporting infrastructure development, and encouraging foreign and domestic investment in the sector.

The DSI is a government department responsible for developing and implementing national science, technology, and innovation policies. The DSI's support for research and development in green hydrogen technologies can drive innovation and help South Africa develop a competitive edge in the global hydrogen market.

Department of Forestry, Fisheries and Environment (DFFE): The DFFE is a government department responsible for ensuring the protection and sustainable use of South Africa's natural resources, including its environment, forests, and oceans. In the context of green hydrogen, the DFFE plays a crucial role in the development and implementation of environmental regulations, policies, and guidelines related to green hydrogen production and usage. The department ensures that green

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hydrogen projects align with South Africa's environmental goals and adhere to established standards for minimizing environmental impact.

Industry/ private companies

Sasol is a major energy and chemical company, Sasol's interest in green hydrogen shows the potential for large-scale industrial applications. Their investment in green hydrogen projects can help drive the growth of the sector and demonstrate the feasibility of hydrogen as an alternative to traditional fossil fuels.

Anglo American Platinum: As a mining company, their involvement in green hydrogen projects showcases the potential for hydrogen to reduce the environmental impact of industries. Their investments in hydrogen technologies can help spur further innovation and adoption.

Impala Platinum, also known as Implats, is one of the world's foremost producers of platinum and associated platinum group metals (PGMs). As a stakeholder in the green hydrogen sector, Impala Platinum plays a significant role in driving the demand for and adoption of green hydrogen and fuel cell technologies. Platinum and other PGMs are crucial components in fuel cells, and their mining and refining operations can directly impact the fuel cell industry. Impala Platinum's involvement in the green hydrogen sector highlights the potential for collaboration between the mining and renewable energy industries, as well as the growing demand for sustainable and clean energy solutions in various sectors.

HyPlat is a South African company specializing in the development and commercialization of high-performance, cost-effective fuel cell components and systems. As a stakeholder in the green hydrogen sector, HyPlat plays a crucial role in the development and deployment of fuel cell technology, which is an essential component of utilizing green hydrogen for various applications, such as transportation and stationary power generation. By focusing on innovative fuel cell solutions, HyPlat contributes to the growth and competitiveness of the green hydrogen sector in South Africa.

Bambili Energy: As a company focused on green hydrogen production projects, Bambili Energy contributes to the development of local capacity in hydrogen production and helps build the necessary infrastructure for a hydrogen economy in South Africa.

Busmark is a bus manufacturer involved in the development of hydrogen fuel cell buses highlighting the potential of hydrogen in the transportation sector. Their collaboration with other stakeholders can lead to the creation of cleaner and more sustainable public transportation options.

Mitochondria Energy Company: By focusing on sustainable energy solutions, including green hydrogen, Mitochondria Energy Company plays a role in the growth of the sector by developing and operating hydrogen production facilities. Their pilot projects can demonstrate the feasibility and scalability of green hydrogen production.

Research Institutions and Universities

HySA plays a central role in the development of green hydrogen technologies in South Africa. They work on various research, development, and demonstration projects, fostering collaboration between academia, industry, and government to promote hydrogen and fuel cell technologies. As

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already mentioned, HySA consists of three CoC, HySA infrastructure co-hosted by North-West University and CSIR, HySA Catalysis co-hosted by Mintek and University of Cape-Town and lastly, HySA Systems hosted by the University of the Western Cape. The University of Stellenbosch, University of Pretoria (UP), University of Johannesburg (UJ) and Tshwane University of Technology (TUT) are also engaging in cutting-edge research and training future experts in the field of green hydrogen.

4.4.4 Hydrogen research and development activities in South Africa

South Africa has been actively investing in the development of clean energy technologies, particularly hydrogen and fuel cell technologies. To facilitate this, the Department of Science and Technology formulated a comprehensive strategy known as the National Hydrogen and Fuel Cells Technologies Research, Development, and Innovation Strategy. This initiative was subsequently branded Hydrogen South Africa (HySA). Launched officially in 2008, this National Flagship Programme is designed to develop intellectual property, knowledge, human resources, products, components, and processes to support South Africa's participation in the international platforms for hydrogen and fuel cell technologies, which are in their nascent but rapidly developing stages. The HySA research, development and innovation (RDI) was extended for ten years, beyond the initial 15-year period, which ended on 31 March 2023. The primary objective of the HySA program is to conduct research and development activities aimed at capturing a significant share of the global Hydrogen and Fuel Cell market by utilizing innovative Platinum Group Metal (PGM) catalysts, components, and systems. As South Africa holds more than 75% of the world's known PGM reserves, the program intends to leverage this strategic advantage to achieve its ambitious goal. To this end, the program is designed to facilitate the simultaneous development of knowledge and technology across the entire Hydrogen and Fuel Cell value chain. This approach will enable the establishment of a robust R&D Hydrogen and Fuel Cell Technology sector capable of exporting PGM materials, components, and finished products with added value.

HySA is comprised of three Centres of Competency (HySA Infrastructure, HySA Catalysis and HySA Systems), each with a specific area of focus. These centres have distinct responsibilities, but they all share a common goal of promoting proactive innovation and developing human resources capable of undertaking competitive R&D activities in the field of Hydrogen and Fuel Cell Technologies. Collaboration between institutions and partners from the R&D sector, higher education, and industry is an essential component of the HySA program's strategy. The Centers of Competence serve as the national network of research "Hubs" and "Spokes" to facilitate this collaboration. Through this network, there is an exchange of knowledge, expertise, and resources, which allows the program to remain at the forefront of hydrogen and fuel cell technology development in South Africa. By working together, these entities can contribute their unique perspectives and strengths to the program, leading to greater innovation and advancements in hydrogen and fuel cell technology.

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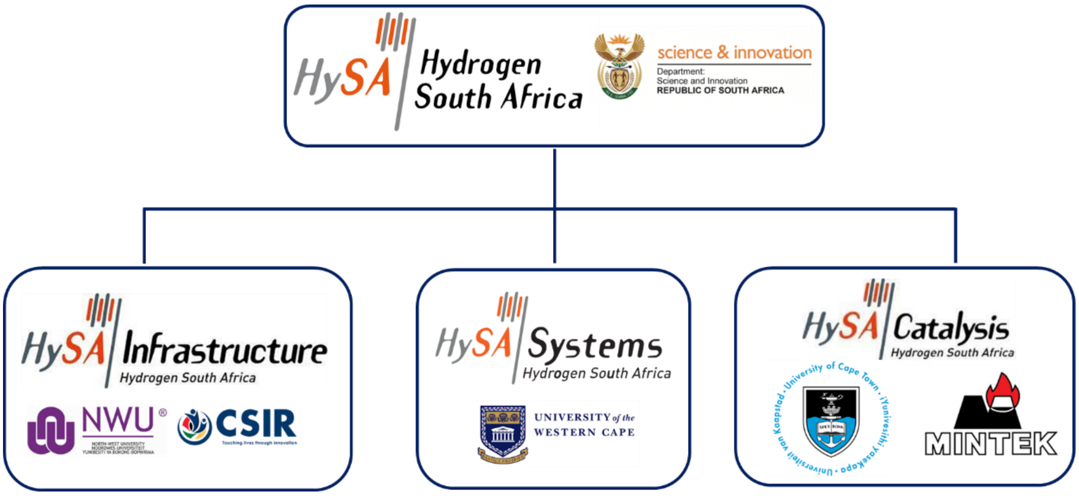

Figure 52: The structure of Hydrogen South Africa

The HySA Infrastructure Centre of Competence (CoC) is a collaborative research and development entity co-hosted by the North West University (NWU) and the Council of Scientific and Industrial Research (CSIR) in South Africa. The main objective of this CoC is to develop new and improved methods for hydrogen production, storage, and transportation, while also addressing issues related to hydrogen safety and standards. Additionally, the CoC aims to explore new applications for this versatile fuel source.

A Centre of Competence (CoC) is envisaged as a collaborative entity or instrument, preferably led by industry, that is resourced by highly qualified researchers associated with Public Research Institutions who are empowered to undertake market-focused strategic research and technology development for the benefit of industry and the economy at large. CoCs are therefore intended to provide a formal, and as far as possible contractually secure, physical or virtual platform upon which to establish collaborative technology innovation and commercialisation partnerships between government, industry, universities and Public Research Institutions, with the explicit aim of technology commercialisation.

Objectives of HySA Infrastructure CoC includes developing technology for green hydrogen and storage and related intellectual property rights (IPR), strategy, roadmaps and partnerships to enter markets for "green" hydrogen production including but not limited to water electrolysis and storage to support HSRM. Refining TDMs (Technology Development Matrix), technical requirements and techno-economic assessments for components and systems. Promoting local and international collaboration (e,g. Clean Hydrogen Partnership) through early engagement of industrial partners and academic institutions into HySA projects. Supply chain development for electrolysis components, hydrogen storage, power-to-gas applications, power-to-liquid and electrochemical hydrogen compression. Conformity analysis and understanding of market needs in renewable hydrogen production and storage as well as PGM recycling and PGM beneficiation (more

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specifically, Iridium (Ir) and Platinum (Pt)) and safety validation for hydrogen in underground mining and ventilation tunnelling.

Over last 12 years of HySA Infrastructure CoC operation and leadership in South African hydrogen research landscape, a great deal of experience and development history of technologies related to electrolytic hydrogen production, components of water electrolysis, hydrogen storage and safety activities and technologies were developed and preserved in the form of IPR, publications, demonstrators, students trained. Current development and Innovation (RD&I) areas that are considered critical to the implementation of the HSRM and are actively pursued by HySA Infrastructure CoC include:

- Develop the necessary human capital to conduct relevant hydrogen RDI.
- The creation of new knowledge, focused on improved material performance and cost reduction.
- Need to develop the physical infrastructure to optimally produce, distribute and utilize hydrogen to benefit South African communities and the environment.
- Expand the RDI community beyond the universities and science councils.
- Increase the delivery of products, incorporating HySA IP to pilot markets.
- Assist in funding further development and commercialisation of RDI outputs and
- Increase the participation of entrepreneurs, SMMEs and global OEMs within the HySA Programme to facilitate the deployment of locally developed IP.

The HySA Systems CoC, on the other hand, is a research and development entity hosted by the University of the Western Cape, South Africa. This CoC distinguishes itself as an Integration & Technology Validation institution, focusing on developing and testing integrated systems for the production, storage, and use of hydrogen fuel. It is strategically located at the South African Institute for Advanced Materials Chemistry, which is renowned for its research in materials chemistry, nanotechnology, and fuel cell technologies.

Finally, the HySA Catalysis CoC is a research and development entity co-hosted by the University of Cape Town and MINTEK in South Africa. This CoC has a predominant focus on scientific research related to fuel cell and fuel-processor catalysts, as well as catalytic devices. The primary objective of this CoC is to develop new catalyst materials and devices to improve the efficiency and performance of fuel cells and other hydrogen-based technologies.

Together, these three CoCs form a comprehensive network of research and development institutions dedicated to advancing the development and use of hydrogen in South Africa and beyond.

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4.4.5 Overview of the Green Hydrogen potential and Initiatives in Namibia

Namibia is aiming to become a green hydrogen key actor at global level also being able to attract foreign investment. As reported in their green hydrogen strategy, the government plans to use it extensively to decarbonize its own economy.

Namibia has a potential to offer low-cost green hydrogen production (second only to Chile) owing to its abundance of solar and wind resources, as well as taking advantage of large land availability and of a good electrification of the country.

It is thus facilitating the research and development in the field of green hydrogen technologies with aid from foreign institutes, with support from partner countries like Germany or the Netherlands.

The new Namibian green hydrogen strategy targets a production of 10-12 million tonnes per annum hydrogen equivalent by 2050 (thus higher than EU import needs).

McKinsey estimates that Namibia could be producing green hydrogen at US$1.5/kg by 2030.

Recently EU and Namibia strengthened their partnership on Renewable Energy and green hydrogen, also taking advantage of the fact that Namibia is currently among countries in the Africa-Europe Investment Package of the EU's Global Gateway strategy,

In 2023, EU and Namibia signed specific agreements where the EU promised to mobilise €1 billion of public and private investment for renewable hydrogen and raw materials infrastructure in Namibia. The German government has already agreed to invest €40m in Namibia's renewable hydrogen production and offer technical and financial support. State-backed firms in the Netherlands have also created a €1 billion sovereign wealth fund in partnership with the Namibian government for renewable hydrogen development in the country. While these commitments boost developer confidence, they should be redeemed in good time to unlock further financing from commercial banks and the private sector and to reduce the time lag on reaching final investment decisions to ensure long-term supply.

The development of a local green hydrogen market is critical to upskill the domestic workforce and maximize local employment, but considering the low inhabitants density of the country, the possibility to setup a local domestic market looks quite challenging for purposes different than industrial ones, look challenging, thus Namibia is mostly proposing itself as a potential producer and exporter of green hydrogen and derivatives to EU and to South Africa.

This is actually the driver of different initiatives currently on-going like:

a. HYPHEN Tsau Khaeb

Following a public tender to select a green hydrogen project developer, the Namibian government is entering into an agreement with Hyphen Hydrogen Energy for a B$9.4. The project is based in an area of ~4,000 km2 of land within the Tsau Khaeb National Park, near the coastal town of Luderitz and will ultimately produce around 300,000 tonnes of green hydrogen per year.

The project will start production in 2026 and the rights to the project has been granted to Hyphen for a 40-year period. The cost of green hydrogen produced in Namibia will be between $1.73-$2.30 per kg, with exports foreseen to start before 2025. The project is expected to create 15,000

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direct jobs during the first four years of construction and further 3,000 permanent jobs, with 90% being locals. The electrolyser capacity target for the Hyphen Tsau Khaeb project is 3 GW.

b. GREEN DAURES Village

The Daures Green Hydrogen Village is situated in the Daures Constituency, the largest constituency in Erongo Region, Namibia, with a population of around 11,350 inhabitants. The majority of the people in this area rely on communal subsistence farming for their livelihoods. The Daures Green Hydrogen Village is set to become Africa's first green hydrogen community. The village's primary objectives of sustainable green hydrogen and ammonia production, fostering local employment and partnerships, demonstrating green hydrogen applications, and enabling a green hydrogen economy will serve as a model for future developments across the region.

The government selected the Dâures Green Hydrogen Consortium, led by Enersense Energy Namibia, to carry out the pilot project, which was launched last year that first target a domestic dimension before scaling up towards international export.

This includes the Dâures Green Hydrogen Village comprising a production plant, community partnerships, green schemes and a fertiliser plant, based on an electrolyser of 0.25 MW. (Fig. 52) Afterwards the project will scale up to 840 MW targeting 2032. One of the key issues of the plant/location is the local yearly water needs, an aspect currently under investigation (estimation states that around 2,2 billion litres of water would be needed at maximum plant operability).

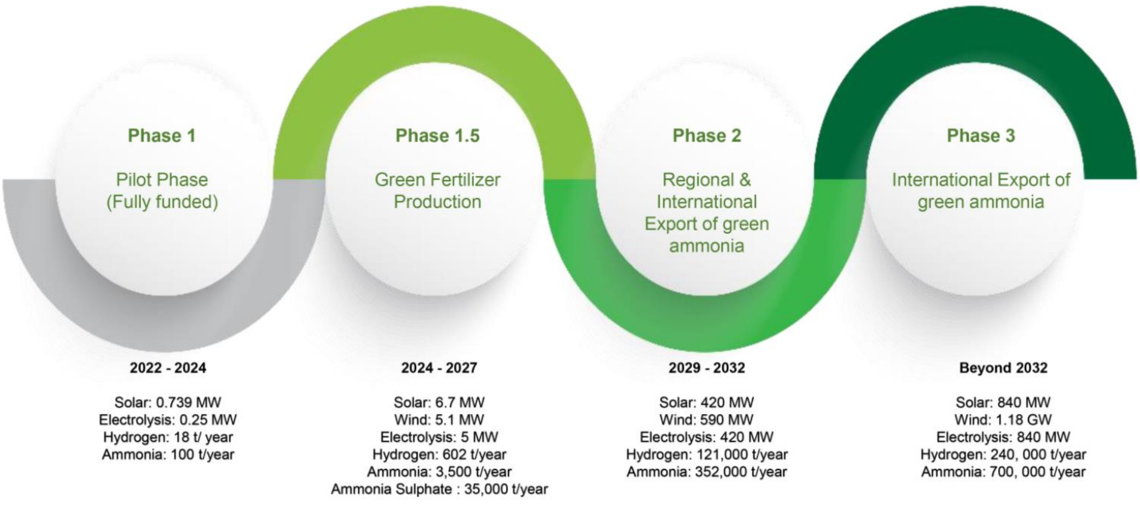

Figure 53: Green Daures Village phases

4.4.5 Overview of the Green Hydrogen potential and Initiatives in Mozambique

As a major exporter of green electricity within Southern Africa, Mozambique is theoretically well placed on the continent to capitalise on the energy transition by using its renewable power generation to create green hydrogen (particularly looking at current power surplus from Cahora Bassa hydropower plant to South Africa and Zimbabwe).

Its renewable generation capacity is set to massively increase when the Mphanda Nkuwa hydro plant, due for completion in 2030, comes online. The Mozambican government has expressed

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interest in the potential of producing green hydrogen, and last year sought to commission a feasibility study on hydrogen production at the new plant of Mphanda Nkuwa.

Nevertheless, due to the LCOE of this hydropower plant, LCOH of hydrogen thereby produced seems not to be so advantageous and, furthermore, as the plant is located in a quite difficult to be accessed area, neither local industrial off-takers nor potential export projects/plans, a local green hydrogen production and distribution value chain to be setup looks quite expensive.

Further to its abundance of hydropower, Mozambique could have the chance to develop its own green hydrogen plan also taking advantage of the existing LNG/O&G know-how and infrastructure available at local level where relevant EU O&G Players (e.g. ENI, ExxonMobil and TotalEnergies) are managing projects and activities.

Officials say Mozambique will be investing USD 80 billion in the hydrogen sector by 2050 and will finalise details this year of the scale of hydrogen production and main export markets.

The local government seems to have intercepted anyhow these opportunities and recently (2024) declared that Mozambique should develop soon its own hydrogen strategy also taking advantage of its relevant International partnerships with global energy players.

Maputo also acknowledges the need to develop appropriate infrastructure, including production facilities, storage, and transport networks, in collaboration with national and international partners. Establishing regional partnerships will allow “for a regional hydrogen economy, reducing the costs of developing hydrogen infrastructure and creating a broad market for hydrogen products and services,” officials say.

Existing resources and infrastructure will also get a boost under the plan with the addition of 3.5 GW of new hydroelectric capacity, achieved largely through modernisation of existing plants, and a boost to solar and wind energy through a renewable energy auction programme.

In parallel, up to 12 GW of PV production has been recently announced.

To absorb this increase in renewable energy generation, the plan also calls for the expansion and modernisation of the national grid.

Nevertheless, the Mozambique hydrogen strategy is currently at its infant stage.

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CONCLUSION

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CONCLUSIONS

This Deliverable "D1.2 Assessment of EU-AU green H2 potential interaction", developed within WP1 aims to present a quite detailed overview of the Green Hydrogen potential in the African continent and of the initiatives that are currently in place in the different African countries.

First of all an analysis of the green hydrogen potential of the continent via a multi-aspects assessment realized by UNIGE has been presented, showing:
- the relevance of socio-economic and grid/infrastructure aspects in defining the effective executive potential of African Countries;
- the relevance of currently not-exploited renewable power capacity in different African Countries which are currently not considered as potential green hydrogen players/actors or that did not attracted yet investors for new green hydrogen projects (also maybe for above mentioned National context issues)

Nevertheless it is worthy to highlight how this chapter 2 analysis underlines the importance of investing not only on new electrolysis projects, but also in enhancing local energy and civil infrastructure as well as in retrofitting and maintenance of renewable power generation plants (e.g. large and aged hydroelectric power plants in Angola, Ethiopia, Mozambique, Egypt, Kenya…) that could enable some first demonstration projects

Afterwards, complementing D1.1 results (where policies of EU-AU countries were deeply analysed) an analysis of the currently on-going projects in Africa country and a helicopter view of most relevant African green hydrogen initiatives currently on going has been presented also highlighting the three main area of interest for developing first green hydrogen projects according to the possibility to develop both domestic and export hydrogen projects (as reported in fig.10):
- Morocco/Mauritania Area
- Egypt
- Namibia/South Africa

Where thanks to the presence of relevant industrial sites as well as of energy, natural gas and port infrastructure both domestic/export initiatives could be more easily deployed.

In Chapter 4, a deep assessment (also via SWOT analysis and assessment of local driver and barriers) of green hydrogen potential and on-going activities in the four African continental sub-zones have been presented by project "local area responsibles" namely IRESEN (North Africa), STRATH (Central – Eastern Africa), JULICH (West Africa), NWU (South Africa). These analyses are presented in a detailed way often with "country per country" assessments also collecting relevant takeaways for the analysis about "Project Use Case" definition to be presented in D1.3.

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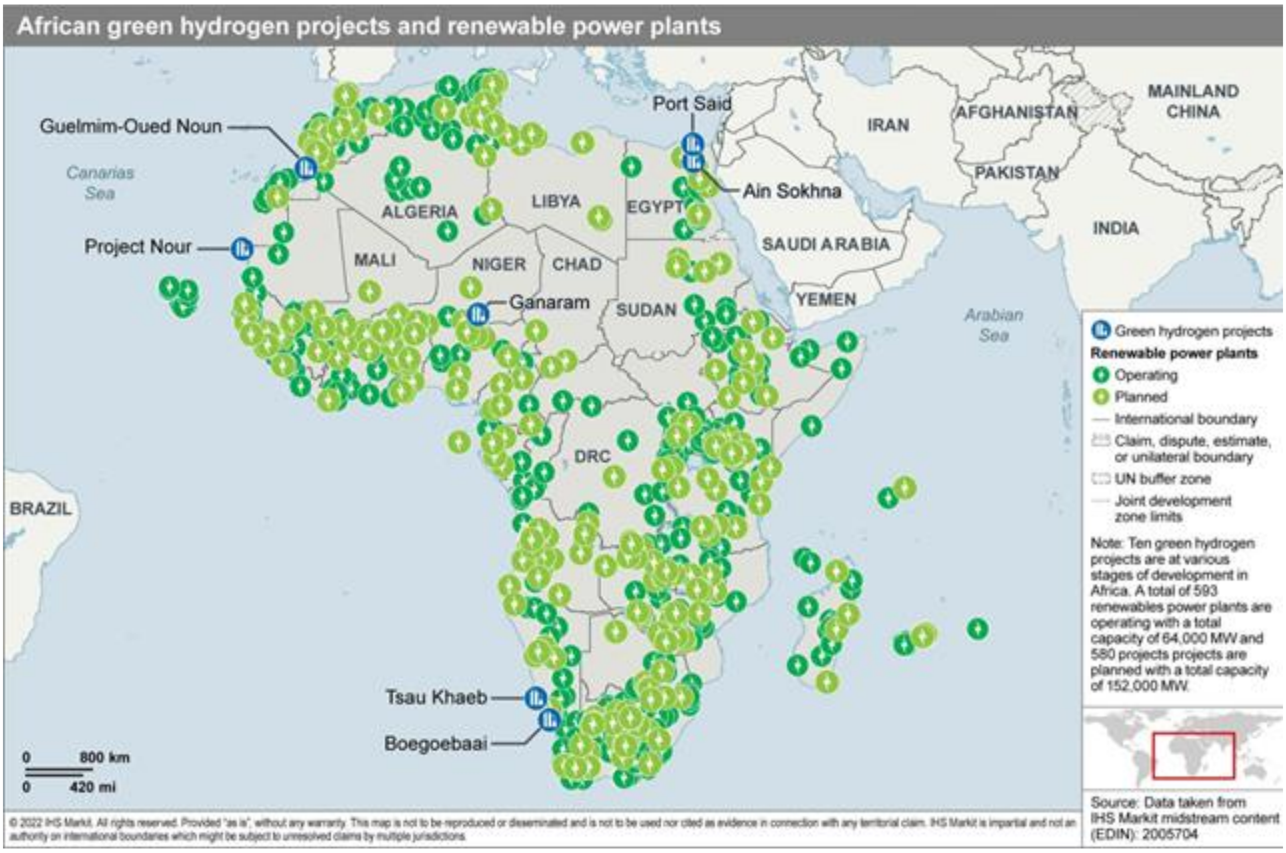

Figure 54: Currently planned and operating Renewable and green hydrogen power plants in Africa (2022)

Generally speaking some key takeaways can be extrapolated from this report (and as reported in fig. 54) and from the overall WP1 activities:

- Despite the huge renewable potential that more or less all African countries (in terms of land availability and natural resources (solar, wind etc.) availability) have, only few of them have a significant political commitment (via dedicated agendas and policies in place) to promote renewables and green hydrogen promotion
- Lots of initiatives currently under discussion and presented in this report (particularly those targeting hundreds of MW of electrolysis) are still at "infancy stage" as MoU or Expression of interest: only few projects are effectively under current deployment and most of them have or a political support (e.g. Daures Green Hydrogen Village in Namibia) or a strong investment support from Extra-African countries (e.g. CWP Global project in AMAN-AMUN (Mauritania-Morocco) and Djibouti areas), usually producing hydrogen for products manufacturing process decarbonization (particularly for products dedicated to extra Africa or driven by companies which are partially nationalized).
- All these initiatives are somehow "biased" by the predominance of project developers as well as of financing institutions that tend to "shout loud" project intentions and ideas more than practically start to develop local real green hydrogen value chains. One of the goal of this report and of WP1 project activities is therefore also to "put order" in the large amount of announcements and "projects in pipeline" already announced.

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- All these initiatives seem to rely on new Renewable Power Capacity and not on valorisation of the existing ones (except for some projects related to Kenya and Ethiopia/Egypt)
- All announced initiatives are not considering to support the creation of a local hydrogen demand and market and most of projects targets electrolysis
- Generally speaking, looking at a strategic promotion of green hydrogen (and derivatives) projects around the continent:
  a) North Africa could be considered as target for projects dedicated to Export to EU (exploiting existing ports/vessels routes but mostly exploiting Natural Gas Infrastructure) and to the use of hydrogen in refineries and hard-to-abate industries available at local level
  b) East Africa could be considered as target for projects dedicated to production of green fertilizers, hydrogen for the domestic market as well as for export to Asian markets
  c) South Africa could be considered as target for projects dedicated to production of green "products" (steel, metals, cement, fertilizers…) and to hydrogen and carriers to be shipped to Europe/Asia/America mostly by vessels
  d) Western Africa could be considered as target for projects dedicated to production of green hydrogen for local refineries, local domestic market and potential transfer (via vessel or road transport) to Northern Africa for its export to EU.
- Despite different projects foresees involvement of EU and AU actors, only in few of these projects the "JUST" approach proposed by JUST GREEN AFRH2ICA is foreseen or promoted, with no interest in developing joint financing instruments nor knowledge sharing and capacity building programmes also to facilitate the setup of an African value chain and skilled workforce on FCH technologies.

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