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Topic:

Demand-driven analysis for the potential green hydrogen market in Africa

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DEDICATION

Always grateful.

I dedicate this to those who supported and continue supporting.

To all people looking for an opportunity to make end meets and cannot afford it for many reasons.

To my family and friends.

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ABSTRACT

Global hydrogen demand reached 95 million tonnes (Mt) in 2023, with the chemical industry consuming 66% of the total hydrogen production annually. Africa consumes nearly 3 million tonnes of hydrogen annually, with 70% used in the chemical industry for nitrogen fertilizers. Most of the hydrogen production is based on fossil fuels, with 96% from natural gas, oil, and coal. This production contributes to 630 million tonnes of direct CO_2 emissions, threatening the environment and requiring new alternatives. Green hydrogen is considered a critical energy alternative and a vital pillar in the energy transition. Building a green hydrogen value chain requires international partnerships, economic and trade relations, political ties, and investments due to the unbalanced renewable energy and technical potential of hydrogen production. Africa is at the core of geopolitical attention due to its large renewable energy potential for the green hydrogen economy, with a theoretical capacity of approximately 900 million tonnes per annum of hydrogen. Nevertheless, more than 90% of African green hydrogen projects are focused on exports. A few roadmaps developed and announced projects targeted the African domestic market. Therefore, this study aims to identify potential market opportunities for green hydrogen in Africa to support the domestic market in decarbonization and sustainable development. A qualitative, quantitative, and comparative analysis was conducted from a bibliographic research method and a survey. The results presented that the global hydrogen project proposals worldwide increased from 359 in 2021 to 1046 in 2023, Africa counting around 52 project proposals focused on exports, with the remainder targeting domestic demand within the transport, chemical, and fertilizer sectors. The demand for hydrogen in Africa is expected to reach 20 Mt by 2050. There is an increase in hydrogen demand. And, because Africa has one of the highest and fastest-growing populations and economic growth in the world. It both will demand energy and be able to supply it. However, currently, there are only six of the many African countries that are developing green hydrogen roadmaps. Therefore, sectors such as **fertilizer**, **power generation, transport, and mobility** are some of the most expected hydrogen applications to unlock the hydrogen market in Africa, in particular West Africa. Building a green hydrogen economy in Africa requires a clear and sustainable policy that secures hydrogen development and implementation. This study recommended three policy pathways to unlock the green hydrogen market in Africa particularly West Africa: (i) Formulate a Regulatory and institutional framework; (ii) Build strategic partnerships; and (iii) Foster regional policy market integration.

Keywords: Green hydrogen, demand, green hydrogen market, Africa.

RESUMÉ

La demande mondiale d'hydrogène a atteint 95 millions de tonnes en 2023, l'industrie chimique consommant 66% de la production totale d'hydrogène chaque année. L'Afrique consomme près de 3 Mt d'hydrogène par an, dont 70% sont utilisés dans l'industrie chimique pour les engrais azotés. La majeure partie de la production d'hydrogène est basée sur les combustibles fossiles, avec 96% du gaz naturel, du pétrole et du charbon. Cette production contribue à 630 millions de tonnes d'émissions directes de CO_2, menaçant l'environnement et nécessitant de nouvelles alternatives. L'hydrogène vert est considéré comme une alternative énergétique essentielle et un pilier essentiel de la transition énergétique. La construction d'une chaîne de valeur de l'hydrogène vert nécessite des partenariats internationaux, des relations économiques et commerciales, des liens politiques et des investissements en raison du déséquilibre entre les énergies renouvelables et le potentiel technique de la production d'hydrogène. L'Afrique est au cœur de l'attention géopolitique en raison de son important potentiel d'énergie renouvelable pour l'économie de l'hydrogène vert, avec une capacité théorique d'environ 900 millions de tonnes par an d'hydrogène. Néanmoins, plus de 90% des projets africains d'hydrogène vert sont axés sur l'exportation. Quelques feuilles de route élaborées et annoncées ciblaient le marché intérieur africain. Par conséquent, cette étude vise à identifier les opportunités de marché potentielles pour l'hydrogène vert en Afrique afin de soutenir le marché intérieur en matière de décarbonisation et de développement durable. Une analyse qualitative, quantitative et comparative a été réalisée à partir d'une méthode de recherche bibliographique et d'une enquête. Par conséquent, les résultats ont montré que les propositions mondiales de projets d'hydrogène dans le monde sont passées de 359 en 2021 à 1046 en 2023, l'Afrique comptant environ 52 propositions de projets axées sur les exportations, le reste ciblant la demande intérieure dans les secteurs des transports, des produits chimiques et des engrais. La demande d'hydrogène en Afrique devrait atteindre 20 Mt d'ici 2050. Il y a une augmentation de la demande d'hydrogène. Et parce que l'Afrique est l'une des populations et de la croissance économique les plus élevées et les plus rapides au monde. Il aura à la fois besoin d'Energie et sera en mesure de le fournir. Cependant, à l'heure actuelle, seuls six des nombreux pays africains élaborent des feuilles de route pour l'hydrogène vert. Par conséquent, des secteurs tels que les engrais, la production d'électricité, les transports et la mobilité sont l'une des applications de l'hydrogène les plus attendues pour débloquer le marché de l'hydrogène en Afrique, en particulier en Afrique de l'Ouest. La construction d'une économie verte de l'hydrogène en Afrique nécessite une politique claire et durable qui garantisse le développement et la mise en œuvre de l'hydrogène. Cette étude a recommandé trois voies politiques pour débloquer le marché de l'hydrogène vert en Afrique, en particulier en Afrique de l'Ouest : (i) Formulation d'un cadre réglementaire et institutionnel ; ii) Établissement de partenariats stratégiques ; et iii) favoriser l'intégration des marchés de la politique régionale.

Mots-clés : Hydrogène vert, demande, marché d'hydrogène vert, Afrique.

RESUMO

A demanda global de hidrogênio atingiu 95 milhões de toneladas em 2023, com a indústria química consumindo 66% da produção total de hidrogênio anualmente. A África consome cerca de 3 milhões de toneladas de hidrogênio anualmente, com 70% usado na indústria química para fertilizantes nitrogenados. A maior parte da produção de hidrogênio é baseada em combustíveis fósseis, com 96% de gás natural, petróleo e carvão. Esta produção contribui para 630 milhões de toneladas de emissões diretas de CO_2, ameaçando o ambiente e exigindo novas alternativas. O hidrogénio verde é considerado uma alternativa energética crítica e um pilar vital na transição energética. A construção de uma cadeia de valor de hidrogénio verde requer parcerias internacionais, relações económicas e comerciais, laços políticos e investimentos devido ao desequilíbrio das energias renováveis e do potencial técnico da produção de hidrogénio. África está no centro da atenção geopolítica devido ao seu grande potencial de energia renovável para a economia do hidrogénio verde, com uma capacidade teórica de aproximadamente 900 milhões de toneladas por ano de hidrogénio. No entanto, mais de 90% dos projetos africanos de hidrogénio verde identificados neste trabalho estão focados nas exportações. Algumas políticas de hidrogenio desenvolvidas e anunciadas visam o mercado interno africano. Portanto, este estudo visa identificar potenciais oportunidades de mercado para hidrogênio verde na África para apoiar o mercado interno em descarbonização e desenvolvimento sustentável. Foi realizada uma análise qualitativa, quantitativa e comparativa a partir de um método de pesquisa bibliográfica e de um inquérito. Portanto, os resultados indicam que as propostas globais de projetos de hidrogênio verde em todo o mundo aumentaram de 359 em 2021 para 1046 em 2023, África contando com cerca de 52 propostas de projetos focados em exportações, com o restante visando a demanda interna nos setores de transporte, química e fertilizantes. A demanda por hidrogênio na África deve chegar a 20 Mt até 2050. Verifica-se um aumento da procura de hidrogénio. E porque África é uma das populações e um crescimento económico mais rápido do mundo. Consequentemente, irá demandar energia e a Africa será capaz de o fornecer. No entanto, atualmente, apenas seis dos muitos países africanos estão a desenvolver políticas e estratégias para o hidrogénio verde. Setores como **fertilizantes**, produção de electricidade, transporte e mobilidade são uma das aplicações de hidrogênio mais esperadas para desbloquear o mercado de hidrogênio verde na África, em particular na África Ocidental. A construção de uma economia verde do hidrogénio em África exige uma política clara e sustentável que assegure o desenvolvimento e a implementação do hidrogénio. Este estudo recomendou três vias políticas para desbloquear o mercado do hidrogénio verde em África, em particular na África Ocidental: (i) Formulação de um quadro regulamentar e institucional; (ii) Construção de parcerias estratégicas; e iii) promover a integração do mercado no âmbito da política regional.

Palavras-chave: Hidrogénio verde, demanda, mercado de hidrogénio verde, África.

ACRONYMS AND ABBREVIATIONS

AFREC- The African Energy Commission

AGHA- African Green Hydrogen Alliance

BF-BOF- Blast Furnace-Basic Oxygen Furnace

BP- British Petroleum

CCUS- Carbon Capture Use and Storage

DRI-EAF- Direct Reduction of Iron- Electric Arc Furnace

ECREEE: ECOWAS Center for Renewable Energy and Energy Efficiency

EU- European Union

GH2- Green Hydrogen Organization

GIZ- German Agency for International Cooperation GmbH

H2- Hydrogen

IEA: International Energy Agency

iH2- Ivoire Hydrogen

IRENA- International Renewable Energy Agency

MMEN- Ministry of Mine and Energy Namibia

Mt- Mega Tonnes

mtpa- Million Metric Tonnes per Annum

OECD- Organisation for Economic Co-operation and Development

PWC- PricewaterhouseCoopers

RES4AFRICA- Renewable Energy Solutions for Africa

SAS- Sustainable Africa Scenario

RMI- Rocky Mountain Institute

WASCAL: West African Science Service Center on Climate Change and Adapted Land Use

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GENERAL INTRODUCTION

1. INTRODUCTION

1.1. GENERAL CONTEXT

Hydrogen presents a wide range of applications and opportunities for usage across the entire energy system or industry. It can be used as a feedstock mostly for chemicals (e.g., petroleum refining, ammonia, and methanol) and large-scale industrial uses, such as the manufacturing of fertilizer. It is used as a source of energy (Tractebel E. GmbH, 2022) mainly for new emerging and evolving applications (e.g., seasonal storage, power generation, transport and mobility, and buildings (Hydrogen Council, 2021).

The global hydrogen demand is potentially high, mostly in refineries and industries. The demand for hydrogen in 2020 reached 87.1 million tonnes (Mt) (IRENA, 2022). The chemical industry for ammonia, methanol, and oil refining consumes approximately 66% of the total hydrogen (H_2) production annually (Norouzi, N., & Fani, M., 2021). Nearly all of today's global hydrogen production 96% is based on fossil fuels through the steam methane reforming (SMR) process or gasification of coal, of which are natural gas (48%), oil (30%), and coal (18%) (Xu L. et al. 2019). Hence, the estimated future global hydrogen demand is expected to reach more than 365 mega tonnes of hydrogen per year (MtH2/year) for the year 2050, based on the reference scenario developed by (Heuser P.M. et al., 2020) in their research work on the worldwide hydrogen provision.

Thus, hydrogen production fossil-based (mainly grey) constitutes an intensive-carbon emission leading to 630 Mt of direct CO_2 emissions on a net basis, or 7% of industrial CO_2 emissions in 2021 (IEA, 2022). While, in 2023 the 95 Mt global hydrogen-equivalent fossil fuels-based generated more than 1 Gt of annual CO2 emissions—2.5% of global annual emissions, on par with the entire aviation sector (Deloitte, 2023). These emissions enhance the greenhouse effect causing global warming and climate change. Hence, in order to mitigate the greenhouse gas emissions, it is worth to find out other alternatives to decarbonize the energy sector targeted in 2050. These alternatives include low-carbon hydrogen production pathways, such as renewable energy-based electrolysis (**green hydrogen**) and carbon capture use and storage (CCUS) technology (**blue hydrogen**).

Green hydrogen is identified as the most critical and indispensable energy alternative (Xu L., et al. 2019), as well as a solution for some hard-to-abate sectors (IRENA, 2022), and as a vital pillar in energy transition, alongside renewable energy, renewable-based electrification, and energy efficiency (IRENA and RMI, 2023). In this case, building up a green hydrogen value chain required international partnership and cooperation, economic and trade relation, political ties, and investments due to the unbalanced renewable energy potential and technical potential of hydrogen production worldwide bringing geoeconomic and geopolitical shifts (IRENA, 2022).

Thus, governments are forming bilateral deals and conversations to facilitate cross-border hydrogen trade. This partnership ranges from feasibility studies to project pilots and demonstrations, memorandums of understanding, and energy partnerships. For example, to mention the partnership between Germany and Morocco, Namibia, among other African countries (IRENA, 2022).

Indeed, Africa is becoming at the core of geopolitical attention due to its blessed renewable energy potential for the green hydrogen economy (EU, 2022), which offers a theoretical potential capacity of approximately 850 terawatts (TW) of solar and wind. If only 2% of this, or 17 terawatts (TW) of renewables, were used for green hydrogen production it would produce about 900 million metric tonnes per annum (mtpa) of hydrogen, equal to about 1.5 times the total global demand of 610 million metric tonnes per annum (mtpa) in 2050 (Masdar, 2022). And this potential is seen as low-cost competitive (Masdar, 2022; IRENA, 2022; Beaucamp L. and Nforngwa E. 2022; GH2, 2022) for a hydrogen economy future export and domestic market-making Africa a potential supplier of hydrogen to the EU's countries and other world's regions. Additionally, the market for energy services in Africa has a lot of reasons to increase (IEA, 2022), and that could lead to high hydrogen demand. Heuser et al., (2020) predicted 28 million tonnes (Mt) of hydrogen demand in Africa by 2050.

As a result, green hydrogen initiatives and projects around the world are increasingly growing. Hydrogen Insights (2023) reported on the state of the global hydrogen economy that the global hydrogen project proposals worldwide increased from 359 in 2021 to 1046 in 2023. Of the total, 795 aim to be fully or partially commissioned through 2030 and represent total investments of USD 320 billion in direct investments into hydrogen value chains through 2030 (up from USD 240 billion). Based on the IEA (2022) hydrogen projects database, Africa counted around 52 project proposals, and IRENA (2022) described four large-scale green hydrogen projects in Egypt, Zimbabwe, Mauritania, and Namibia, west Africa accounting for three projects, Ivory Coast hydrogen projects, Niger (iH2 CAP2023, 2021) and Ghana (The article).

Unlocking the green hydrogen market required a sustainable energy policy and strategy (Jefferson M., 2015) and effective governance, and a successful certification system (IRENA and RMI, 2023). However, in 2023 The IEA Policies database (last accessed 15/07/2023) computed 110 green hydrogen policies, national strategies, and roadmaps worldwide. There are a few African countries that developed green hydrogen policies, national strategies, roadmaps, and baseline studies for green hydrogen implementation, such as Morocco (RES4AFRICA and PWC, 2022), South Africa (Science & Innovation, 2021), Kenya (Tractebel Engineering GmbH, 2022), Namibia (MMEN, 2022), Algeria (TRACTEBEL, 2021; GIZ GmbH, 2021). While, in west Africa, recently ECREEE (2023) gathered together a broad spectrum of stakeholders from government representatives, the private sector, and international organizations to validate the methodology for developing the strategy and action plan, as well as the mechanisms for validating the study and its implementation schedule for west African region.

Despite the growing interest in green hydrogen projects in Africa, including West Africa, the majority of reviewed project proposals, studies baseline, policies, hydrogen national strategies, and roadmaps that exist are focused on export rather than the local market. Indeed, Masdar (2022) outlines that, more than 90% of projects are focused on exports (mainly ammonia), with the remainder targeting domestic demand within the transport, chemical, and fertilizer sectors. For that reason, this study figured out to understand that gaps to fill to enable exposing potential market opportunities in Africa and leveraging the policy recommendation roadmap for the green hydrogen local market.

1.2. STRUCTURE OF THE THESIS

(1) **General Introduction** gives a general overview of state of art of hydrogen applications and demand, green hydrogen future perspective, and justification of the study, it displays the problem statement, the research question, and the objectives and the scope)

(2) **Chapter I** constitutes the literature review (Hydrogen applications and demand in the world and Africa; Green hydrogen applications and future perspective; Green hydrogen policy and projects, and the Research gap)

(3) **Chapter II** illustrates data collection and research methods used and the technology maturity;

(4) **Chapter III** presents the result, key findings, and discussion; and policy recommendation;

(5) **Conclusion and Perspectives.**

1.3. PROBLEM STATEMENT AND MOTIVATION

Despite African's great renewable energy potential and capacity for green hydrogen production, there is a few studies tailored to Africa local market. Indeed, the majority of hydrogen projects and initiatives including research studies, focuses on the export of the green hydrogen. Therefore, this master thesis seeks to investigate the green hydrogen potential market opportunity in Africa and explore the possible pathways for hydrogen economy development in the continent.

1.4. RESEARCH QUESTIONS

- Where do hydrogen applications make the most sense in Africa from an African perspective?
- What is the status quo of the hydrogen (mainly grey) applications and demand, technology pathways?
- What is the state of the art of green hydrogen applications and demand, technology pathways and maturity, and future perspective?
- Which of the energy-related economic activities that green hydrogen could play a key role in the African case in terms of volume and time frame?
- What are potential scenarios and forecasting developed to meet the hydrogen domestic market?
- What is the green hydrogen policy that supports the hydrogen market?
- What policy recommendations can drive the hydrogen market in Africa?

1.5. RESEARCH OBJECTIVES

- **General objective**

Identify and explore potential market opportunities for the green hydrogen market in Africa.

- **Specific objectives**

1) Analyse and evaluate the industrial and technological pathways applications of hydrogen in different economic sectors;
2) Analyse and evaluate the current green hydrogen policy and initiatives;
3) Develop an expert survey to collect African perspectives and define the geographical scope of the study;

4) Identifying the key economic sectors that green hydrogen could play a role in the African case;
5) Compare demand-driven scenarios developed from a global view and the African view;
6) Leverage measures for green hydrogen policy and strategy formulation in Africa.

1.6. RESEARCH SCOPE

This study is limited to hydrogen applications, technology maturity, policy, and expert views perspective. It does not take into account economic stakes.

CHAPTER I: LITERATURE REVIEW

2. Introduction

This section gives an overview of the state of the art on the master's thesis topic. It reviews published works on the topic to understand the current knowledge, allowing to identify gaps. It provides a broader context of hydrogen applications, use, demand, and the future perspective of green hydrogen globally and in particular the African case.

2.1. Hydrogen Applications, Use, And Demand

2.1.1. Global overview

Hydrogen is primarily used as a feedstock or catalyst in various industrial technological pathways, making hydrogen a key player in the transformation of industry. The current hydrogen production can be divided into three segments (IRENA, 2022; Connelly E. et al., 2019).

I. "**Merchant**" hydrogen—hydrogen generated on-site or in a central production facility and sold to a consumer;

II. "**Captive**" hydrogen—hydrogen produced by the consumer for internal use;

III. "**By-product**" hydrogen—hydrogen that is recovered from by-product process streams and can be consumed by the same company (as with captive) or sold to another company (as with merchant).

The hydrogen demand and use in the industry vary from one sector to another sector. Three industrial sectors make up the majority of uses for hydrogen production, such as oil refineries, ammonia production, and methanol production (**see Figure 1.**) (IRENA, 2022; IEA, 2022; Tractebel Engineering, 2022; Clean Hydrogen, 2022). However, with a new need to lower carbon emissions, hydrogen is increasingly being considered in other new emerging applications, including iron and steelmaking, light industries, transport and mobility, mining and quarrying, and buildings (IEA, 2022; Tractebel Engineering, 2022; Clean Hydrogen, 2022; Connelly E. et al., 2019) with a negligible amount in the current shares of consumption compared to the three aforementioned sectors. The global demand for hydrogen in 2020 reached 87.1 Mt (IRENA, 2022) and more than 94 Mt in 2021 (IEA, 2022), mainly grey worldwide, produced from natural gas and coal through gas-based steam reforming and gasification processes respectively (IRENA, 2022; IEA, 2022; Tractebel Engineering, 2022; Clean Hydrogen, 2022).

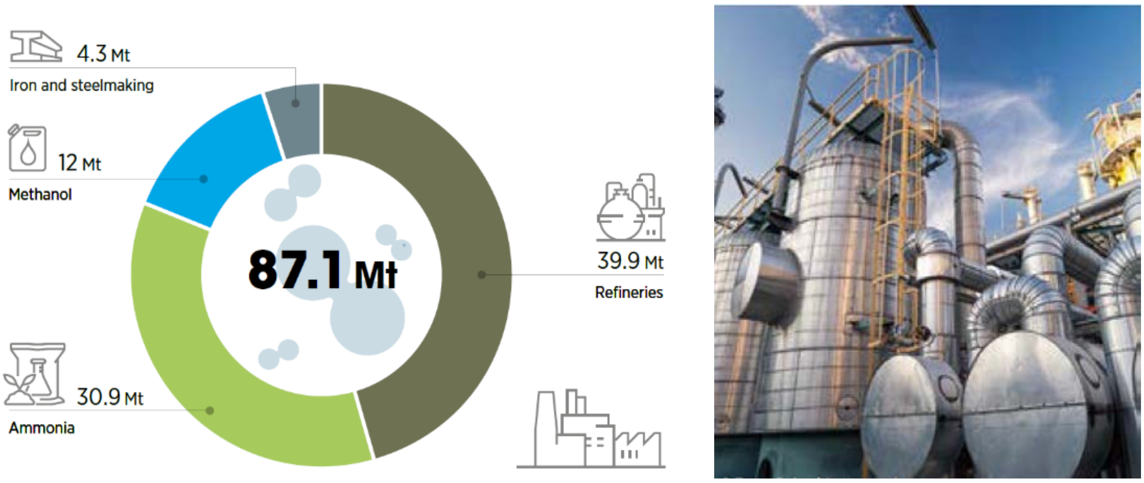


Figure 1. Pure hydrogen demand in industry, global, 2020

Source: IRENA (2022)

2.1.1.1. Hydrogen in oil refineries

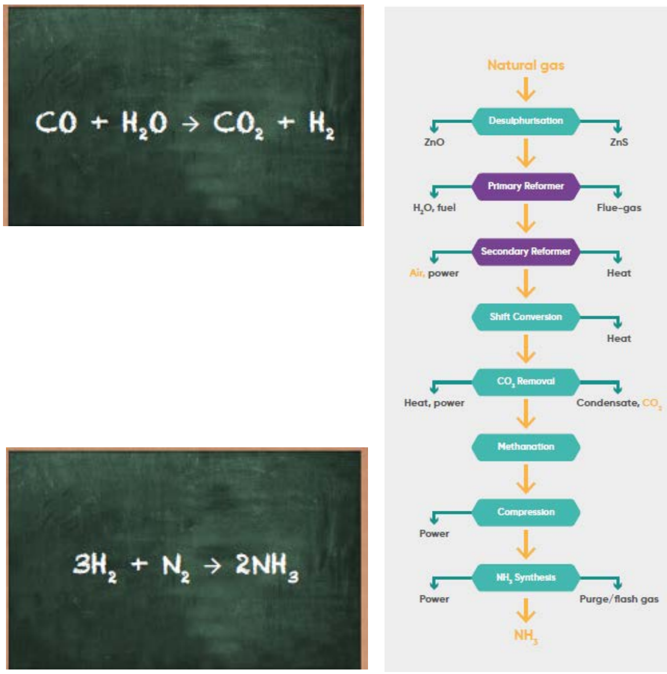
In oil refineries, hydrogen is used mainly in two technological processes: hydrocracking and hydrotreating. The hydrocracking process is used for converting heavy and low-quality gas oil into more valuable fuels, upgrading heavy oil fractions into lighter products, and Hydrotreating is used for removing impurities, especially sulfur, and other contaminants (IRENA, 2022; IEA, 2022; IEA, 2019). Hydrogen used for oil refineries represents almost 40 Mt in 2020, representing the highest rate of hydrogen consumption and counting around 15% of the total CO2 emissions of a refinery in the United States and Europe (IRENA, 2022). Meanwhile, this trend is expected to decrease in 2050, according to IRENA's 1.5 °C Scenario, due to the replacement of fossil fuels in the global economy.

2.1.1.2. Hydrogen in the chemical industry

In the chemical industry, hydrogen is used as feedstock for chemical products such as ammonia, methanol, and other chemicals. In this session, we focused on ammonia and methanol about their level of hydrogen demand.

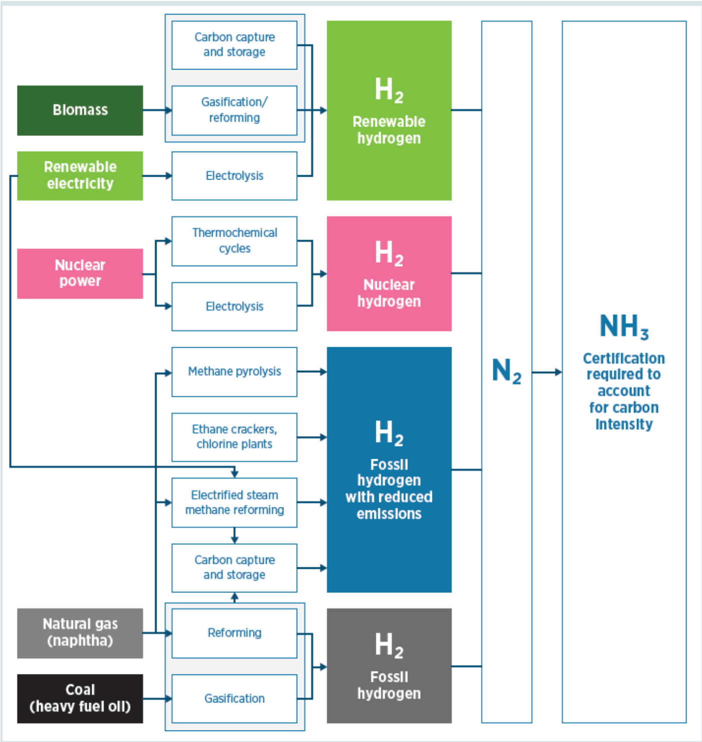
(i) Ammonia

The need for hydrogen for ammonia production represents the second largest global hydrogen demand, it consists of the main use of hydrogen in the industry (IEA, 2022), and it is the second most widely produced chemical commodity by volume, the global production of ammonia in 2020 was more than 183 Mt, of which 85% is for fertilizers manufacturing (IRENA, 2022). Ammonia is produced from hydrogen and nitrogen. The current production of ammonia mainly relies on fossil fuels, which are 70% via gas-based steam reforming technology, and most of the remaining via coal gasification (IRENA, 2022; IEA, 2022). In addition, there are also other technology hydrogen production pathways, the use of various sources of energy (see **Figure 2b**) for hydrogen production as a feedstock for ammonia production, such as low carbon emission technologies, electrolysis, and carbon capture storage and use (IRENA and AEA 2022). The technology and production process are described in (Cantalloube B.B. et al., 2023; IRENA and AEA 2022), (see **Figure 2a**). However, gas-based steam reforming and coal gasification technology pathways are the main energy sources for ammonia production. Ammonia plays a crucial role in the global agricultural systems making a great contribution to global food security through its use for mineral nitrogen fertilizers. Despite its importance in the global food chain and manufacturing, ammonia is emission-intensive (IRENA, 2022; IEA, 2022; IEA, 2021; Cantalloube B.B. et al., 2023).



a) Ammonia production process with hydrogen production through SMR

Source : Cantalloube et al. (2023).



b) Production of ammonia from various feedstocks.

Source: IRENA and AEA (2022).

Figure 2. Ammonia production process and technology pathways

(ii) Methanol

The demand for hydrogen for methanol production in the chemical industry is the third-largest global hydrogen application and the second-largest industrial hydrogen application (IEA, 2022; IEA, 2021). Methanol is mainly used to synthesize heavier alcohols, gasoline, and many other complexes accounting for more than 60% of global methanol production in 2019, and, it is used as an alternative to conventional transport fuels (IRENA, 2022; IEA, 2022). The global production reached 98 Mt in 2019 (IRENA, 2022). The methanol production process mainly relies on steam reforming and coal gasification, with 65 % from natural gas, 35 % from coal, and less than 1 % from biomass or renewables (Tammy Klein, 2020). Steam reforming and coal gasification process can be found in detail in (Tammy Klein, 2020, IRENA AND METHANOL INSTITUTE, 2021). Methanol is a very flexible chemical commodity and energy source due to its wide array of feedstock **(see Figure 3)** including biomass, renewable energy sources through electrolysis, and the use of carbon capture storage and use technologies, which are increasingly gaining space in the market (Tammy Klein, 2020, IRENA AND METHANOL INSTITUTE, 2021). Methanol is used as a synthetic to produce other chemicals derivative for a wide range of applications, such as transport and mobility, pharma, manufacturing, and construction (IRENA, 2022; IEA, 2022, IRENA AND METHANOL INSTITUTE, 2021).

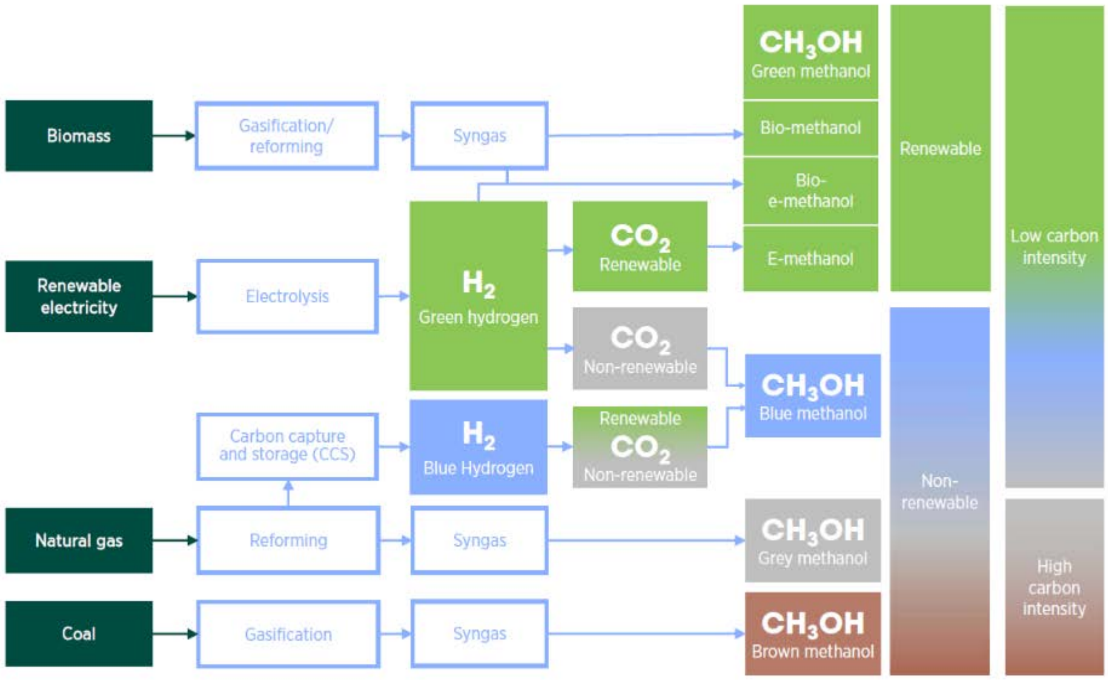
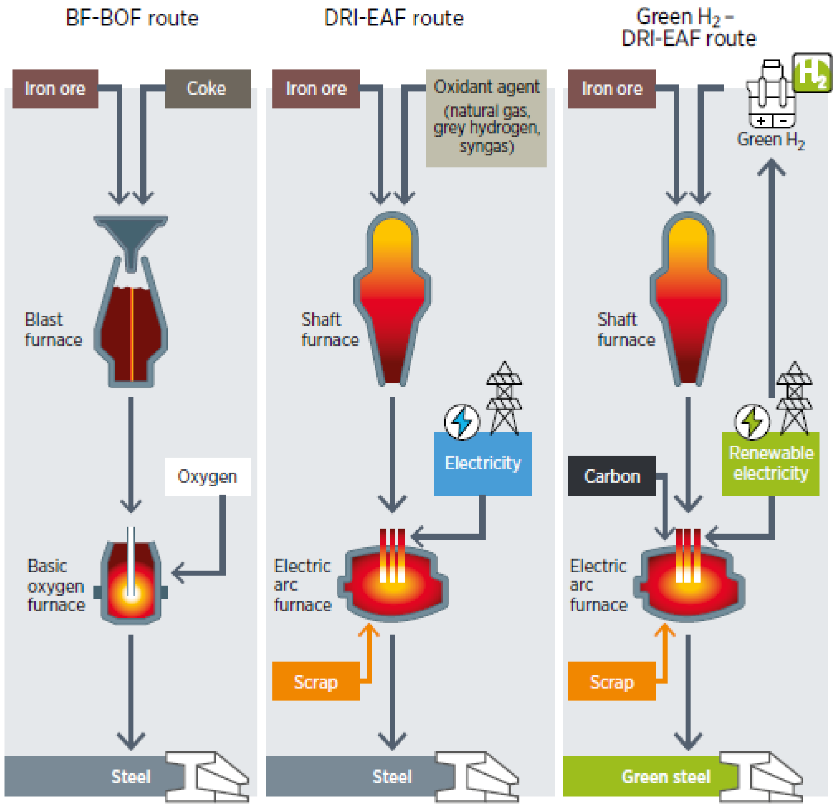


Figure 3. Principal methanol production routes

Source: IRENA and METHANOL INSTITUTE (2021)

2.1.1.3. **Hydrogen in iron and steelmaking**

Apart from the production of ammonia and methanol part of hydrogen in the industries is used for steelmaking particularly in a variety of heating applications, for example, the production of direct reduction of iron (DRI), which is seen as an alternative to replace coke. Accounting for 5 Mt of hydrogen in today's demand (IEA, 2022). DRI is the group of processes for making iron from iron ore, using syngas (IRENA, 2022), hence hydrogen is a component of the syngas, which together with carbon monoxide reduces iron ore to sponge iron (IEA, 2021). Therefore, the iron and steelmaking sector is highly energy and emission-intensive, due to its reliance on natural gas and coal, however, green hydrogen is expected to play an important role in the process of direct reduction iron electric arc furnace (DRI-EAF) (IEA, 2020). In the figure below, are the main steel production pathways.



Notes: BF-BOF= Blast Furnace-Basic Oxygen Furnace

Figure 4. Steel production pathways

Source: IRENA (2022)

Other global hydrogen industrial uses are less than 1 % of the global hydrogen demand (IEA, 2020), manufacturing, and the food industry (Sturm H., 2017). Nevertheless, hydrogen applications in new emerging economic sectors are increasingly growing, such as transport and mobility, buildings, etc. Therefore, in the context of the energy transition, these new applications required clean technological pathways for hydrogen production such as green and blue hydrogen.

2.1.2. Overview of hydrogen application and demand in Africa

Data about current hydrogen applications in different energy economic-related sectors and demand in the African continent is more challenging to identify. The majority of the evaluated studies from the African perspective, including reports and papers put a strong emphasis on using hydrogen from low-carbon production sources from a hydrogen demand projections point of view, which is partially in line with the corresponding national strategies, green hydrogen initiatives, and hydrogen and derivatives strategies as also outlined by (World Energy Council, 2021).

Nevertheless, grey hydrogen is produced by several nations, most notably South Africa and Morocco, and is used in the mining and fertilizer industries (NGAM, 2023). The IEA Report 2021, “The Global hydrogen review” reveals that Africa presently produces all of its hydrogen using fossil fuels, including the part used to make nitrogen fertilizers. Nearly 3 Mt of hydrogen is consumed annually, of which 70% is utilized in the chemical industry, primarily to make nitrogen fertilizers, which increase agricultural yields and restore soil nutrients, and are thus an essential part of food security on the continent (IEA, 2021). While The IEA Africa Energy Outlook in the Sustainable Africa Scenario points out that the total hydrogen production will increase from nearly 3 Mt today (2022) (all of it based on unabated fossil fuels) to more than 5 Mt by 2030 (15% of which is low-carbon from electrolyzers or fossil fuel plants fitted with carbon capture) and to 20 Mt by 2050 (80% low-carbon) (IEA p.100, 2022). Nevertheless, the IRENA (2022) report on the Geopolitics of the Energy Transformation stated that the Hydrogen consumption in 2020 in Egypt was 1.4 Mt, this value was derived mainly from the production of ammonia, methanol, refining, and direct reduced iron for steel.

Africa is continent rich in natural diversity and holds resources such as Oil and Gas. Africa’s major oil-reserved countries, including Libya, Nigeria, Algeria, Angola, Egypt, and South Africa, and Egypt are home to many of the world’s oil refinery plants due to the large quantity export of crude oil as described and shown by (Silva R. and Paixão R.; AFREC, 2022; AFREC, 2019). African refineries can only refine 3,3 million barrels per day despite a need for 4,1 million barrels per day (AFREC, 2022), making the local refining output far too low (Silva R. and Paixão R.). Countries such as South Africa, Nigeria, Egypt, and Algeria are Africa's top refining hubs, and many other African countries have built refineries in the last decades (Mbendi, 2018). The high demand for hydrogen in the refineries sectors globally, and newly discovered and proved oil and gas reserves in Africa (see BP, 2021) the high and fastest growing population and economic growth (IEA, 2022 p.57; Mukelabai et al., 2022), as aforementioned previously, justify the expectation of building new refineries to meet the local demand. Indeed, Africa has seen significant economic progress, in this century, which is accompanied by a rise in the need for energy services (IRENA, 2015). The continent's rapid population growth (estimated to reach 2.5 billion in 2050) and economic expansion (+2.2 to +3.1 percent annually, despite a decline of 2.1 percent in 2020 due to COVID-19) will increase energy consumption and emissions, which could account for 5 to 20 percent of global emissions in 2050 (Mukelabai et al., 2022). Additionally, the IEA report (2022 p.63-64), "Africa Energy Outlook" in the Sustainable Africa Scenario (SAS), 2020-2030 recognized that the market for energy services in Africa has a lot of reasons to increase. The potential for rapid expansion in both population and income is especially true to lead to high energy demand in various economic-related sectors, such as transportation, industry products, and cooling in homes and commercial buildings. On the strength of expanding construction and expanded industrial production, it is predicted that Africa's energy demand for industrial products will increase by at least a third between 2020 and 2030 (**see Figure 5**). In addition, the work of (Heuser et al., 2020) predicted the provision of hydrogen demand in Africa in the reference scenario by 2050 to reach 28.1 Mt. In conclusion, despite the current low hydrogen application in the continent, hydrogen future applications present an opportunity for Africa to not only decarbonize its energy use and enable clean energy access for all but also to export renewable energy (Mukelabai et al., 2022). In that regard in the next section, we explore green hydrogen technological pathways and potential opportunities for African cases.

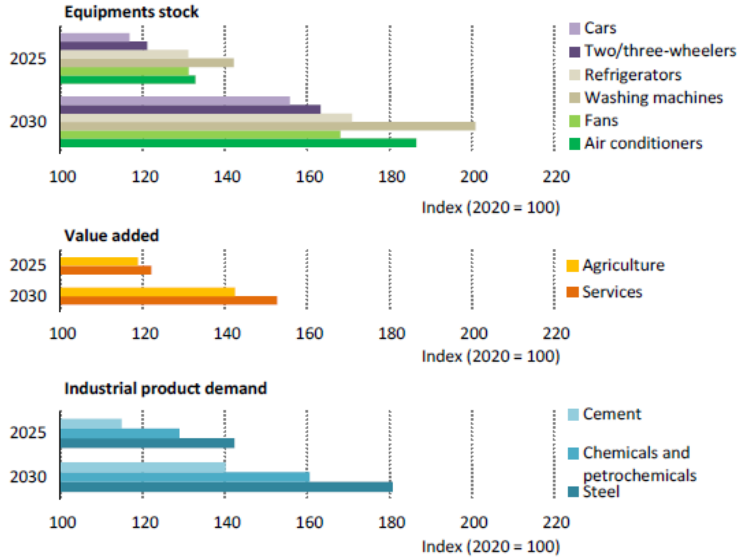


Figure 5. Growth in selected energy-related economic activities in Africa, in the SAS 2020-2030.

Source: IEA (2022).

2.2. GREEN HYDROGEN APPLICATIONS AND FUTURE PERSPECTIVE

2.2.1. Global overview

A wide range of options exists for using hydrogen (see **Figure 6**), **as a commodity or feedstock**, mostly for chemical and large-scale industrial uses, such as the manufacturing of fertilizer. As a result, it has a long history and a variety of applications across the globe. Up until now, it has been largely provided through carbon-intensive fossil fuel production, primarily using natural gas and coal gasification. And, **as a source of energy**, hydrogen has only been used as an energy source for specialized purposes despite having a high energy density (almost three times that of natural gas) and technology being available for more than 150 years. This is because hydrogen is merely an energy carrier and not a primary energy source like fossil fuels or renewable energy sources. It needs to be created with a lot more energy (Tractebel E. GmbH, 2022).

As a result, hydrogen by being a versatile energy carrier that can be used in many applications of possibilities provides an alternative for long-term policy solutions (IRENA, 2022). The potential uses for hydrogen, some of which can provide early demand for hydrogen and help the industry take off are presented in **Figure 6**.

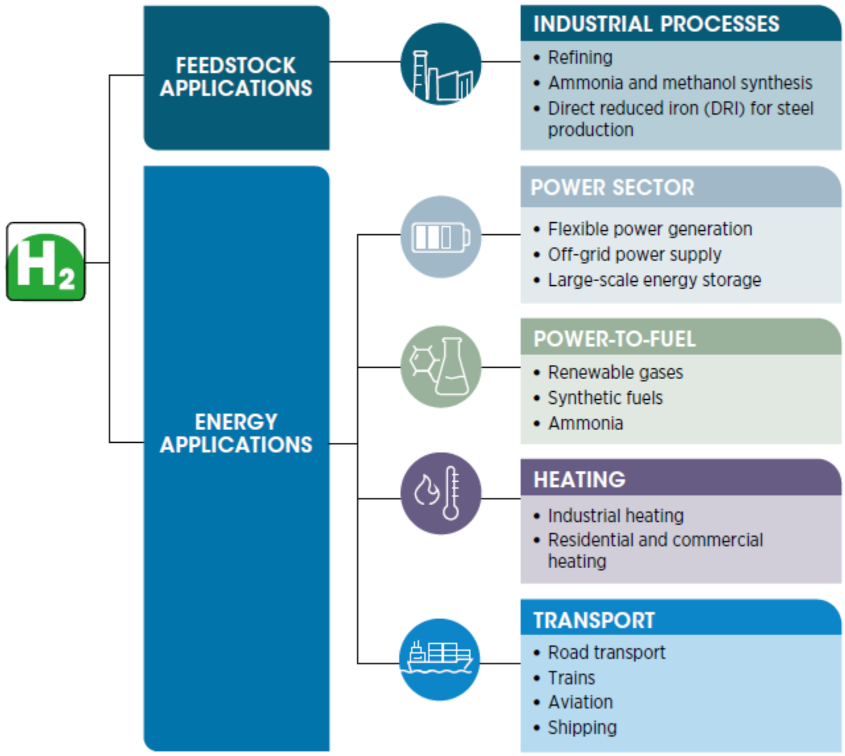


Figure 6: Potential uses for clean hydrogen

Source: IRENA (2022)

Nowadays, it is a common agreement in the scientific and political arena that green hydrogen could play a vital role in the global agenda to accelerate decarbonization and reach a net-zero target by 2050. Nevertheless, the mean of hydrogen production through decarbonized technological pathways from electrolysis accounts for around 5% of the global hydrogen produced (TRACTEBEL,2021). Hence, as more scenarios are being released to explore low-carbon hydrogen potential for net zero, the role of hydrogen is becoming more prominent (OECD, 2022).

This section, it is discussed and analyzed different scenarios released by the scientific community to evaluate the role of green hydrogen in achieving net zero and the future perspective of the new priority settings for green hydrogen applications.

The IRENA's 1.5°C Scenario reveals that the primary energy supply from oil will need to decrease from 140 EJ in 2018 to 14 EJ in 2050 (IRENA, 2022). The Organization for Economic Co-operation and Development (OECD) conducted a study on "Green hydrogen opportunities for Emerging and developing economies: Identifying success factors for market development and building enabling conditions", the paper summarises scenarios released (**see Figure 7**) to discuss the projected share of hydrogen in total final global energy consumption according to different scenarios in 2050. It illustrates that the projected low-carbon hydrogen will cover 12% to 22% of the global energy demand in 2050, estimated to be around 340-420 exajoules (EJ) (OECD, 2022). The IRENA's 1.5°C Scenario highlights that two-thirds of the 612 Mt of hydrogen needed by 2050 will be green (IRENA, 2022; OECD, 2022). While Deloitte's outlook pointed out that the clean hydrogen market capacity should increase to 170 million tons (MtH2eq) in 2030 and to 600 MtH2eq in 2050 to reach climate neutrality by that year (Deloitte, 2023). Therefore, these listed proposed scenarios support this study to develop accurate analysis and pledge the future of potential green hydrogen opportunities in the African market.

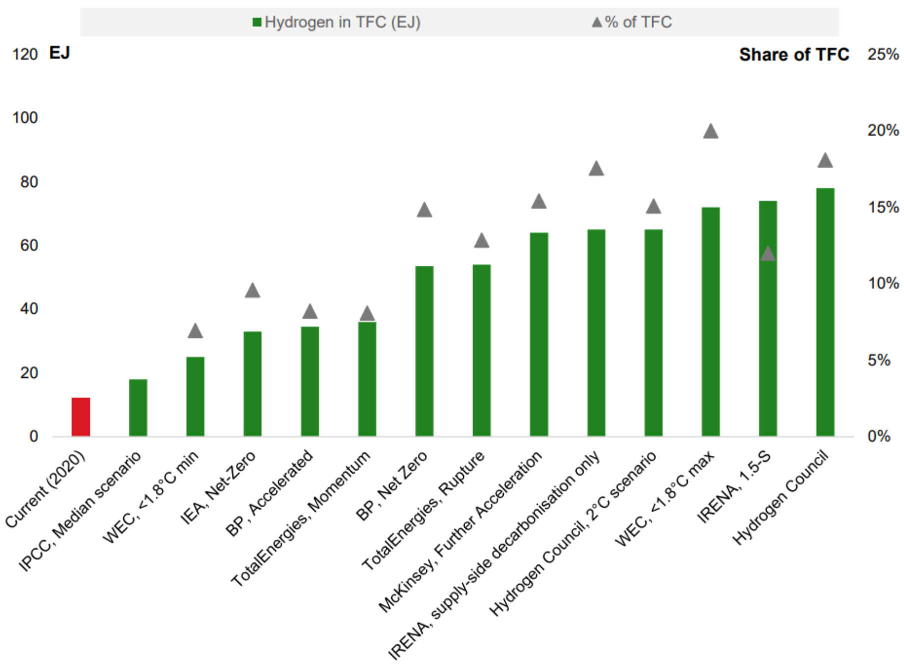


Figure 7. Share of hydrogen in total final global energy consumption

Note: According to different scenarios in 2050.
The calculation for the percentage of the Total Final Consumption (TFC) is the ratio of the hydrogen production divided by the Total Final Consumption, except for the IRENA 1.5-S Scenario, in which the part of the hydrogen demand that is explicitly not part of the final energy demand (e.g. hydrogen use as feedstock for high-value chemicals) is excluded

Source: OECD, 2022

Green hydrogen applications present a wide range of opportunities for usage across the entire energy system or industry. However, the use of green hydrogen in a large-scale capacity translates into a larger renewable investment cost and challenges to overcome (IRENA, 2022). The use of green hydrogen is generally prioritized in net-zero scenarios for hard-to-abate industry sectors with significant process heat requirements that cannot be easily met by another low-carbon emission. Hydrogen is thus reserved as well for uses where there are few alternatives or where electrification is challenging, such as international transport shipping and aviation, heavy-duty transport, chemicals, steel, and seasonal storage (OECD, 2022; IRENA, 2022).

Green hydrogen and its derivatives, such as ammonia and methanol could be important enablers to align these sectors with the net-zero emissions goal. However, by 2050, green hydrogen and its derived products are projected to have a large market share in several sectors OECD, 2022):

- Ammonia and methanol: to substitute the current fossil fuel-based hydrogen production in steam methane reformers or gasifiers, as well as to provide clean transport fuels for shipping.
- Olefins: to develop methanol-to-olefins and electro-synthesis production routes instead of steam crackers that use natural gas, naphtha, and gas oil.
- Iron and steel: to replace natural gas as a reducing agent for DRI production, which can subsequently be smelted with scrap in electric arc furnaces (EAF). The green hydrogen-fuelled DRI-EAF route can replace traditional blast furnaces and eliminate coal use.

Ammonia plays an important role in the food value chain. It is a key product in the fertilizer and chemical industries as described in (IEA, 2021). It is also provisioned to be a hydrogen carrier, serving as a clean hydrogen storage medium (ROLAND BERGER, 2021) for hydrogen transportation and it is foreseen as a fuel-based solution for the transport sector and mobility, including maritime transport (IRENA and AEA, 2022). Methanol will play a key role in the sustainable future as a synthetic chemical and as an e-fuel. Therefore, to drive the change toward a sustainable future, strong policies and regulations will be needed to push the production and use of renewable fuels and materials (IRENA AND METHANOL INSTITUTE, 2021).

The new emerging hydrogen application is increasingly growing. In 2022, IEA released its "Global hydrogen review" outlining and discussing in detail a wide range of new applications of hydrogen in various energy-related economic sectors such as transport, mining and quarrying, buildings, and power generation.

Between 2019 and 2021, hydrogen demand in the transport sector has grown by 60% since 2020, with hydrogen-fuelled vehicles being deployed worldwide. In 2021 alone, the demand for hydrogen in transportation exceeded 30 kt. Despite this, the number of fuel-cell electric vehicles on the road surpassed 50,000 in 2021, indicating a positive trend. Germany has conducted trials for hydrogen-fuelled trains, and interest in hydrogen, ammonia, and methanol in the maritime and aviation sectors is growing. While hydrogen usage in buildings is nearly negligible, emerging options, such as pure hydrogen or blending, are being explored. In the short term, blending hydrogen with existing natural gas networks is likely, with demand projected to reach 0.15 Mt H2 by 2030. Fuel cell micro combined heat and power (micro-CHP) systems are also being adopted, with Japan having over 430,000 micro-CHP units in 2021. Several countries are already using hydrogen blends of up to 20% in boilers operating on methane mixtures. European equipment standards are expected to accelerate the implementation of 100% hydrogen boilers from 2023 to 2025. Pure hydrogen is also being used for heating, hot water, power generation, and cooking. Although hydrogen's use for electricity generation is currently low, there are technologies like gas engines, gas turbines, and fuel cells that can operate on hydrogen-rich gases or pure hydrogen (IEA p.39-67, 2022). Given that, green hydrogen provides a great opportunity toward the net zero pathway. The IRENA trade's outlook and the guide to policy making (2022) for 2050 illustrate policy priority settings for hydrogen applications across the energy system (see **Figure 8**) (IRENA and IRENA 2022).

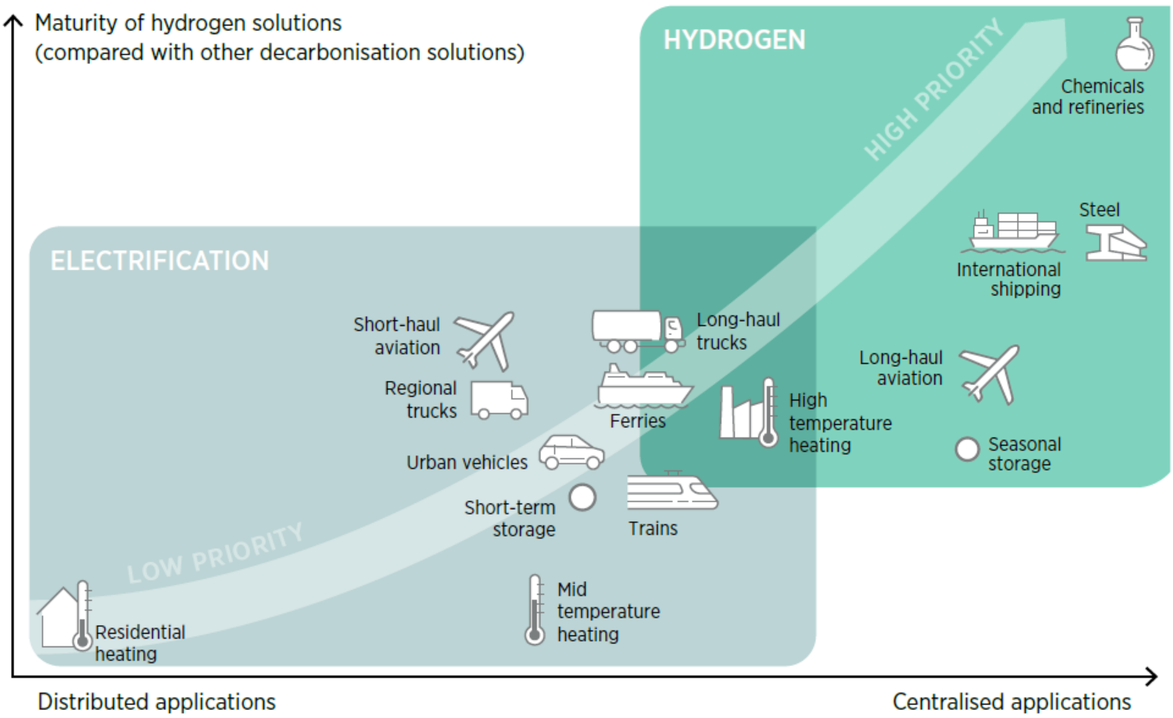


Figure 8. Policy priority settings for hydrogen applications across the energy system

Source: IRENA and IRENA (2022)

2.2.2. Green hydrogen application and future perspective in Africa

The use of low-carbon hydrogen in Africa today is minimal. Low-carbon hydrogen is expected to significantly contribute to Africa's transition to clean energy, replacing fossil fuels in sectors like fertilizer production. Currently, Africa's industrial hydrogen is not low-carbon, mainly used for ammonia fertilizers and to refine oil in North Africa and Nigeria. While South Africa generates ammonia from coal on a slightly lower scale, the majority of Africa's hydrogen generation for ammonia is dependent on natural gas feedstock (IEA, 2022).

This section provides a broad review and analysis of the green hydrogen technical potential in Africa and its impact on the African energy-related economic sectors in terms of the growth path. The rapid economic expansion of Africa has been increasing the need for energy, so the top agenda is to enable economic growth and assess energy for those lacking it (AbouSeada N. et Tarek M. H. 2022). Although Africa’s growth prospects are bright, they differ not only country by country but also sector by sector (McKinsey & Company, 2010). Therefore, the review will consider the regional technical potential to provide a more detailed approach.

According to European Union (2022), “EU-Africa - Global Gateway Investment Package” Africa has a blessed renewable energy potential for the green hydrogen economy, and this potential is seen as low cost-competitive (ADSW, 2022; IRENA, 2022; Beaucamp L. et Nforngwa E. 2022; GH2, 2022) for a hydrogen economy future export and domestic market, making Africa a potential supplier of hydrogen to the EU’s countries and other world’s regions. The Masdar and Abu Dhabi Sustainability Week (ADSW) report (2022) reported that “Africa has a theoretical potential capacity of approximately 850 terawatts (TW) of solar and wind. If only 2% of this, or 17 TW of renewables, were used for green hydrogen production it would produce about 900 mtpa of hydrogen, equal to about 1.5 times the total global demand of 610 mtpa in 2050”. Furthermore, The United Nations (2022), Office of the Special Adviser on Africa (OSAA) show that the untapped renewable potential is estimated at 350 GW for hydropower, 110 GW for wind power, 15 GW for geothermal power, and 1,000 GW for solar. In light of that, Africa is becoming the core of the geopolitical attention for the development of a green hydrogen economy. Under the IRENA (2022) scenario USD 1.5/kg by 2050, adopted as well by Beaucamp L. et Nforngwa E. (2022) outlined that: “the ability of different regions to produce large volumes of low-cost green hydrogen varies widely. Africa is one of the regions with the highest technical potential”. Countries’ technical renewable potential is not the only factor determining how likely they are to become major producers of green hydrogen. It is crucial to take into consideration many other factors that come into play, including existing infrastructure and “soft factors”, as well human capital (e.g. government support, business friendliness, political stability) and the current energy mix and industry (e.g. renewable plans, the potential demand for hydrogen) (IRENA, 2022). Considerably lower costs than in other parts of the world (**see Figure 9**), as well as the potential and the energy policy solution that could potentially drive domestic industrialization, could make green hydrogen a crucial resource for African countries (Beaucamp L. et Nforngwa E., 2022). Therefore, Countries and regions with high renewable potential and a low levelized cost of electricity can use their resources to become major producers of green hydrogen.

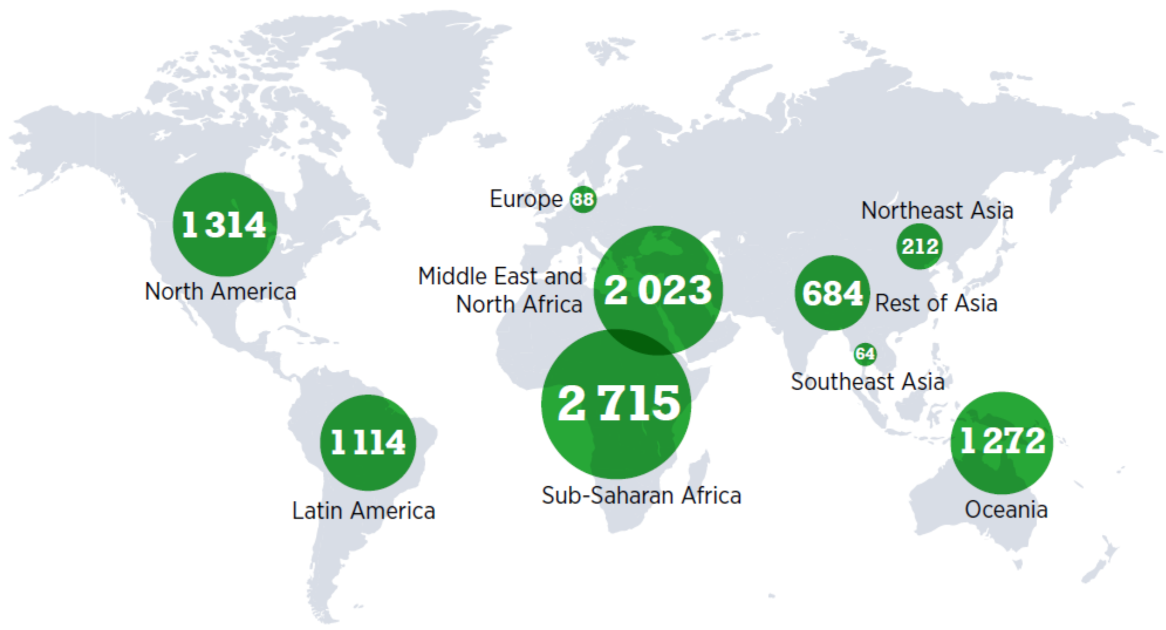


Figure 9. The technical potential for producing green hydrogen is under USD 1.5/kg by 2050, in EJ

Note: Description of the assumptions made from the source.

"Assumptions for capital expenditures (CAPEX) 2050 are as follows: PV: USD 225-455/kW; onshore wind: USD 700-1 070/kW; offshore wind: USD 1 275-1 745/kW. The weighted average cost of capital: Per 2020 values without technology risks across regions. The technical potential has been calculated based on land availability considering several exclusion zones (protected areas, forests, permanent wetlands, croplands, urban areas, slope of 5% [PV] and 20% [onshore wind], population density). Water availability was not considered in the analysis. EJ = exajoule; kW = kilowatt."

Source: IRENA (2022)

The McKinsey and Hydrogen Council report (2022) presents insights on the African Hydrogen production potential by 2050, into market Competitiveness across global regions. The results have shown a competitive value range of production for the two considered regions North Africa with 597 million tons per annum (Mtpa), and Namibia and South Africa with 66 and 134 million tons per annum (Mtpa) based on the Cost of production $/kg in the established scenarios. This potential production of hydrogen falls into two categories in terms of global regional market competitiveness: (i) Competitive for exports to proximate markets; (ii) Competitive for exports to any market (see more in McKinsey and Hydrogen Council, 2022). Moreover, it recognized that the production costs and commercial potential for each region differ widely and are driven by three main factors:

1. The levelized cost of hydrogen production, which is driven by local renewable resources and electrolyzer utilization or the local cost of methane and carbon capture and storage (CCS).

2. The availability and costs to access other critical feedstocks—for example, biogenic CO2 for synthetic fuels or high-quality iron ore for direct reduced iron (DRI) used in green steel.

3. Country-specific factors, including the region's investment attractiveness (market efficiency, workforce availability, or country risk factor) and local public acceptance of building new infrastructure.

According to Green Hydrogen Organization (2022), green hydrogen presents a chance to create clean energy-intensive industries in Africa that are competitive in overseas markets, particularly those with high carbon prices. "Building reliable, modern energy systems can also help Africa develop its industrial base and manufacturing capacity, including for clean-energy technologies, whose market is set to grow rapidly this decade. The continent is already a major player in producing the raw materials needed for clean-energy technologies and is home to more than 40% of global reserves of cobalt, manganese, and platinum – key minerals for batteries and hydrogen fuel cells", Dr. Ruto and Dr. Birol write in the article for (Project Syndicate, 2023). Furthermore, African domestic demand is primarily to be driven largely by transportation, cement, mining, manufacturing, construction, food, and agriculture (see **Figure 10**). Hydrogen and ammonia are the major end products, with methanol, synthetic kerosene, and direct reduced iron playing smaller roles. By 2050, Africa could self-supply its full domestic demand potential of between 10-18 Mt of hydrogen equivalent (GH2, 2022). Meanwhile, this achievement will depend on the state of technology readiness, national ambitions, funding, and available incentives, as well as the actions taken by various African nations between now and 2030. Africa's renewable resources offer economic opportunities for low-carbon hydrogen production, including ammonia. Hence, developing policy and strategy for the local markets is more than necessary.

Large-scale export projects with European companies are being considered, but most are in the early stages (IEA, 2022). The next section discussed ongoing projects and policy strategy.

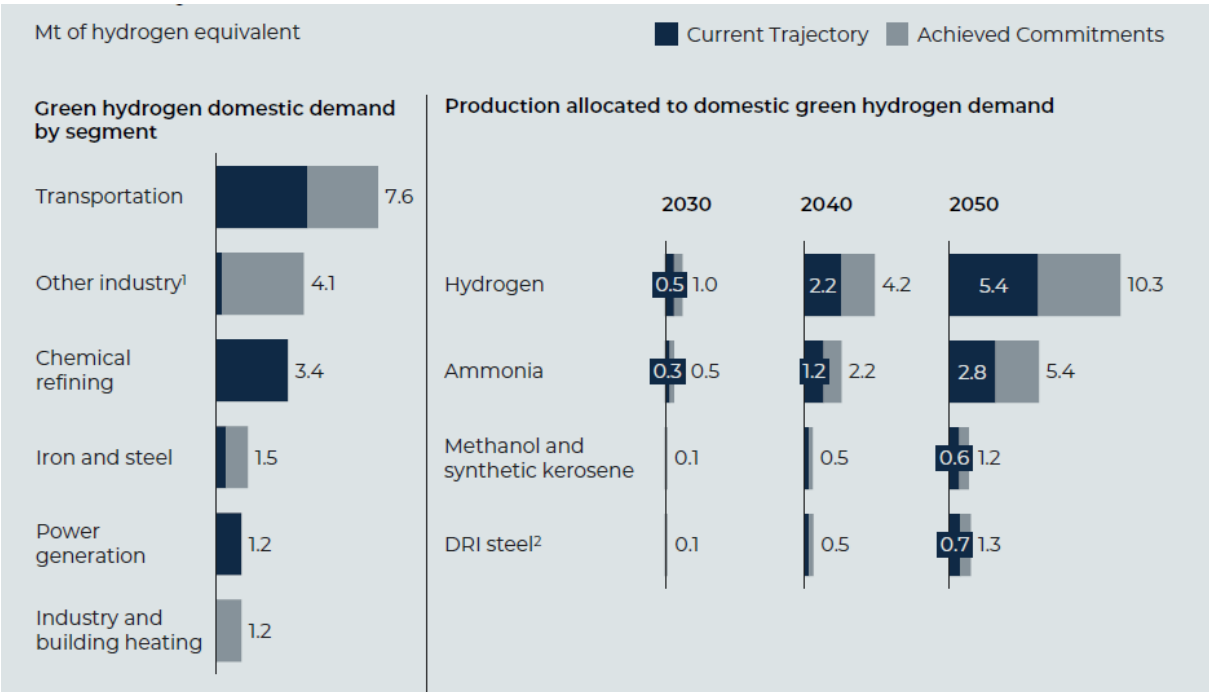


Figure 10. Africa's domestic demand for green hydrogen and its derivatives, from GH2.

Source: GH2 (2022).

2.3. GREEN HYDROGEN POLICY AND GREEN HYDROGEN PROJECTS

2.3.1. Green hydrogen policy

In the modern energy economy, politics, and climate change sustainable energy policy solutions, and responsible and committed governance are required in the process of policy and strategy formulation to meet the zero target. Jale Tosun (2017) defines Energy policy as a comprised of rules concerning energy sources, energy efficiency, energy prices, energy infrastructure, and climate and environmental aspects of energy production, utilization, and transit. At the core of enhancing any sustainable energy policy and strategy sit the vision of improving the provision and use of energy in a way that promotes sustainable development (Jefferson M., 2015). Hence, the policy structure should provide the framework for the overarching policy goal of sustainable development, along with supporting strategies, policies, and instruments that would help markets work better, as described by (Jefferson M., 2015). For it to occur, governments and policymakers must develop reasonable trade-offs between affordable, secure, and clean energy to reduce the negative health and environmental impacts related to energy use (Tosun J., 2017[56]; Jefferson M., 2015).

IRENA (2020) developed Green Hydrogen a guide to policymaking that illustrates three pathways or policy stages (**see Table 1**) that should follow the expansion and evolution of hydrogen deployment and as well as four (4) policy pillars needed to support a green hydrogen transition (**see Table 2**) which are described and detailed in (IRENA, 2020). In January 2022, during the World Economic Forum in Japan, IRENA presented an Enabling Measures Roadmaps for Green Hydrogen (Europe and Japan) that highlights important steps to accelerate green hydrogen initiatives.

Table 1. The stages of green hydrogen policy support

Policy stages	Green hydrogen deployment evolution	Description
First stage	Technology readiness	At this stage, green hydrogen is a niche technology with limited use and limited infrastructure development. Policymakers should aim: (i) In short-term policies to leverage R&D&I funding, risk mitigation policies, cooperation and partnership, and prototypes and demonstration projects to help close investment and operational cost gaps; while (ii) In the Long-term- to encourage and accelerate technology deployment through long-term signals, like net zero commitment and reduces barriers related to high cost. End-uses at the demonstration stage may require mission-driven innovation programs and sustainable governance systems.
Second stage	Market penetration	At this stage, green hydrogen applications are operational, demonstrating its capabilities and costs. Scaling up technologies and learning-by-doing reduce costs and close the profitability gap. Synergies between applications increase hydrogen demand and enable economies of scale in production and infrastructure. Industrial clusters, hydrogen valleys (e.g. cities), or hubs (e.g. ports) can drive green hydrogen corridors connecting regions with demand centers. International trading routes and a global hydrogen market are established, but sufficient renewable electricity generating capacity is crucial to prevent green hydrogen production from replacing efficient direct electrification.
Third stage	Market growth	At this stage, green hydrogen is becoming a popular and widely used energy carrier, with competitive supply and end uses. Private capital replaces public support, allowing flexibility in converting to other energy carriers. Decarbonized power systems and natural gas infrastructure are being used, enabling convenient alternative transportation.

Source: Own illustration, adopted from IRENA (2020)

Table 2. The four policy pillars (P) needed to support a green hydrogen transition

#	P1	P2	P3	P4
	NATIONAL STRATEGIES	ESTABLISH POLICY PRIORITIES FOR GREEN HYDROGEN	GUARANTEE OF ORIGIN SCHEME	GOVERNANCE SYSTEM AND ENABLING POLICIES
Steps	R&D programmes; Vision document ; Roadmap; Strategy-Public-private partnership.	National green hydrogen policymakers should carefully assess, to set up their policy priorities.	Hydrogen certification systems and governments to know the origin and quality of the hydrogen.	Participatory and inclusive dialogue; Concrete Action Plan.

Note: according to different scenarios in 2050.
Source: Own illustration, adopted from IRENA (2020)

According to IRENA (2020), green hydrogen is at the first stage for most sectors. For that reason, to accelerate green hydrogen deployment and market national policy reforms and the development of international policy and market infrastructure must be defined (Megwai et al., 2017). Based on the literature review conducted a wide range of countries across the world has developed policy, national strategy, and green hydrogen roadmaps. The IEA Policies database (last accessed 15/07/2023) lets you search energy-related policies by topic and country, hereby it computed 110 green hydrogen policies across the world and Africa accounts for around 6 countries with green hydrogen policies and initiatives based on the literature found including Morocco, South Africa, Kenya, Namibia, Algeria, and Mauritania. In a recent commentary, President William Ruto of Kenya and the IEA Executive Director are calling for a "New Energy Pact for Africa" at the African Climate Action Summit in Nairobi this September and ahead of the United Nations Climate Change Conference (COP28) that ensures the continent is not left out of the new global energy economy that is rapidly emerging. The pact aims to foster deeper collaboration between African countries and their international partners which could accelerate green hydrogen policy and strategy within the continent (Project Syndicate, 2023). In another hand, the Africa Green Hydrogen Alliance (AGHA) was launched in Barcelona on May 18, 2022, it constituted six African countries: Egypt, Kenya, Mauritania, Morocco, Namibia, and South Africa. These countries have announced their intention to intensify collaboration toward the development of green hydrogen projects on the African continent. The moment is right for African countries to explore domestic partnerships to tap into the continent's green hydrogen potential and deliver domestic economic growth and climate benefits while supporting the world in its transition toward net zero (GH2, 2022).

In recent years, in the ECOWAS region, the concept of green hydrogen has evolved as a new beacon of opportunity, offering a transformative solution to address critical energy, environmental, and economic challenges in the region (ECREEE, 2023). In October 2021 in Niamey, Niger the West African Science Service Canter on Climate Change and Adapted Land Use (WASCAL) launched an International Master's Program in Energy and Green Hydrogen Technology (IMP-EGH) for 15 ECOWAS countries members, the project is an innovative capacity-building program, to prepare the next generation of green hydrogen technology expert sponsored by the German Federal Ministry of Education and Research (BMBF) and partnered with RWTH Aachen University and Forschungszentrum Jülich (FZJ). Nevertheless, developing a legal framework and legislative instruments, policy, and strategy are required to ensure secure investment and green hydrogen deployment in the region. Therefore, the study of (Ballo A. et al. 2022) pointed out that the ECOWAS countries have strived to design consistent legal instruments regarding renewable energy in developing comprehensive legislation and bylaws to consolidate it and encourage investments in renewable energy. Despite all these countries having a legislative basis for regulating renewable energy, there are still no existing laws and policies regarding green hydrogen production and use. Furthermore, recently ECREEE (2023) gathered together a broad spectrum of stakeholders from government representatives, the private sector, and international organizations to validate the methodology for developing the strategy and action plan, as well as the mechanisms for validating the study and its implementation schedule. This as well followed up with the 11th meeting of ECREEE's National Focal Institutions (NFIs). Although, it does exist green hydrogen projects in the region, such as iH2 IVOIRE HYDROGEN (Ivory Coast) and EMERGING ENERGY CORPORATION (EEC) (Guinea).

2.3.2. Green hydrogen projects

The announced low-carbon projects across the world in increasingly growing. The IEA (2022) hydrogen projects database listed around 2000 projects (since 2000), including CCUS, which have been announced globally, which the majority of the projects focus on hydrogen and ammonia products and the end-use for sectors such as mobility counting for 443 projects, power sector 196, and ammonia 174 projects respectively. These projects are categorized by the following: (i) Confidential projects; (ii) non-energy related projects; (iii) Individual projects; (iv) National projects bringing together several projects together; (v) multi-project initiatives that may contain other individual projects of the list (see the Appendix). Just in 2021, 131 large-scale projects (focus on >1MW) were announced globally, increasing the total to 359 hydrogen projects. Including both large-scale projects as well R&D and demonstration projects. With over 80% of new projects located in Europe, the region remains the leader in the emerging hydrogen economy. This is estimated that the total associated investment through 2030 will amount to USD 500 billion of which USD 130 billion investment is directly associated with the announced projects (JÚLIO C.H.A. and SORAYA V.T., 2023; Hydrogen Insights, 2021). In addition, Hydrogen Insights (2023), updated its report on the state of the global hydrogen economy and found that the global hydrogen project proposals increased from 359 to 1046. Of the total, 795 aim to be fully or partially commissioned through 2030 and represent total investments of USD 320 billion in direct investments into hydrogen value chains through 2030 (up from USD 240 billion).

Based on the IEA (2022) hydrogen projects database, Africa counted around 52 project proposals, and IRENA (2022) described four large-scale green hydrogen projects in Egypt, Zimbabwe, Mauritania, and Namibia. The Ivory Coast hydrogen projects (iH2 CAP2023, 2021) developed a green hydrogen initiative and projects map to illustrate and ease information access (**see Figure 11**). In that regard, West Africa counts 6 projects in Ivory Coast, Niger, Ghana, Mali, Togo, and Guinea (non-energy-related) projects.

Figure 11. Green hydrogen initiative and projects map in Africa

Source: iH2-CAP23, (2021) - Ivoire Hydrogène

Despite the increasing interest in green hydrogen projects in Africa, the majority of project proposals and hydrogen national strategies and roadmaps that exist opt for export rather than the local market. Indeed, Masdar (2022) outlines that green hydrogen projects have grown over the past three years with more than 20 projects across Africa (see **A.7**) amounting to approximately 48 gigawatts (GW) of electrolyzer capacity. Meanwhile, more than 90% of these volumes focus on exports (mainly ammonia), with the remainder targeting domestic demand within the transport, chemical, and fertilizer sectors. Furthermore, they highlighted that about $30 billion in hydrogen value chain investments and $70 billion for renewables are announced, with 60% targeting hydrogen supply and the rest building out infrastructure and applications and it counts as 3% of the global announced projects.

Most of the literature provides trade flow routes that illustrate high hydrogen volumes from Africa making Africa potential export and Europe is considered a potential importer (IRENA, 2022; McKinsey and Hydrogen Council, 2022; GH2, 2022; Masdar, 2022). Hence the export potential could widely vary for different types of products across different parts of Africa (Masdar, 2022) and for the ability to produce large volumes of low-cost green hydrogen (IRENA, 2022).

CONCLUSION

This chapter went in-depth on the use and application of hydrogen, the technology maturity and roadmap, and the potential for green hydrogen in the future. The outcomes demonstrated that hydrogen, green hydrogen in particular, may play a special role in the overall energy system (including electricity, oil refineries, chemical industries, iron and steel making, transport and mobility, and buildings). From domestic uses like cooking and heating to heavy industrial uses.

This momentum is mostly caused by commitments to reduce carbon emissions to achieve net-zero target and the versatility of the usage of hydrogen. Both as an energy source and a commodity. Because of this, hydrogen directly or indirectly affects all economic activity related to energy.

Growing energy-related economic activity, population increase, and economic growth are some of the factors influencing the green hydrogen market potential in Africa. Governmental frameworks, however, are what determine the viability and potential for the adoption of green hydrogen across the continent. The framework that satisfies energy needs, makes use of renewable energy sources, and opens the door to technological advancements.

The following sections' methodology, results, and discussions, explore in broader detail current green hydrogen initiatives, projects, national strategies, and roadmaps across Africa.

CHAPTER II: DATA COLLECTION AND METHODOLOGY

3. Introduction

This chapter focuses on the methods and approaches used to collect data and analysis developed for the research study to answer the research questions and achieve the study goals. The data collection and the methods aim to gather relevant and reliable information and conduct comprehensive analyses. The data collection process is crucial as the quality of the data directly impacts the validity and reliability of the findings. Therefore, this chapter provides a comprehensive overview of the data collection strategies, methods used, and data analyses.

The method used includes qualitative and quantitative analysis, and comparative analysis through bibliographic research, survey, scenarios forecasting, and policy recommendations.

3.1. DATA COLLECTION

The data collection is divided into two stages: - Data for a literature review and an online survey. Both quantitative and qualitative methods are used. Hence, before the collection of various data, it is predefined data selection scope, presented in **Table 3**.

Table 3. The selection scope of the data collection for the literature review

Geographic scope	Period	Climate mitigation pathways	Hydrogen demand available
Global, regional, and national studies are evaluated.	The focus is on studies published between 2010-2023.	For the scenarios study the focus is on Paris Agreement and net-Zero target scenarios.	The focus is on studies quantifying the demand for hydrogen in different economic energy-related sectors.

Source: Own illustration, adopted from (Riemer, M. et al., 2022)

3.1.1. Data collection for a literature review

Data and information for the literature review were gathered from a wide range of data sources available online and individual supports. The table below (**Table 4)** is presented a few relevant data sources and studies used for a comprehensive understanding of the research topic status quo and to identify the research gap. The studies focused on demand-driven scenarios and scenarios analysis was considered to envision the future perspective of green hydrogen's impact on the entire energy-related economic sector globally and in the African case.

Table 4. A few relevant data sources and studies used for the literature review

Publisher	Study	Year	No. of scenario	Geographic scope
IRENA	Green hydrogen for industry: A guide to policy making	2022	Scenario analysis	Global
	Global hydrogen trade to meet the 1.5°C climate goal	2022	1	Global
	Green Hydrogen: A guide to policy making	2020		Global
IEA	Global hydrogen review	2022	2	Global
	Ammonia Technology Roadmap Towards more sustainable nitrogen fertilizer production	2021	3	Global
	Africa Energy Outlook	2022	1	Africa
AFREC	Africa and Just Energy Transition	2022	3	Africa
WEC	hydrogen demand and cost dynamics	2021	Scenarios Analysis	Global
OECD	Green hydrogen opportunities for emerging and developing economies: Identifying success factors for market development and building enabling conditions	2022	Scenarios Analysis	Global
McKinsey	Africa's path to growth: Sector by sector	2010		Africa
GH2	Africa's green hydrogen potential	2022	2	Africa
Masdar	Hydrogen's role in unlocking Africa's untapped renewables	2022	2	Africa
Energies	Law and Policy Review on Green Hydrogen Potential in the ECOWAS Countries	2022	paper	West Africa (ECOWAS)
RES4AFRICA and PWC	Green Hydrogen in Morocco: Policy Recommendations to implement the national roadmap	2022	Roadmap	Morroco
Tractebel Engineering GmbH	Baseline Study on the Potential for Power-to-X / Green Hydrogen in Kenya	2022	Baseline study	

Source: Own illustration

3.1.2. Data collection for the survey

The data collection of the survey was conducted through an online Google form with key stakeholders to gather insights into the current hydrogen talks and its market in Africa.

The survey constituted 15 questions, it was targeted to three languages English, French, and Portuguese to ensure massive participation. The targeted number was 50 people. It was online on Jun 30th, 2023. The survey overview is presented in the table below (**Table 5**).

Table 5. Scheme of the questionnaire for the survey

<table>
<tr><th></th><th>Question</th><th>Target community</th></tr>
<tr><td>1</td><td>Professional affiliation*</td><td rowspan="15">• Academia (professors, researchers, scientists, educators)

• Industry (engineers, energy consultants, technology developers, financial analysts, manufacturing supervisors, energy journalists)

• Government/Public Institution (government officials, regulators, policymakers)

• Civil Society/NGO/Youth Movement;

• Student;</td></tr>
<tr><td>2</td><td>Job position</td></tr>
<tr><td>3</td><td>Name of the organization, company, or institution</td></tr>
<tr><td>4</td><td>Years of experience in the Energy field</td></tr>
<tr><td>5</td><td>Years of experience in the Ptx (Hydrogen) field. *</td></tr>
<tr><td>6</td><td>Green hydrogen experience in Africa</td></tr>
<tr><td>7</td><td>The region</td></tr>
<tr><td>8</td><td>Country</td></tr>
<tr><td>9</td><td>Green hydrogen and its derivative for the local African market or only for export</td></tr>
<tr><td>10</td><td>Means for transport for African case</td></tr>
<tr><td>11</td><td>The type of hydrogen or its derivative is projected to have higher market demand and export potential as a commodity *</td></tr>
<tr><td>12</td><td>The most probable hydrogen applications for the local African market</td></tr>
<tr><td>13</td><td>Projected future volumes (Low, medium, high, and not relevant) of green hydrogen applications in Africa (All application sectors of hydrogen were computed for a choice)</td></tr>
<tr><td>14</td><td>The key role of green hydrogen in Africa in the short, medium, and long term (All application sectors of hydrogen were computed for a choice)</td></tr>
<tr><td>15</td><td>Any comment or add any missing point</td></tr>
</table>

Source: Own illustration

The survey enabled us to assess and define the study area of this report, based on the stakeholder location and regional experience and expertise in power to x (PtX) technology.

3.2. METHOD AND DATA ANALYSIS

The data analysis process was conducted in parallel with data collection, literature review, and survey. Both qualitative and quantitative analyses were conducted. The qualitative phase enabled to explorer and understand the factors related to hydrogen application, use, demand, and future perspectives in the global context, including Africa. The quantitative analysis ensured to measure and quantify the data and information acquired, such as the potential demand for hydrogen, the number of participants in the survey, years of experience, and the variation in percentage. This was done through bibliographic research and a survey method. This study performed an analysis of the literature reviewed, and the survey outcome. After all, a comparative analysis was performed. The following sections present and describe the data analysis procedure.

3.2.1. Bibliographic research

The review of the literature enabled a more comprehensive understanding of the potential application of hydrogen in general, green hydrogen state art, ongoing and planned projects, and policy-related and future perspective. The literature reviewed includes studies conducted by prestigious and recognized scientific and research institutions, governments, companies, and organizations exploring reports, outlooks, scenarios, papers, and journals.

The analysis is performed using Microsoft Word. A table was built to extract the information based on the parameters predefined. The tables were built by the following: (i) hydrogen application and potential use in the 25 selected sectors and subsector, including green hydrogen; (ii) Ammonia and methanol applications and potential use; (iii) Potential export and import of ammonia, anhydrous in Africa by country; (iv) West Africa fertilizer production; (v) Existing and planned green hydrogen projects; and (vi) Green hydrogen policy, strategy and roadmap in Africa.

To identify a wide range of green hydrogen projects across Africa, the author explores as well the IEA's Hydrogen Projects Database (**Appendix C1.1.**) and Ivory Coast Green Hydrogen Projects Maps in Africa (iH2 CAP2023). Both enable to quantify the projects in terms of applications and focus area.

Due to the wide range of the tables, this section presents only part of the data analysis procedure table (**see Table 6**), the remaining is presented in the annex of this report.

The table 6, describe the potential use of hydrogen in the key energy-related economic sectors, such as oil refineries, iron and steelmaking, and chemical production. It also illustrates the hydrogen demand in each sector, as well in terms of green hydrogen perspective use in the future. In each sector it was taken step further to analyse and understand the technology process, emission contribution into the atmosphere, and policy priority in terms of decarbonization perspective.

3.2.2. Survey

As part of the methodology of this research, a survey through an online Google was conducted with key stakeholders to gather insights into the current hydrogen talks and its market in Africa. The aim is to capture diverse stakeholders' views from different fields of expertise to ensure a comprehensive analysis of which sectors and technology pathways could a green hydrogen economy play a role in Africa in terms of probability, quantity, and timeframe: -short; medium; and long-term perspective. Therefore, the data analysis is performed using Excel (Annex) to ensure the assessment and interpretation of the result.

The survey enabled us to assess and define the study area of this report, based on the stakeholder location expertise on power-to-x (PtX) technology and green hydrogen.

3.2.3. Comparative analysis

Comparative analysis is performed from the global view of hydrogen application and use and the African perspective. Different demand-driven analyses and scenarios forecasting were evaluated to explore the different perspectives and identify opportunities for hydrogen deployment in Africa.

Conclusion

Chapter II provided an overview of the data collection and methodology employed in the research study. It utilized a combination of qualitative and quantitative analyses, including a literature review and an online survey, to explore the potential market opportunity of green hydrogen in Africa. The literature review analysed global and African studies, while the survey engaged key African stakeholders. Qualitative analysis helped understand factors related to hydrogen application, demand, and future prospects, while quantitative analysis measured potential hydrogen demand and survey responses.

The comparative analysis phase explored various demand-driven analyses and scenario forecasting, providing clear understanding of perspectives between global and African applications of hydrogen.

Table 6. Summary of hydrogen potential use and potential future hydrogen (**green**) use

#	Sectors/ Subsector	Kind of use (Technology/process)	Global Demand of h2/year	Current greyH2 use (Quantity)	Global CO2eq Contribution (by sector)/ year (Quantity)	Status Quo/Future greenH2 use (Quantity)	Probability of greenH2 use	The perspective of greenH2 use (Time frame)	Relevance /policy priority of green hydrogen use to the sector
1.1	Iron and steelmaking [1,2,5,7]	Reducing Agent / Direct reduced iron (DRI) [1,3,5]	4,3 Mth2 / 2020 [1]	Small [1,2,5]	Large [1]	R&D/ Large [1,5]	High (DRI) with CCS&CCUS [1,5]	Medium to Long-term [1,5]	Medium/High [1,5]
		Protection gas, welding [5]		Medium [5]		Small/ Medium [5]	high [5]		
1.2	Chemical production [1,2,5,7]	Ammonia [3]	30,9 Mth2 / 2020 [1]	Large [1,2]	Large [1]	small/Large [1]	High [1]	Medium-term [1,5]	Medium/High [1,5]
		Methanol [6]	12 Mth2 / 2020 [1]	Medium [1,2]	Large [1]	Small/Large [1]	High [1]	Medium-term [1,5]	Medium/High [1,5]
1.3	Oil Refineries [1,2,5,7]	Hydrocracking [1] Hydrotreating [1]	40 Mth2 / 2020 [1]	Large [1]	Large [1]	Large/… [1]		Medium to Long-term [1,]	Low/High [1,5]
1.4	High-temperature/Industrial heat [1,2,5,7]	Iron and Steel Chemicals Cement Provide high heat temp. [1,2]	n/a	Large (as a by-product) [1,2]	Large [1]	Large/… [1,2]	Low due to cost-related [1]	Long-term [5]	Medium/Medium [1,5]

Source: Own illustration

CHAPTER III: RESULTS AND DISCUSSION

4. Introduction

This section presents the main findings of this research study and discusses the key implications concerning the hydrogen market application and use, particularly in Africa.

The section is divided into two parts: (i) **Results**- this part focus on the presentation of the results; (ii) **Discussion**- this part discusses the result and the implications.

4.1. RESULTS

The results for hydrogen applications and potential use, green hydrogen applications, and future perspective in Africa from the bibliography's point of view are first presented followed by the result of the survey and the demand. The results are presented in tables.

4.1.1. Hydrogen potential application and use

Table 7, present the result of the main energy-related economic sectors of hydrogen potential application and use worldwide. The data were first categorized and summarized by sector application and kind of use, then quantified in terms of demand, probability of green hydrogen future application, and time perspective. Sectors such as oil refineries, production of ammonia and methanol, and iron and steelmaking constitute three main consumers of hydrogen. Meanwhile, these sectors represent hight policy priority for decarbonization. In addition, the transportation sector is one of the most emerging applications of hydrogen. Hence, it is expected to have high demand for green hydrogen. The building sector have low use of hydrogen; however, research and demonstrations are being developed.

In the Iron and steelmaking sector hydrogen is used as Reducing Agent, Direct reduced iron (DRI) in a small quantity and as protection gas, welding. However, research is being developed in the field for a green hydrogen application. It is expected the deployment of green hydrogen in the medium to long-term perspective.

In the building sectors companies are deploying micro-CHP for a Combined (low) heat and power supply to residential and commercial buildings, industry using natural gas. However, it is worth to mention that there is low application of green hydrogen in the commercial buildings representing low policy priority of green hydrogen use in the sector.

Whereby **table 8**, presents the result of green hydrogen projected future demand worldwide, particularly in the African case, including production capacity based on the different identified scenarios from different studies. The table summarized projected future demand of hydrogen

Table 7. Hydrogen application and potential sector use

#	Sectors/ Subsector	Kind of use (Technology/process)	Global Demand of h2/year	Current greyH2 use (Quantity)	Global CO2eq Contribution (by sector)/ year (Quantity)	Status Quo/Future greenH2 use (Quantity)	Probability of greenH2 use	The perspective of greenH2 use (Time frame)	Policy priority of green hydrogen use in the sector
1.1	Iron and steelmaking [1,2,5,7]	Reducing Agent / Direct reduced iron (DRI) [1,3,5]	4,3 Mth2 / 2020 [1]	Small [1,2,5]	Large [1]	R&D/ Large [1,5]	High (DRI) with CCS&CCUS [1,5]	Medium to Long-term [1,5]	High [1,5]
		Protection gas, welding [5]		Medium [5]		Small/ Medium [5]	high [5]		
1.2	Chemical production [1,2,5,7]	Ammonia [3]	30,9 Mth2 / 2020 [1]	Large [1,2]	Large [1]	small/Large [1]	High [1]	Medium-term [1,5]	High [1,5]
		Methanol [6]	12 Mth2 / 2020 [1]	Medium [1,2]	Large [1]	Small/Large [1]	High [1]	Medium-term [1,5]	High [1,5]
1.3	Oil Refineries [1,2,5,7]	Hydrocracking [1] Hydrotreating [1]	40 Mth2 / 2020 [1]	Large [1]	Large [1]	Large/… [1]		Medium to Long-term [1,]	High [1,5]
1.4	Transport and mobility	Fuel cells, liquid fuels [2,5]	30 kt/2021 [2,]	Small [5]	n/a	Small/large [2,5]	High [2,5]	Short-Medium [2,5]	Medium [1,5]
1.5	Buildings: Stationary uses (micro-CHP) [2,4,5,7]	Combined (low) heat and power supply to residential and commercial buildings, industry [2,5]	n/a	Low (with natural gas) [,5]	n/a	Commercial start with green H2/large [,5]	Low [,5]	Long-term [,5]	Low [1,5]

Source: Own illustration

in Africa and globally. It gives a picture of hydrogen perspective in Africa in terms of quantity and period, in million tonnes of hydrogen per year (MtH2/year). This enables to develop a comparative analysis between African market and global market.

Meanwhile, **Annex three (A.3.)** presents the result of ammonia (anhydrous) export/import from/to Africa, since ammonia constituted the largest consumer of hydrogen in the industry for fertilizer production. Countries such as Egypt, South Africa, Kenya, Morocco, Namibia, Benin, and many others already African exporters of ammonia. The overall, exporter countries are listed in (**A.3.1**). Furthermore, Countries such as Tunisia, Senegal, Mauritania, Angola, and many others are as well importers of ammonia. The results are presented in **(A.3.2.).** While **Annex four (A.4.)**, presents the result of fertilizer production in West Africa. It summarized the different fertilizer products produced in the West African region. The different products include Urea, Monoammonium Phosphate, Diammonium Phosphate, Organic Fertilizer, NPK unspecified, Phosphate Rock. Therefore, the list of countries is illustrated in the Annex four (**A.4.**).

4.1.2. Green hydrogen future perspective

In the previous section (**section 2.3.2**) it is illustrated green hydrogen projects and initiatives **(Figure 11**)**.** The Annex five **(A.5.) presents** existing and planned Green Hydrogens worldwide**,** including Africa. Therefore, (**A.5.2.**) presents green hydrogen existing and planned projects in Africa, identified in this study**.** The table (**A.5.2.**) gives overview of the focus of the projects, the timeframe, the production capacity and the technology pathway, and the electricity source. Furthermore, green hydrogen development and development will depend on the policy in place and the will of government and their development partners. Therefore, the results of the hydrogen policy and policy that support green hydrogen implementation are presented in (**table 9**) and Annex six **(A.6)**. The table 9 and **(A.6)** presents the list of the identified countries that developed green hydrogen policy. It illustrates the focus of the policy, the key strategy target, and the roadmap pathways for the green hydrogen implementation. The implications of these results are discussed in the section of the Discussion.

Table 8. Green hydrogen projected future demand under different scenarios

Publisher	Study	Scenario	Hydrogen Production (Mth2/year)	Hydrogen Demand (MtH2/year)		Period
			Africa	Global	Africa	
IRENA (2022[40])	Global hydrogen trade to meet the 1.5°C climate goal	1.5°C scenario	n/a	614	n/a	In 2050
IEA (2022[2]; [23])	Global hydrogen review	Announced Pledges Scenario (APS)	n/a	130	n/a	By 2030
	Africa Energy Outlook	Sustainable Africa Scenario	20	n/a		
Deloitte (2023) [20]	Green hydrogen: Energizing the path to net zero	net zero scenario	44 (H2eq) only North Africa	600	54 (Middle East and North Africa)	In 2050
GH2 (2022 [5])	Africa's green hydrogen potential	Achieved Commitments	60 (AGHA members)	607	10-18	By 2050
		the Current Trajectory	30 (AGHA members)	n/a		
Masdar (2022) [54]	Hydrogen's role in unlocking Africa's untapped renewables	Achieved Commitments	60	610	10-20	in 2050
		the Current Trajectory	30	n/a		
M.M.E.N (2022) [13]	Namibia Green Hydrogen and Derivatives Strategy	net zero scenario	10-12 (Namibia)	660	n/a	By 2050

Source: Own illustration

Table 9. Green hydrogen policy and policy that support hydrogen economy in Africa

Country	Report	Roadmap pathway implementation	Status (published in)	Policy and Framework that support green economy	Source / URL
Morocco	Policy recommendation to implement the national roadmap	Technological developments and cost savings; investment and procurement; market and demand- Those axes are translated into eight identified actions to take for 2050.	2021	Moroccan Hydrogen Plan; NDC; Renewable Energy policy target	[11; article; NDC; RES]
South Africa	Securing a clean, affordable, and sustainable energy future for South Africa	South Africa identified 6 pathways, which translated into 70 key actions	2021	South Africa's Green Economy Targets;	[12]; Climate Champions
Kenya	Baseline Study on the Potential for Power-to-X / Green Hydrogen in Kenya	Identified #5 industrial pathways to further pursue the use of green hydrogen, these include fertilizer, industrial processes, transport, and mobility, for large-scale use, and isolated use/ off-grid. This is defined based on short-, medium- and long-term time frames and supported by ACTION PLAN structured upon 6 actions	2022	Green Incentive Policy Framework; NDC Strategy; Long Term Low Emission Development Strategy (LTS) 2050; National Climate Change Fund (CCF); Kenya Vision 2030	[5], Climate Champions
Namibia	Namibia Green Hydrogen and Derivative Strategy	To foster a sustainable pathway Namibia set up 6 strategies and an action plan for 2025 clustered into three and under 12 actions, therefore Namibia is on the road to developing a Roadmap for hydrogen	2022	Reduction of GHG emission by 91% by 2030; Aspired to support the global transition to net-zero, Set a major exporter of Gh2 and derivatives;	[13]; CC; NamH2;
Mauritania	Is under preparation by the government.	Is under preparation by the government	-----	---------------------	Maur , CC

Note: NDC= Nationally Determined Contribution

Source: Own illustration

4.1.3. Survey's results

The result of the participation of targeted stakeholders is presented in **Table 10a)**. The answers are quantified and summarized based on the individual responses from question one (Q1) to question twelve (Q12). While the answer the question thirteen (Q13) is in (**Anex B1)** and question fourteen (Q14) is presented in **table 10b)**. It details the African perspective for hydrogen applications in Africa in terms of short, medium, and long-term. The colors described the three highest-rated sectors.

Table 10. Survey's Results

a) Survey result Q1-Q12 Zero minimum medium maximum

	Category	Result (quantity of people)	
	Total participant	51	
1	Academia (professors, researchers, Scientists, educators)	9	
2	Industry (engineers, energy consultants, technology developers, financial analysts, energy journalists)	16	
3	Government/Public Institution (government officials, regulators, policymakers)	3	
4	Civil Society/NGO/Youth Movement	3	
5	Student	20	
6	People with experience in the Hydrogen field	39	
7	Green h2 Experience with the African context	26	
8	Region of experience	North Africa	0
		West Africa	24
		Central Africa	1
		East Africa	2
		South Africa	4
9	Green h2 for African Market	Pros	38
		Cons	13
10	Transport means	Shipping	18
		Tankers	20
		Pipeline	17
11	Projected h2/derivative to have higher market demand	Ammonia	12
		Green h2	19
		Methanol	5
12	Most probable hydrogen applications in the African market	Ammonia/Fertilizer	10
		Power Generation	14
		Transport and mobility	7
		Industry	3
		Storage	2

Source: Own illustration

b) Expected sectors for green hydrogen application in Africa (Q14)

#	Sector	Short-term (2030)	Medium (2040)	Long-term (2050)
1	Steel Making	7	21	18
2	Chemicals (ammonia and methanol)	17	17	11
3	Maritime (mainly cargo)	10	21	21
4	Industrial heat	8	17	19
5	Glass production	9	15	20
6	Fertilizer	27	13	12
7	Heavy-duty vehicles	10	17	19
8	Mining and Quarrying	10	14	20
9	Oil Refineries	12	16	15
10	Power Generation	21	18	16
11	Light duty vehicles	12	19	15
12	Off-grid Applications	14	19	13
13	Rails	8	15	21
14	Buildings	12	12	19
15	Seasonal storage	15	22	11
16	Backup Power	12	17	17

Source: Own illustration

4.2. DISCUSSION

The potential market for green hydrogen in Africa is a topic of growing interest. The bibliographic research results and the survey results present an opportunity for green hydrogen market deployment in the continent. This section discusses the implications of the results.

4.2.1. Hydrogen applications and potential use in Africa

Hydrogen is applicable in different key energy-related economic sectors worldwide, such as oil refineries, chemical industries, iron and steel making, and transport and mobility (**Table 7**).

Many published works believed that, these sectors have high probability for green hydrogen application. Iron and steelmaking sector present challenges in terms of carbon neutrality in the whole chain of the technology process. However, the use of carbon capture uses and storage (CCUS) could be a solution. Transport and mobility, chemicals and refineries, seasonal storage, and steel rank among the highest policy priority for decarbonization (IRENA, 202; IRENA, 2022).

While In the African context studies have shown that the data about hydrogen applications and use are limited. As shown by World Energy Council (2021) and NGAM (2023) that the use of hydrogen in Africa is insignificant in terms of quantities. Nearly 3 Mt of hydrogen is consumed annually, of which 70% is utilized in the chemical industry, primarily to make nitrogen fertilizers (IEA, 2021).

The report of Hydrogen Insights (2023), reported that Africa presents a low local hydrogen demand therefore the region is expected to be one of the major exporters of clean hydrogen. Meanwhile, many studies as well have shown that Africa's energy-related economic sectors are expected to grow. Countries such as South Africa, Nigeria, Egypt, and Algeria are Africa's top refining hubs, and many other African countries have built refineries in the last decades (Mbendi, 2018).

Furthermore, Africa is one of the highest and fastest-growing populations and economic growth, this is justified by (IEA, 2022 p.57; Mukelabai et al., 2022). Such economic activities are expected to grow by 2030 in cement, chemicals and petrochemicals, steel, services and agriculture, and electricity consumption (IEA, 2022), which requires a high energy supply.

The continent's rapid population growth (estimated to reach 2.5 billion in 2050) and economic expansion (+2.2 to +3.1 percent annually, will increase energy and food consumption, and emissions, which could account for 5 to 20 percent of global emissions in 2050 (Mukelabai et al., 2022). Therefore, these growths in the region required effort to increase energy supply as well as food production which could offer a hydrogen market opportunity in Africa. In particular, for fertilizer production since Africa has undeveloped arable land equivalent to 25 percent (25%) of the world's fertile land (AGRA, 2022).

Furthermore, the World Bank (2020) indicators database indicated that Sub-Saharan Africa counts 9.3 % of arable land (% of land area) and 42.5 % of agricultural land (% of land area). Hence the fertilizer consumption is around 22.5 kg/ha (kilograms per hectare) of arable land.

Thus, fertilizer consumption in the West Africa region varies from one country to another, for example, **Ghana** counts 107.4 kg/ha of arable land, **Cote d'Ivoire 51.9 kg/ha**; **Senegal** 25.3 kg/ha; and **Nigeria** 19.6 kg/ha. Whilst the Africa Fertilizer (2023) apparent fertilizer consumption database has shown that Nigeria is the highest consumer of fertilizer, followed by Ghana and Senegal (see **Figure 12**).

Africa already presents a growing ammonia market, both for export (**A.3.1.**) and import (**A.3.2.**). Providing a market opportunity for ammonia, consequently hydrogen. Egypt is the largest exporter of ammonia. Furthermore, many West African countries (**A.4.**) are fertilizer producers (described in section 4.1.1.). Senega's fertilizer market is the most diverse, in terms of fertilizer products. And, Nigeria is the largest producer of urea in the region. Therefore, this existing market can be explored to enhance and boost the green ammonia market in the continent in particular in West Afraica.

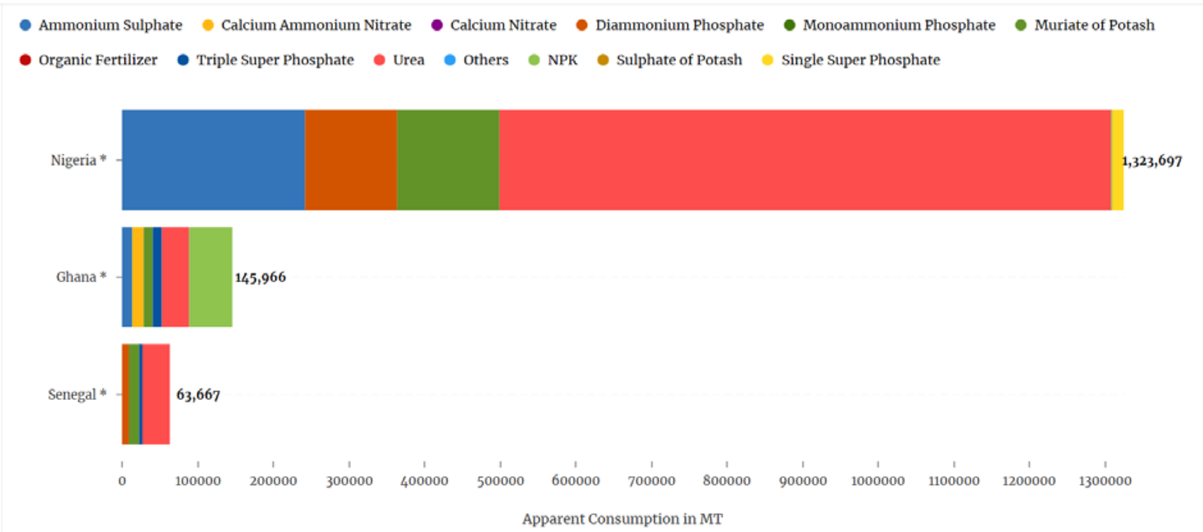


Figure 12. Apparent Fertilizer Consumption in West Africa

Note: MT= Metric tonne; Data yet to be validated by the Fertilizer Technical Working Groups

Source: Africa Fertilizer (2023)

Despite the current state of hydrogen application and use, many studies focused on hydrogen production capacity and domestic demand projections in Africa confirming the increased potential opportunity in Africa.

4.2.2. Green hydrogen future perspective in Africa

Africa profit of great green hydrogen theoretical potential. A study showed that if only 2% of its renewable energy capacity (17 TW) were used for green hydrogen production it would produce about 900 mtpa of hydrogen, equal to about 1.5 times the total global demand of 610 mtpa in 2050. Moreover, some studies stated that Africa presents low cost-competitiveness for the green hydrogen market. That makes Africa a potential supplier of green hydrogen to the world.

Thus, several studies focus on hydrogen production capacity and demand projections point of view exploring different potential scenarios to provision the hydrogen market in the continent presented in (**table 8 section Results)**.

From the scenarios explored hydrogen domestic demand in Africa varies from 10 million tonnes of hydrogen per year (MtH2/year) in the current trajectory scenario to 20 for the achieved commitments scenarios by 2050. That shows the existing market for hydrogen in the continent. While the global demand for hydrogen is expected to reach 600 Mt in 2050.

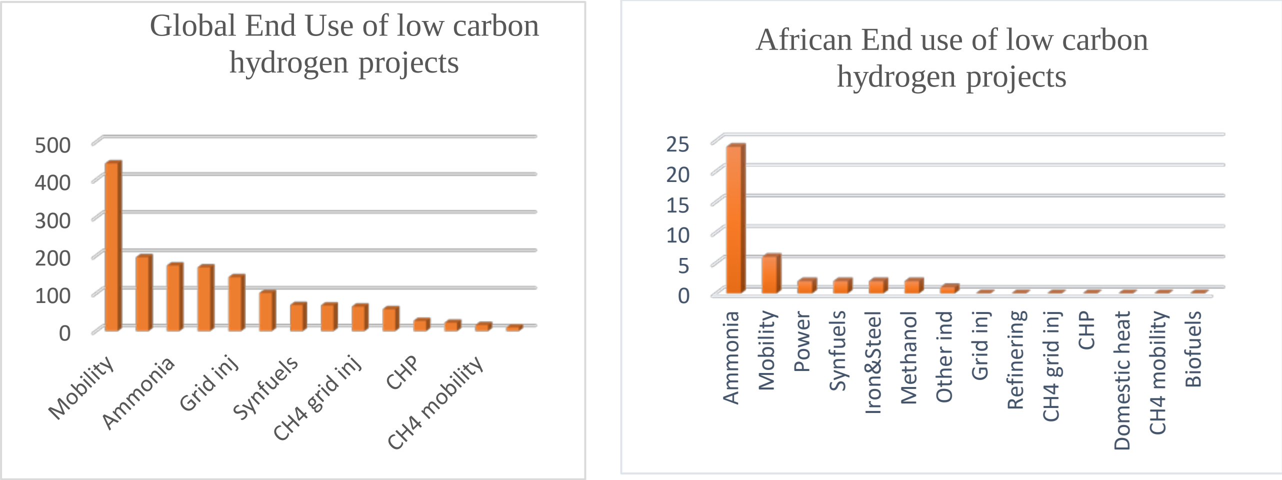
Furthermore, the Green Hydrogen Organization (2022) reported that the production capacity of green hydrogen in the African Green Hydrogen Alliance (AGHA) members could reach 60 MtH2/year by 2050 based on the announced project.

Though, the hydrogen market is expected to grow worldwide due to the regional unbalance of renewable resources. Increasing the need for international partnerships and cooperation. Several projects' partnerships, and memorandums of understanding have been announced across the world.

The number of low-carbon hydrogen projects across the world varies from one region to another. The IEA projects database counted around 1933 projects since the year 2000 (**Appendix C1.1.**), including projects expected to be online by 2030. Among this project 52 (**Appendix C2.1.**) are to be implemented in Africa until 2030. Therefore, the author used the IEA database to perform quantitative analysis to identify key areas of the end use of these projects (**see Figure 13a.**). And they were ranked from highest to lowest. Therefore, the mobility sector, power sector, and ammonia ranked among the highest.

Thus, this justifies the growing market of hydrogen in the transport sector, especially road transport. While in the African case (**see Figure 13b**) ammonia, mobility, and power sector ranked among the three highest. However, the study by Masdar (2022) has shown that Africa counts only 3% of global announced projects and 90% of them are focused on export.

Moreover, Hydrogen Insights (2023) updated on the state of the global hydrogen economy projects which of 553 are for large-scale industrial use, 191 for mobility, and 112 for giga-scale production projects. Africa counted 19 projects announced projects from 2022-2023.



a) Globally **b) Africa**

Figure 13. End use for low-carbon projects

Therefore, in the GH2 (2022) and Masdar (2022) both scenarios demonstrated that green hydrogen can meet Africa's domestic demand for affordable clean energy and reduce the fossil fuel imports used. Particularly in the production of nitrogen-based fertilizers or refined petrochemicals. It can as well unlock domestic end-uses like transport and mobility, and off-grid energy systems.

Moreover, the result from the bibliographic research showed that transportation, chemicals, including fertilizer and refining, and power generation are among the key sectors expected to have the highest demand for hydrogen and its derivatives in Africa. Nevertheless, it does not precise the time frame in terms of short, medium, or long term, as well as in terms of probable volume in every sector. Hence, the next section deals with the **Survey's Results.**

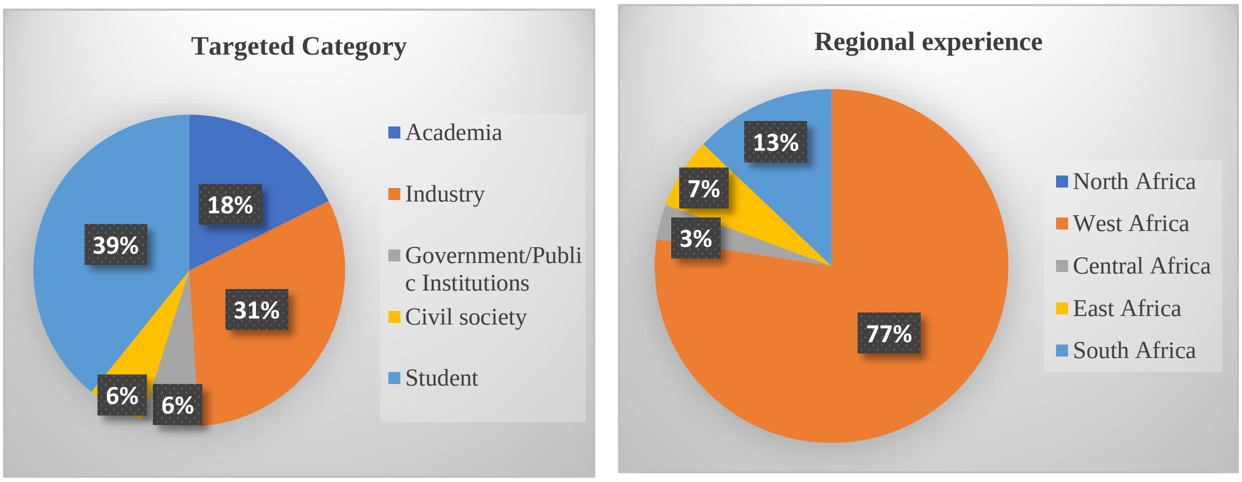
4.2.3. Green hydrogen future perspective in Africa (survey's result)

To capture diverse stakeholders' views from different fields of expertise to ensure a comprehensive analysis of which sectors and technology pathways could a green hydrogen economy or its derivatives play a role in Africa. Opinions from energy experts, researchers, government representatives, policymakers, industry, academia, and civil Society were collected. The results (see section **4.1.3., Table 10)** were analyzed and evaluated using Excel.

Diverse insights were gathered from 51 African perspectives from targeted stakeholders (see **Figure 14a**) which of 39% were students, 31% were experts from industries, 18% from researchers, scientists, and 6% Civel Society and Government respectively. The quality of the answers was evaluated using strategic questions that allowed identifying years of experience in the power to x field or hydrogen field. Hence around 77% of answers collected had experience in the green hydrogen field whether from graduation programs or expert fields.

Although the Government and Civil Society, were less represented, the results collected are favorable considering the number of targeted communities and the representativeness. Government and Civil Society both play a crucial role in shaping the green hydrogen economy and supporting policy implementation. As supported by IRENA (2020) in policy pillar 4, governance system and enabling policies. In total 75% of the people support and expect the deployment of a green hydrogen market in the continent, particularly in West Africa.

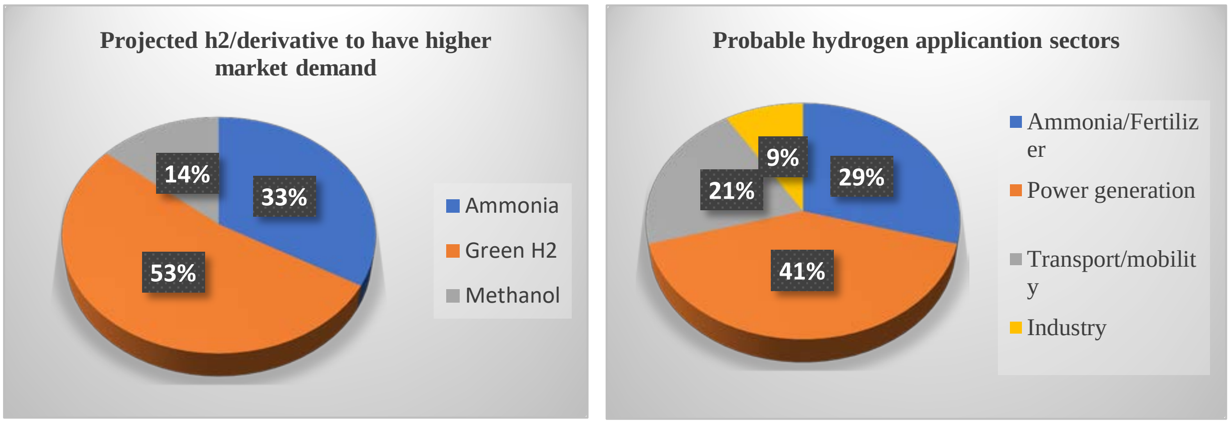
Thus, 77% of the people had experience with hydrogen-related experience in the **West African region** (see **Figure 14b**). Though, all the African regions were represented as part of Northern Africa. In light of that, the demand-driven scenarios should focus on the West African region.



a) Targeted category b) Region of experience

Figure 14. People's Experience in the Hydrogen Field and the region of experience

Furthermore, the majority of people expect green hydrogen, ammonia, and methanol (see **Figure 15a**) to have higher market demand playing a crucial role in the following energy-related economic sectors: (i) Ammonia/fertilizer; (ii) Power generation; (iii) Transport and mobility; and industry (see **Figure 15b**). Therefore, the latter is justified by the study of GH2 (2022) and Masdar (2022).



a) Projected products b) End-use sectors

Figure 15. Most probable Future demand for hydrogen and its derivatives, and End Uses

Therefore, both hydrogen and ammonia can play a vital role in Africa, provided that Africa's economy and population are highly expected to grow the demand for energy and food production. Hence, Africa as a continent of fertile soil and high agricultural land (see section **4.2.1.)** can unlock market opportunities for green hydrogen and fertilizer deployment. This was as well shown by McKinsey & Company, (2010), in its study "Africa's path to growth" because a successful agricultural system requires reliable access to fertilizer.

In addition, to have a wider comprehension and understanding of the hydrogen deployment in various sectors in terms of volume (**B1**) and timeframe: short-term (2030); medium-term (2030); and long-term (2050) (see **Figure 16**). The targeted participants were asked to identify the key probable sectors in that hydrogen could play a role in terms of timeframe. The targeted period (2030;2040; 2050) goes alongside the sustainable development goals (2030), considering the commitment made and the net-zero target (2050). Therefore, in the short-term run fertilizer and power generation are expected to be the main player for hydrogen application. Whilst, in the medium-term seasonal storage, maritime (mainly cargo), and steel making are expected to take the lead. Hence, seasonal storage or an off-grid system could be an option, in particular for the rural areas, provided that the need for power in the remote areas. Indeed, Masdar (2022) pointed out that off-grid or backup power could play a role in African remote areas. Meanwhile, it requires skills and innovation which as well could increase jobs opportunity.

Finally, in the long term, the participants indicated the transport sector as a major player, particularly rails and maritime. In addition, mining and quarrying, and glass production are expected to play a role as well. Hence, the rapid economic growth (mentioned in **section 2.2.2.**) and hydrogen deployment would boost labor demand in the near future. Consequently, increase the need for urbanization and new construction. As statistically demonstrated by MMEN (2022), claiming that hydrogen could accelerate socio-economic development. For example, in the scenarios developed for Namibia's hydrogen development, it is reported that hydrogen would boost labor demand by generating up to 80,000 additional jobs by 2030, and up to 600,000 by 2040.

However, sectors such as chemical production including fertilizer, power generation, transport, and mobility are one of the most expected hydrogen applications to unlock the hydrogen market in Africa, in particular West Africa. Though, it required effective governance and policy.

In order to understand the current technology maturity of the most probable applications of hydrogen in Africa, the following section provide an overview of the technology maturity of four (4) applications sectors. The four sectors were chosen based on the aforementioned results.

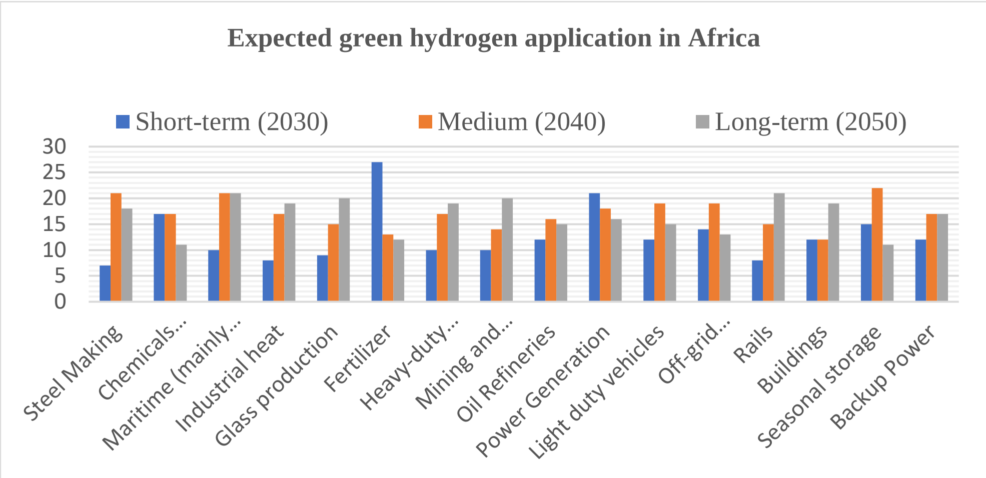


Figure 16. Green hydrogen application in Africa in the short, medium, and long-term period

4.3. GREEN HYDROGEN APPLICATION TECHNOLOGY MATURITY

The system technology readiness level enables comparison between different types of technology and it consists of nine levels (9) used to determine the maturity as described in (Slobodan Petrovic and Eklas Hossain, 2020). The maturity of green hydrogen application technology is still evolving, already available for many ends uses with advancements and ongoing research in various areas (IRENA, 2022). The Technology Readiness Levels (TRLs) support the assessment of the maturity of a particular technology. The description of each level is shown in (Slobodan Petrovic and Eklas Hossain, 2020). Therefore, based on the outcome of the survey (see the Result Section) and the literature reviewed this section outlined three (3) energy economic-related sectors to describe probable potential applications of green hydrogen in West Africa such as ammonia production for fertilizer application, power generation, transport, and mobility. In light of that, the detailed technology readiness level and hydrogen proportion used by technology are presented (see **Table 11**).

The development of low carbon-emission technology for the ammonia industry is now at different stages of development. IEA (2021) selected a few green ammonia projects (including Fertiberia and Iberdrola, +3 Iberdrola, YARA) to evaluate the deployment status of the ammonia industry, therefore concluded that variable renewable energy-powered electrolysis for ammonia production is being developed, with large-scale demonstrations and commercial plants in development stages (TRL 8 for full chain), particularly relevant for fertilizers and ammonia applications. While The Royal Society (2020) pointed out that the production of green ammonia via electrolysis is at TRLs 5 – 9. However, the stoichiometric consumption of hydrogen for ammonia and fertilizer production is defined by the following: 178 kgs of hydrogen are required for each ton of ammonia; 570 kg of ammonia for a ton of Urea, and 200 kg of ammonia for a ton of diammonium phosphate (DAP) (Anuraag Nallapaneni and Shaifali Sood, 2022).

For power generation, the fuel cell technology maturity readiness level range between 5-6, according to (Slobodan Petrovic and Eklas Hossain, 2020 [65]) and Hyfindr. Nevertheless, the amount of hydrogen needed can be calculated based on the type of fuel cell and the efficiency of the fuel. The equation is shown in **Table 11.** Furthermore, green hydrogen offers an opportunity for blended or direct use in turbines (see **Table 11**).

Green hydrogen in Marine and Rail is evolving. The technology readiness level and hydrogen proportion are listed in the table below.

Table 11. Technology maturity of Green Hydrogen Application

#	Sectors/ Subsector	Kind of use (Technology/process)	Demand (Greykgh2/year)	Average avoided emission (kgCO2/kg H2)	Stoichiometric consumption of hydrogen by technology	Green hydrogen Technology Readiness Level (TRL)
1.1	Iron and steelmaking [1,2,5,7]	Reducing Agent / Direct reduced iron (DRI) [1,3,5]	4,3 Mth2 / 2020 [1]	11 [66]	For hematite: 54 kgH2/t(iron) [43]; 51 kgH2/t(steel) [47]	n/a
1.2	Chemical production [1,2,5,7]	Ammonia [3]	30,9 Mth2 /2020 [1]	11 [66]	I78 kgh2/tNh3 [45]	(TRLs 5 – 9) [44]; TRL 8 for full chain [3]
1.2	Chemical production [1,2,5,7]	Methanol [6]	12 Mth2 / 2020 [1]	11 [66]	I88 kgh2/tme [46]	n/a
1.2.1	Fertilizer [1,2,3,5,7,8]	Nitrogen-based fertilizer		11 [66]	Urea: 570kg/t (urea) [45]	n/a
1.3	Transport and Mobility – Maritime [1,2,5,6,8]	Ammonia [2,5, 63]; Methanol [2,5, 63]; H2 fuel cell [2,5, article, 63]	n/a	11 [66]	n/a	Pilot and Demonstration, R&D [2, 63, article]
1.3	Transport and Mobility – Rails [2]	Fuel cell [2,5] – FCHPP [2, Article]	n/a	11 [66]	100km/kgh2 [FAQ]	TRL7 achieved in Spain (2023) [Aritlce]
1.4	Power Generation	H2 Direct use in Turbines – Blended or 100% h2 [2, 64, article2]	n/a	11 [66]	Gas Turbine (e.g. GE-10) ~11,700 (~446,000) m3/hour [64, article2]	Pilot and R&D [2, 64, article2, article3]
1.4	Power Generation	Fuel Cell technology (Article) – polymer Electrolyte Membrane (PEM); Alkaline (AFC); Solid Oxide (SOFC); Molten Carbonate (MCFC); Phosphoric Acid (PAFC)	n/a	11 [66]	The amount of hydrogen can be calculated based on the efficiency of the fuel $m(h2) = \frac{P(kW)*t(h)*3600s}{\eta(\%)*LHV\left(\frac{kJ}{kg}\right)}$ [article]	TRL 5-6 [65, Article]

4.4. POLICY RECOMMENDATION

Hydrogen deployment in Africa in particular in West Africa requires emerging and sustainable policy due to the current dynamic and interest in the hydrogen economy development. Governments and policymakers should create policies that promote the development of green hydrogen in the identified sectors. However, it could follow the necessary steps or stages (as **described in section 2.3.1.**). Considering the fact that from hydrogen technology readiness to large-scale market growth is a long way to go. Based on the key findings of this study, it is pointed out policy recommendations that can support the adoption of green hydrogen and its derivatives in Africa to facilitate the transition towards a hydrogen-based economy. Therefore, policy recommendations based on the results, presented by the following:

i. Formulate a Regulatory and institutional framework

The production of green hydrogen in Africa is gaining momentum, and regulatory frameworks play a crucial role in fostering a supportive environment. Hence, this is required to strengthen institutional capacity in terms of skills and resources.

Thus, to develop and create a supportive environment for the development of green hydrogen, including green hydrogen **policies**, **national strategies** are crucial that countries develop **a regulatory and institutional framework** from the Country-level frameworks and extend it to the regional level or vice-versa. Considering the importance of the cross-broader market and regional integration within the African continent. Finally, building accountability and transparency mechanism for green hydrogen projects in Africa.

ii. Build strategic partnership

Building strategic partnerships locally and internationally for the green hydrogen economy in Africa can open new doors to build reliable relationships and enlarge the market scale. Provided that the deployment of green hydrogen requires human capital and capacity building, R&D partnership, policy alignment, investments, and industrial policies and the market at large. Therefore, Africa could take advantage of its renewable potential position to build a dynamic partnership.

iii. Foster Regional policy market integration

Unlocking the hydrogen market on a large scale in Africa will be required to put in place free trade area policy. Hence, it can promote market harmonization, economies of scale, infrastructure development, knowledge and research sharing, policy coordination, and investment attraction. Therefore, regional policy market integration is crucial for the development of the green hydrogen economy. Market integration can accelerate the transition to a sustainable and low-carbon energy future powered by green hydrogen.

Furthermore, the discussion on market integration in Africa is a top agenda of the flagship of Agenda 2063 “the African Continental Free Trade Area (AfCFTA)”. Although, it does exist policies related to regional integration in Africa including the free trade area of the Economic Community of West African States (ECOWAS).

CONCLUSION

This chapter presents and discusses the key findings of this research study, focusing on the applications of hydrogen on key sectors like oil refineries, ammonia and methanol production, iron and steelmaking, and transportation. It highlights the growth potential in the building sector and the ongoing research for green hydrogen applications and its future perspectives in African market. The chapter also discusses Africa's potential as a major exporter of clean hydrogen and the growing interest in the green hydrogen market. It emphasizes the need for effective governance and policy support to unlock the green hydrogen African market, particularly in sectors like fertilizer, power generation, transportation, and industries. The chapter also emphasizing the role of government and civil society in shaping the green hydrogen economy through sustainable policy solutions for African case.

CONCLUSION AND PERSPECTIVES

This study delved deeply into the application and use of hydrogen, technology maturity and pathway, and the green hydrogen future perspective. The results showed that hydrogen, in particular, green hydrogen can play a unique role in the entire energy system (including electricity, oil refineries, chemical industries, iron and steel making, transport and mobility, and buildings). From the heavy industrial use to domestic use, such as cooking and heating purpose.

Thus, green hydrogen is increasingly gaining momentum. This momentum is mostly driven by decarbonization commitments and the recognition of the fact that hydrogen is a versatile energy resource. Both as a commodity and energy source. For that reason, hydrogen applies to all energy-related economic activities directly or indirectly. Therefore, despite the technology maturity challenges and the investment cost barriers the demand for hydrogen and political will for a green hydrogen economy is increasingly growing.

Factors driving green hydrogen market potential in Africa include growing energy-related economic activities, population growth, and economic growth. However, the viability and potential for the adoption of green hydrogen across the continent depends on governmental frameworks. The framework that meets the energy demand, takes advantage of the availability of renewable resources and unlocks the technology breakthroughs.

The findings highlight that Africa possesses significant untapped potential for green hydrogen production, driven by its abundant renewable resources and growing energy needs. The continent offers low-cost market competitiveness. A study showed that if only 2% of its renewable energy capacity (17 TW) were used for green hydrogen production it would produce about 900 mtpa (million metric tonnes per annum) of hydrogen, equal to about 1.5 times the total global demand of 610 mtpa in 2050. Furthermore, the hydrogen domestic demand in Africa is expected to vary from 10 million tonnes of hydrogen per year (MtH2/year) in the current trajectory scenario to 20 for the achieved commitments scenarios by 2050.

The study found 52 ongoing projects in Africa to be implemented by 2030, which of majority focus on the following end-use sectors ammonia, mobility, and power sector. In addition, the Africa Green Hydrogen Alliance (AGHA) was launched in Barcelona on May 18, 2022, it constituted six African countries: Egypt, Kenya, Mauritania, Morocco, Namibia, and South Africa. These countries have announced their intention to intensify collaboration toward the development of green hydrogen projects on the African continent. Moreover, these countries have announced developing green hydrogen policy and some have developed a roadmap for green hydrogen development, including Egypt and Algeria.

However, Africa counts only 3% of global announced projects, and 90% of them are focused on export. Hence, the results pointed out that power generation, transport, and mobility, fertilizer, and industry are the most probable possible applications of green hydrogen in Africa. Nevertheless, the majority of participants in the survey believed that green hydrogen could make sense in the following timeframe:

(i) Short-term (2030): Fertilizer; power generation; and chemicals (ammonia and methanol)

(ii) Medium-term (2040): Seasonal storage; Transport (maritime); Steelmaking; and Off-grid application.

(iii) Long-term (2050): transport (Maritime and Rails); Glass production and mining; Buildings and heavy-duty transport.

Therefore, sectors such as fertilizer, power generation, transport, and mobility are one of the most expected hydrogen applications to unlock the hydrogen market in Africa, in particular West Africa. Though, it required effective governance and policy.

As the world transitions towards more sustainable energy solutions, green hydrogen stands out as a promising avenue for both decarbonizing various sectors and fostering economic growth in Africa. However, successful implementation will require collaborative efforts from governments, private sector players, and international stakeholders to create an enabling environment that incentivizes investment, research, and development.

The potential market for green hydrogen is significant, but there are challenges that need to be addressed. Therefore, further demand-driven analysis of the potential green hydrogen market could be a valuable research opportunity from the results of this work. The analysis could focus on the **demand projections** in West Africa, and build up a national survey method in the West African region for a larger participation. The analysis could project the demand for green hydrogen in different sectors, such as fertilizer, transportation, industry, and power generation.

Therefore, building a green hydrogen economy in Africa requires a clear and sustainable policy that secures hydrogen development and implementation. Hence, leverage strong partnerships and mobilize the necessary financing to ramp up African economies and help ensure that the continent thrives in the new global energy landscape.

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ANNEXES

A1. Results Of Hydrogen Application and Potential Sector Use

#	Sectors/ Subsector	Kind of use (Technology/process)	Global Demand of h2/year	Current greyH2 use (Quantity)	Global CO2eq Contribution (by sector)/ year (Quantity)	Status Quo/Future greenH2 use (Quantity)	Probability of greenH2 use	The perspective of greenH2 use (Time frame)	Relevance /policy priority of green hydrogen use to the sector
1	**Heavy Industry**								
1.1	Iron and steelmaking [1,2,5,7]	Reducing Agent / Direct reduced iron (DRI) [1,3,5]	4,3 Mth2 / 2020 [1]	Small [1,2,5]	Large [1]	R&D/ Large [1,5]	High (DRI) with CCS&CCUS [1,5]	Medium to Long-term [1,5]	Medium/High [1,5]
		Protection gas, welding [5]		Medium [5]		Small/ Medium [5]	high [5]		
1.2	Chemical production [1,2,5,7]	Ammonia [3]	30,9 Mth2 / 2020 [1]	Large [1,2]	Large [1]	small/Large [1]	High [1]	Medium-term [1,5]	Medium/High [1,5]
		Methanol [6]	12 Mth2 / 2020 [1]	Medium [1,2]	Large [1]	Small/Large [1]	High [1]	Medium-term [1,5]	Medium/High [1,5]
1.3	Oil Refineries [1,2,5,7]	Hydrocracking [1] Hydrotreating [1]	40 Mth2 / 2020 [1]	Large [1]	Large [1]	Large/… [1]		Medium to Long-term [1,]	Low/High [1,5]
1.4	High-temperature/Industrial heat [1,2,5,7]	Iron and Steel Chemicals Cement — Provide high heat temp. [1,2]		Large (as a by-product) [1,2]	Large [1]	Large/… [1,2]	Low due to cost-related [1]	Long-term [5]	Medium/Medium [1,5]

#	Sectors/ Subsector	Kind of use (Technology/process)	Global Demand of h2/year	Current greyH2 use (Quantity)	CO2eq (by sector)/ year (Quantity)	Status Quo/Future greenH2 use (Quantity)	Probability of greenH2 use	The perspective of greenH2 use (Time frame)	Relevance /policy priority of green hydrogen use to the sector
2	**Light industry**								
2.1	Food products(processing)/ [4,5,7]	Hydrogenation (saturation fats, sugar alcohols), packaging/conservation Refrigerant (ammonia), Bleaching, antimicrobial /sterilizing (H2 peroxide) Bleaching, antimicrobial /sterilizing [2,5]		Medium [5]		R&D/Medium [5]	High [5]	Medium to long-term [5]	High/…[5]
2.2	Semiconductors/ electronics and other machinery, and equipment [5,6]	Protection gas, carrier gas, leakage test, and cooling agent (ammonia also widely used in the electronics industry) [2,5]		Small [5]		…/Small [5]	High [5]	Medium to long-term [5]	Low / …[5]
2.3	Glass production [1,2,5,7]	Protection gas/protective atmosphere (with nitrogen) in float glass tin bath for high temperature (replacement of natural gas for burners) [2,5]		Small [5]		…/Small [5]	High [5]	Medium-term [5]	Medium / …[5]
2.4	Textile, wood, leather, rubber, pulp, etc. (Material processing) [5,7]	Reagent (bleaching, cleaning, and other treatments with H2 derivatives, including wastewater treatment, and purification of water) [5]		Small [5]		…/Small [5]	High [5]	Medium to long-term [5]	Low / … [5]

#	Sectors/ Subsector	Kind of use (Technology/process)	Global Demand of h2/year	Current greyH2 use (Quantity)	CO2eq (by sector)/ year (Quantity)	Status Quo/Future greenH2 use (Quantity)	Probability of greenH2 use	The perspective of greenH2 use (Time frame)	Relevance /policy priority of green hydrogen use to the sector
3	**Transport/ Mobility**								
3.1	Heavy-duty vehicles including trucks and buses [1,2,5,7]	Fuel [2,5]	30 kt/2021 [2,]			Small/large [2,5]	High [2,5]	Short-Medium [2,5]	High/Medium [1,5]
3.2	Light duty vehicles [1,2,4,5,6,7]	Fuel [2,5]		Small [5]		Small/large [2,5]	High [2,5]	Medium [5]	High/Medium [1,5]
3.3	Maritime transport (mainly cargo) [1,2,5,6,8]	Production of liquid fuels (ammonia, methanol, ethanol) [2,5]		Pilots (only derivatives) [5]		…/ large [5]	Medium [5]	Long-term [5]	High/High High/Medium [1,5]
3.4	Rails transport	Fuel [2,5]				Pilot/large [2,5]	High [5]	In the near term [2]	
3.5	Aviation [2,5]	Fuel [2,5]		Pilot (Experimental) for e-Kerosene (green H2) started [,5]		R&D/large [,5]	Medium to high [,5]	Long-term [,5]	Medium/ High (for the long haul) [1,5]
3.6	Space exploration (mainly future) [2,]	..		…		…	..	…	…
3.7	Fuel exports/energy carrier [5,8]	Hydrogen/ammonia/methanol as an energy commodity (hydrogen carrier) [5]		Low [5]		R&D/High [5]	High [5]	Medium to long-term [5]	Low/…[5]

#	Sectors/ Subsector	Kind of use (Technology/process)	Global Demand of h2/year	Current greyH2 use (Quantity)	Global CO2eq Contribution (by sector)/ year (Quantity)	Status Quo/Future greenH2 use (Quantity)	Probability of greenH2 use	The perspective of greenH2 use (Time frame)	Relevance /policy priority of green hydrogen use to the sector
4	**Buildings: residential and commercial, industry**								
4.1	Heating/ cooling [2,4,5,7]	Use of low heat from electrolyzes/ micro-CHP [5,]		Low (with natural gas) [,5]		Commercial start with green H2/large [,5]	Low [,5]	Long-term [,5]	Low/low [1,5]
4.2	Cooking (Blended h2 with natural gas and Methanol as fuel) [2,5]	Domestic use for Cooking [2,5]		..		R&D/medium [2,5]	Medium [2,5]		
4.3	Stationary uses (micro-CHP) [2,4,5,7]	Combined (low) heat and power supply to residential and commercial buildings, industry [2,5]		Low (with natural gas) [,5]		Commercial start with green H2/large [,5]	Low [,5]	Long-term [,5]	Low/Low [1,5]
4.4	Power (fuel cell) [2,4,5,6]	Fuel cell [2,]							Medium/Low [1,5]
4.5	Seasonal Storage [2,4,5]	Seasonal energy storage (focus electricity supply) [5]		…		…/large [5]	High [5]	Long term [5]	Medium/Low [1,5]
5	**Agriculture**								
5.1	Fertilizer production (ammonia) [1,2,3,5,7,8]	Production of nitrogen content [5]		Large [5]		Small/large [5]	High [5]	Medium-term [5]	High [5]

#	Sectors/ Subsector	Kind of use (Technology/process)	Global Demand of h2/year	Current greyH2 use (Quantity)	CO2eq (by sector)/ year (Quantity)	Status Quo/Future greenH2 use (Quantity)	Probability of greenH2 use	The perspective of greenH2 use (Time frame)	Relevance /policy priority of green hydrogen use to the sector
6	**Power**								
6.1	Direct use of h2 [1,2]	Pilot (with green H2, experimental) [2,5]		Pilot (Experimental) [2,5]		R&D/large [5]	Low [5]	Long-term [5]	Medium /…[5]
6.2	Electricity (via another fuel/blended h2/ gas turbine) [1,2]	Fuel liquid, methanol/ammonia/ syngas [2,5]		Low (pilots with green H2 and ammonia) [5]		R&D/ Small [5]	Medium [5]	Medium-term [5]	Low/… [5]
6.3	Seasonal Storage [2,4,5,8]	Seasonal energy storage (focus electricity supply) [5]		…		Pilot&R&D/large [1,5]	High [5]	Long-term [5]	Medium/ High [1,5]
7	**Mining and Quarrying**								
7.1	Fuel liquid, methanol as fuel [5,]	Methanol as fuel for transport, and power supply [5]		Low [5]		Pilot&R&D/ Medium[5]	Medium [5]	medium [5]	Medium/…[5]
7.2	Mining of metal ores and other – materials [5,]	Blasting agent (ammonia nitrate), extraction of some metals from ores [5]		Low (via ammonia) [5]		R&D/small [5]	Medium [5]	Medium-term [5]	Low/…[5]
7.3	Mining of metal ores and other – power supplies [5,]	Off-grid power/energy supply (Electricity generation and storage direct H2 / via ammonia) [5]		…		Pilot&R&D/small [5]	Medium [5]	Medium to long term [5]	Low/… [5]
7.4	Open pit mining of metal ores – vehicles [5,]	Heavy-duty, specialized vehicles (fuel) [5,]		…		R&D (experimental)/small-medium [5,]	Medium [5,]	Medium-term [5,]	Low/…[5,]

A2. Results Of Ammonia and Methanol Applications and Their Potential Sector Use

A2.1. Ammonia applications

#	Derivative/ Kind of use	Global Demand (chemical)/year	Traditional use of h2(Quantity)	CO2eq (by sector) (Quantity)	Status Quo of the use of greenh2 (Quantity)	Future greenH2 use in the sector (Quantity)	Probability of greenh2 in the sector	The perspective of greenH2 use (Time frame)
1	**Ammonia**							
1.2	Fertilizer/ Production of nitrogen content [1,2,3,5,7,8,9]	0.7*190 Mt/2021 [2]	Large [1,2,3,5]		Low [2,3,9]	Large [2,3,9]	High [2,3]	Short-medium term [2,3]
1.3	Explosive [7,8,9]		Low [2,]		Low [9]			
1.4	Fuel transport (Shipping or Fuel Cell) [1,2,7,8,9]				R&D [8,9]		High [2,8]	Medium [9]
1.5	Power generation/ Stationary Fuel [1,2,5,7,8,9]					Low [9	Medium [2,8]	Medium [9]
1.6	Chemicals Industries [3,8,9]	0.3*190 Mt/2021 [2]		Large [1,2,3,9]				
1.7	Plastics/Textiles/electronics [3,9]							
1.8	Energy carrier [1,2,5,8,9];				R&D [9]	Large [8,9]	High [2,8,9]	Medium-long [8]
1.9	water and waste treatment [9]							
1.10	Soda ash [3,8]							
1.11	Refrigeration and air-conditioning tech [8,9]							
1.12	Pharmaceuticals [9]							
1.13	Mining [9]							
1.13	Synthetic fabric [7,8,9]							

A2.2. Methanol Applications

#	Derivative/ Kind of use	Global Demand (chemical)/year	Traditional use of h2(Quantity)	CO2eq (by sector) (Quantity)	Status Quo of the use of greenh2	Future greenH2 use in the sector (Quantity)	Probability of greenh2 in the sector	The perspective of greenH2 use (Time frame)
2	**Methanol**							
2.1	Transportation fuels [6,5,10]				Low [6]	Large [6]	High [6]	
2.2	Fuel for cooking (DME or BioDME) [6,5,10]		Low [6]		Low [6]			
2.3	Synthetic gas/produces other chemical derivatives [1,2,6,10]	98 Mt/2019 [10]						
2.4	Power generation [6,5,10]			Large [2,6,10]	Low [6]			
2.5	Heat for industries [6,10]							
2.6	Blending fuels [1,2, 6,10]				Low [6]	Large [6]	High [6]	
2.7	Pharma [6]							
2.8	Construction [6,10]							
2.9	Plastic and products [10]							

A.3. POTENTIAL EXPORT-IMPORT OF AMMONIA, ANHYDROUS IN AFRICA

A.3.1. Ammonia, anhydrous exporter in Africa

Country	Trade flow	Quantity (t/yr)	Year	To where	Trade Value 1000USD	Source / URL
Ammonia; anhydrous						
Egypt	Export	459692	2021	world	259,828.51	WITS,2021
South Africa	Export	24219.6	2021	world	14,110.58	
Kenya	Export	73.916	2021	Rwanda, Tanzania, Uganda	167.99	
Rep. Congo	Export	21.364	2021	Cameroon	43.74	
Senegal	Export	4.488	2021	Mauritania, Guinea	36.42	
Morocco	Export	1	2021	Mauritania	2.14	
Tanzania	Export	0.1	2021	Rwanda	0.03	
Algeria	Export	148008	2021	Morocco, Senegal	55,052	WITS
Libya	Export	14,951.1	2021	Morocco	6,188.38	WITS
Namibia	Export	45.540	2021	Angola	12.76	WITS
Benin	Export	0.474	2021	Togo		

A.3.2. Ammonia, Anhydrous Importer in Africa

Country	Trade flow	Quantity (t/yr)	Year	From where	Trade Value 1000USD	Source / URL
Ammonia; anhydrous						
Morrocco	Import	1,653,580	2021	world	769,421.89	WITS,import
Tunisia	Import	188,166	2021	world	94,874.61	
South Africa	Import	158,652	2021	world	88,811.88	
Madagascar	Import	20,416,	2021	world	13,980.46	
Zimbabwe	Import	317,014	2021	South Africa	13,057.37	
Senegal	Import	22,346,400	2021	world	11,444.22	
Namibia	Import	4,084.4	2021	world	3,377.26	
Tanzania	Import	68.256	2021	world	170.74	
Kenya	Import	74.570	2021	world	99.17	
Mauritania	Import	42.744	2021	world	84.24	
Angola	Import	47.3	2021	world	13.13	
Benin	Import	7.512	2021	Nigeria, France	12.72	
Togo	Import	0.474	2021	Benin	0.94	

A.4. West African Country's Fertilizer Production

Country	Product	Quantity (Mt/yr)	Year	Source / URL
Fertilizer production				
Senegal	Monoammonium Phosphate	55,000.00	2021	AFO
	Diammonium Phosphate	30,000.00		
	Organic Fertilizer	1,400.00		
	NPK unspecified	105,000.00		
	Phosphate Rock	553,447.00		
Ghana	Organic Fertilizer	4,624.00		
Cote d'Ivoire	Organic Fertilizer	4,562.00		
Burkina-Faso	Organic Fertilizer	3,500.00		
	Phosphate Rock	2,400.00		
Togo	Phosphate Rock	1,456,368.00		
Nigeria	Urea	2,701,279.00		
Benin	Organic Fertilizer	15,000.00		
Mali	Organic Fertilizer	58,000.00		
	Phosphate Rock	65,000.00		

A.5. Existing and Planned Green Hydrogens Worldwide

A.5.1. A few Global Green Hydrogen and its Derivatives Projects by 2030-2050

Country	Company	Sector/Sub sector	Electrolyser Capacity [MW]	Capacity prod. (t/yr)	Focus	Start-up/Time frame	Backed By	Inv. Cost	Tech. pathway	Electricity source	Source/ URL
Germany	Shell starts up REFHYNE	Refinery	10	n/a	Green Hydrogen	2021/ long term	EU	n/a	PEM	Offshore wind	[2] REFHYNE project
Poland	ORLEN Południe	Refinery/chemical industry/transport	2	n/a	Green Hydrogen production/glycol/ fuel cell	2019/long term	n/a	n/a	Electrolyser	n/a	[2] ORLEN
Colombia	ECOPETROL GROUP	Refinery	0.050	20 kg/day exper.	Green hydrogen	2022/ long term if it succeeded	n/a	$2.5billion by 2040	PEM	Solar	[2] Ecopetrol
Denmark	HySynergy / Everfuels	Refinery/ industry/ transport	20 (Step I)	n/a	Hydrogen/ power to x facility/storage	2022/2030	Danish Ministry of Energy	n/a	Low carbon emission technology	Fluctuating renewable energy	[2] Denmark
Sweden	Fertiberia	Green ammonia/fertilizer	600	520k (ammonia)	Hydrogen/green ammonia/fertilizer	2021/long term	Swedish gov	around €1 billion	Electrolyser (water and air)	wind and hydropower	[2] Sweden
Swiss	hydrogen-fuelled stoves for cooking	Buildings	n/a		H2 Cooking stoves/ h2 blended in natural gas is been used	R&D / Swiss research institute Empa	n/a	n/a	n/a	n/a	[2] h2_stove
US/CHINA /CANADA	n/a	n/a	n/a	0.2 M	n/a	Operating today	n/a	n/a	Electrolyser and CCS-equipped plants	n/a	[2]

Note: TBD = to be determined

Country	Company	Sector / Subsector	Electrolyser Capacity [MW]	Capacity prod. (t/yr)	Focus	Start-up/ Time frame	Backed By	Inv. Cost	Tech. pathway	Electricity source	Source / URL
The USA	Lapis Energy El Dorado	Industry/ammonia	n/a	44k (h2)	Blue hydrogen/ammonia	2025	n/a	n/a	CCUS technology	Fossil based	[2] Eldorado
Denmark/France/ Chile	Methanol projects	Industry cement/transport/mobility	n/a	n/a	Hydrogen/ methanol/biofuels	n/a	n/a	n/a	n/a	n/a	[2] e.g.Biofuels
The USA	Lake Charles, Louisiana	Industry	n/a		Hydrogen/ methanol/	2020	n/a	$3.8 bn	Gasification and CCUS technology	Oil (petcoke)	[2] methanol
Germany, the UK, Japan, China and etc.	Fuel cell/ FCEV	Transport/mobility	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	[2]
Europe, Japan, Korea	Micro-CHP fuel cell	Buildings	n/a	n/a	Micro-CHP hydrogen-based	n/a	n/a	n/a	n/a	n/a	[2] e.g. ENE_FARM
Quebec, Canada	Hy2Gen	n/a	n/a	183k	Green ammonia	2025	n/a	n/a	Alkaline or PEM	Hydro	[9], (Hy2Gen AG, 2021)
China	Dalian Institute of Chemical Physics	n/a	n/a	1000 (e-methanol)	e-methanol	2020	n/a	n/a	CO2 and H2 from water electrolysis	Solar	[10], AAAS, 2020
Germany	Dom	n/a	n/a	200k (e-methanol)	e-methanol	n/a	n/a	n/a	CO2 and H2 from water electrolysis		[10], Schmidt, 2020

A.5.2. African Green Hydrogen and its Derivatives Projects by 2030-2050

AFRICAN PROJECTS											
Country	Company	Sector / Subsector	Electrolyser Capacity [MW]	Capacity prod. (t/yr)	Focus	Start-up/ Time frame	Backed By	Inv. Cost	Tech. pathway	Electricity source	Source / URL
Kenya	Maire Tecnimont	Fertilizer	n/a	45k	Green ammonia	2025	n/a	n/a	n/a	Solar, geothermal	[9], Kenya
Mauritania	CWP (Project Aman)	n/a	n/a	11425k (ammonia)	Green H2 and PtX (ammonia)	TBD	n/a	$40 b	n/a	Wind, solar (30 GW)	[9], Mauritania, a , b
Mauritania	Chariot (Project Nour)	n/a	n/a	n/a	Green H2 for export	n/a	n/a	n/a	n/a	Wind, solar (10 GW)	a , c
Mauritania	ArcelorMittal (Green Steel)	Steel industry	n/a	2.5 M (green steel)	Green h2 for green steel	n/a	n/a	n/a	n/a	n/a	a , d
Egypt	ThyssenKrupp	n/a	n/a	TBD	Green h2, ammonia	TBD	n/a	n/a	n/a	n/a	[9], Egypt
Egypt	US-based Plug Power	Green ammonia/ fertilizer	100	90k (ammonia)	Green ammonia	2024-planned to start	n/a	n/a	PEM	n/a	[2]EBIC_EGYPT
Jorf Lasfar, Morocco	OCP, Fraunhofer IMWS	n/a	n/a	0.7 k	H2, ammonia, fuel (Shipp)	TBD	n/a	n/a	n/a	Solar	[9], AYII ,Brown
Rabat, Morocco	Fusion Fuel	Fertilizer	n/a	183k (green ammonia)	Green ammonia	2026			PEM	Wind, Solar	[9], Marroco
Namibia	HYPHEN Hydrogen Energy	n/a	n/a	300 k (green h2)	green hydrogen & ammonia product	2026	n/a	$9.4 b	n/a	n/a	Namibia, Nam

Note: TBD = to be determined

Country	Company	Sector / Subsector	Electrolyser Capacity [MW]	Capacity prod. (t/yr)	Focus	Start-up/ Time frame	Backed By	Inv. Cost	Tech. pathway	Electricity source	Source / URL
South Africa	Sasol Ltd	Refinery/ Aviation	TBD	TBD	Green hydrogen and Power to liquid (fuel)	End of 2021	Germany	n/a	Electrolyser + Biomass as a source of carbon	Renewable sources (TBD)	[2] Sasol
Angola	Sonangol	Export to Germany		280k (green ammonia)	GH2, via ammonia	2024 (export)				Hydro (400 MW from 2GW installed capacity)	Pt, Sonan1, sonan2
Tunisia	GIZ	n/a	n/a	6M (h2)	GH2 and its Derivatives	Launched 2022 and 2050 export target	n/a	n/a	n/a	n/a	GIZ , GIZ2
Algeria	n/a	n/a	n/a	n/a	Green hydrogen	By 2040/2050	n/a	n/a	n/a	n/a	Alg, alg2
West Africa (ECOWAS REGION)											
Niger	EMERGING ENERGY CORPORATION (EEC)	n/a	n/a	n/a	Feasibility study for green hydrogen production	Agreement signed 2022	n/a	n/a	n/a	n/a	iH2 , EEC, Article
Guinea	MAHYTEC	n/a	n/a	n/a	Supply of a dialysis center thanks to a solution including hydrogen energy storage	2020	n/a	n/a	n/a	n/a	Article ; iH2 ; MAHYTEC
Mali	HYDROMA	n/a	n/a		Deposit exploitation natural hydrogen						Article, iH2
Ivory Coast	iH2 IVOIRE HYDROGENE	Transport and mobility			Green hydrogen for bus (Demonstration purpose)	CAP 2023					iH2-CAP2023 , iH2-news

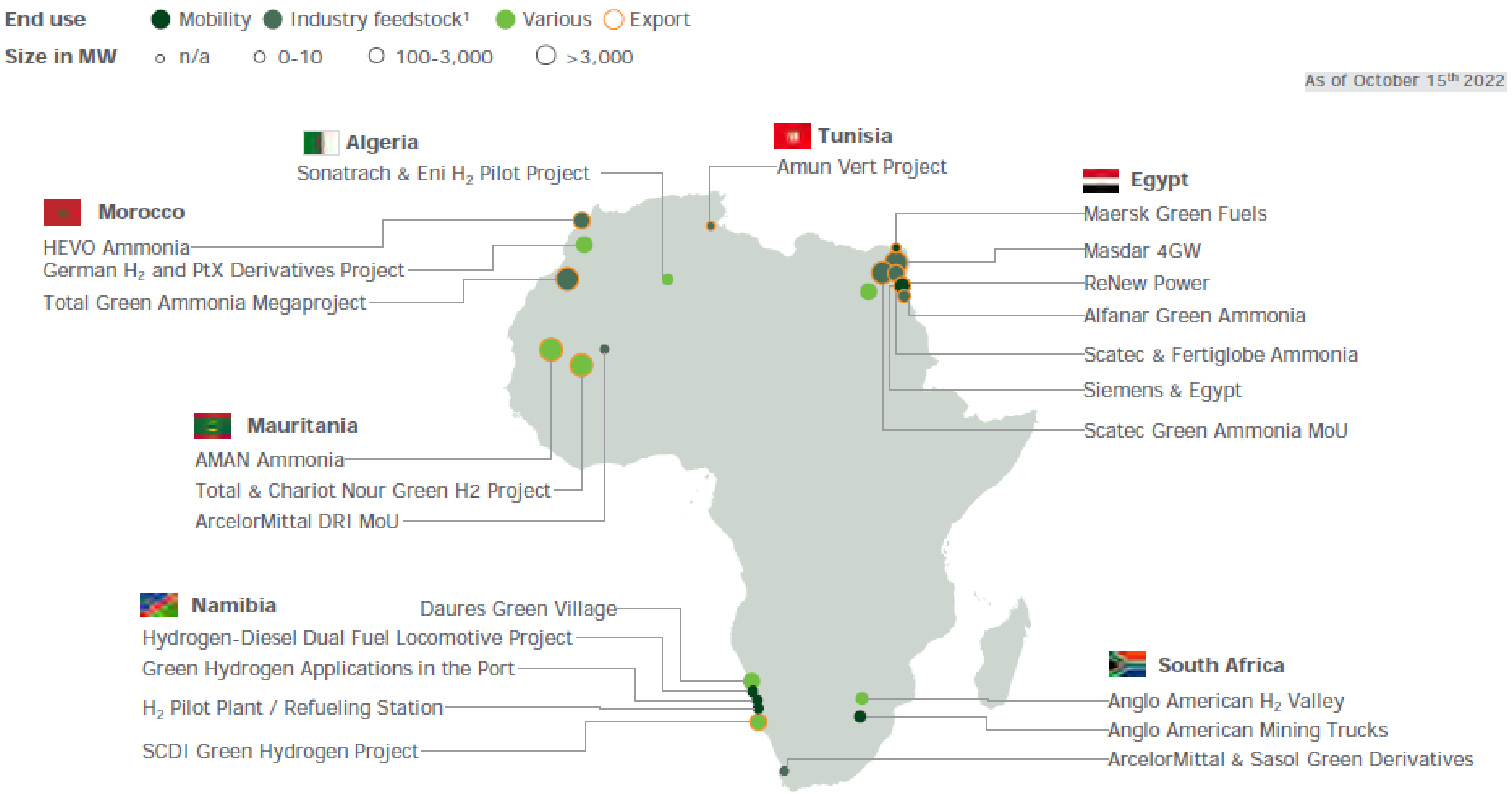
A.6. Green Hydrogens Roadmaps, National Strategies, And Policies In Sub-Saharan African Countries

Country	Title	Focus	Key Strategy Target	Policy recomendation	Roadmap pathway implementation	Status	Policy and Framework that support green economy	Source / URL
Morocco	Policy recommendation to implement the NRmap	Design National Roadmap for Green Hydrogen	Strategic positioning; Implementation and support; Governance	This provided 10 policy reccomendtion for GH2 Rmap	Technological developments and cost savings; investment and procurement; market and demand- Those axes are translated into eight identified actions to take for 2050.	published in 2021		[11]
South Africa	Securing a clean, affordable and sustainable energy future for South Africa	Facilitate implementation of Hydrogen Society Roadmap			South Africa identify 6 pathways, which translated into 70 key actions	2021		[12]; Climate Champions
Kenya	Baseline Study on the Potential for Power-to-X / Green Hydrogen in Kenya	To identify the potential use of green hydrogen, including PtX opportunities, Action Plan Outline, and Investment Perspective	Conducted baseline study to identify key pathway for hydrogen economy in Kenya		Identified #5 industrial pathways to further pursue the use of green hydrogen, these include: Fertilizer, industrial processes, transport and mobility, for a large-scale use, and isolated use/ off-grid. This is defined based on short-, medium- and long-term time frame and supported by ACTION PLAN structured upon 6 actions	2022	Green Incentive Policy Framework; NDC Strategy; Long Term Low Emission Development Strategy (LTS) 2050; National Climate Change Fund (CCF); Kenya Vision 2030	[5], Climate Champions

Note: NDC= Nationally Determined Contribution

Country	Title	Focus	Key Strategy Target	Policy recomendation	Roadmap pathway implementation (incl. action plans)	Status	Policy and Framework that support green economy	Source / URL
Namibia	Namibia Green Hydrogen and Derivative Strategy	Definition of strategic and realistic achievable market share	• 2030: 1-2 Mtpa hydrogen equivalent • 2040: 5-7 Mtpa hydrogen equivalent • 2050: 10-15 Mtpa hydrogen equivalent		To fostering sustainable pathway Namibia set up 6 strategy and action plan to 2025 clustered into three and under 12 actions, therefore Namibia is on the road of developing Roadmap for hydrogen	2022	Reduction of GHG emission by 91% by 2030; Aspired to support the global transition to net-zero, Set a major exporter of Gh2 and derivatives;	[13]; CC; NamH2;
Mauritania	Is under preparation by the government.				Is under preparation by the government			Maur , CC
								[5]

A.7. Green hydrogen projects in Africa



Source: Masdar (2022). Abu Dhabi Sustainability Week.

B.1. Survey's Results: Projected future volumes of green hydrogen applications in Africa

#	Sector	Irrelevant for the African case ((people)	Low (people)	Medium (people)	High (people)
1	Steel Making	7	17	16	11
2	Chemicals (ammonia and methanol)	9	19	16	7
3	Maritime (mainly cargo)	13	10	23	5
4	Industrial heat	13	12	16	10
5	Glass production	19	10	11	11
6	Fertilizer	6	17	16	12
7	Heavy-duty vehicles	15	9	19	8
8	Mining and Quarrying	12	12	15	11
9	Oil Refineries	14	11	18	8
10	Power Generation	4	10	23	14
11	Light duty vehicles	7	19	16	9
12	Off-grid Applications	7	21	21	2
13	Rails	21	13	12	5
14	Buildings	10	17	16	8
15	Seasonal storage	7	14	25	5
16	Backup Power	10	20	19	2

Appendix

C1. Global Low-carbon hydrogen projects data base (Excel File)

C1.1. Excel_Data_base

C2. African Low-carbon hydrogen projects data base (Excel File)

C2.1. Excel_Africa_Data_base

C3. Survey Data Analisys (Excel File)

Excel_Survey_Data_Analisys

C4. Survey Questionnaire

General Information

	Question	Answer
1	Professional affiliation*	◯ Academia; ◯ Industry ◯ Government/Public Institution ◯ Civil Society/NGO/Youth Movement; Student; ◯ Other:
2	Job position	
3	Name of the organization, company, or institution	
4	How many years of experience do you have in the Energy field? (Please provide your answer in numerical format)	
5	How many years of experience do you have in the Hydrogen field? * (Please provide your answer in numerical format)	

Experience with the African context

	Question	Answer
1	Have you been directly or indirectly involved in an African project (program, organization) about green hydrogen or its derivatives?	○ Yes ○ No
2	If yes, in which region have you been working?	☐ North; ☐ West; ☐ Central; ☐ East; ☐ South.
3	In which country?	
4	Do you see a local African market for hydrogen and its derivatives, or only as an energy carrier for export?	○ Only for export ○ The domestic market as well
5	If for domestic market, which means of transport (from the production to end-users) do you foresee as suitable for African case?	☐ Shipping; ☐ Tankers; ☐ Pipelines; ☐ Others;
6	Which of hydrogen (Green, Grey, Pink, blue) or its derivative (ammonia, methane, methanol) is projected to have higher market demand and export potential as a commodity (in case of multiple answers, please list them and order them by higher probability)? *	
7	What are the most probable hydrogen applications that you foresee in the local African market (in case of multiple answers, please order them by higher probability)?	

Green hydrogen opportunities for specific industrial pathways to ramp up the green hydrogen market in Africa

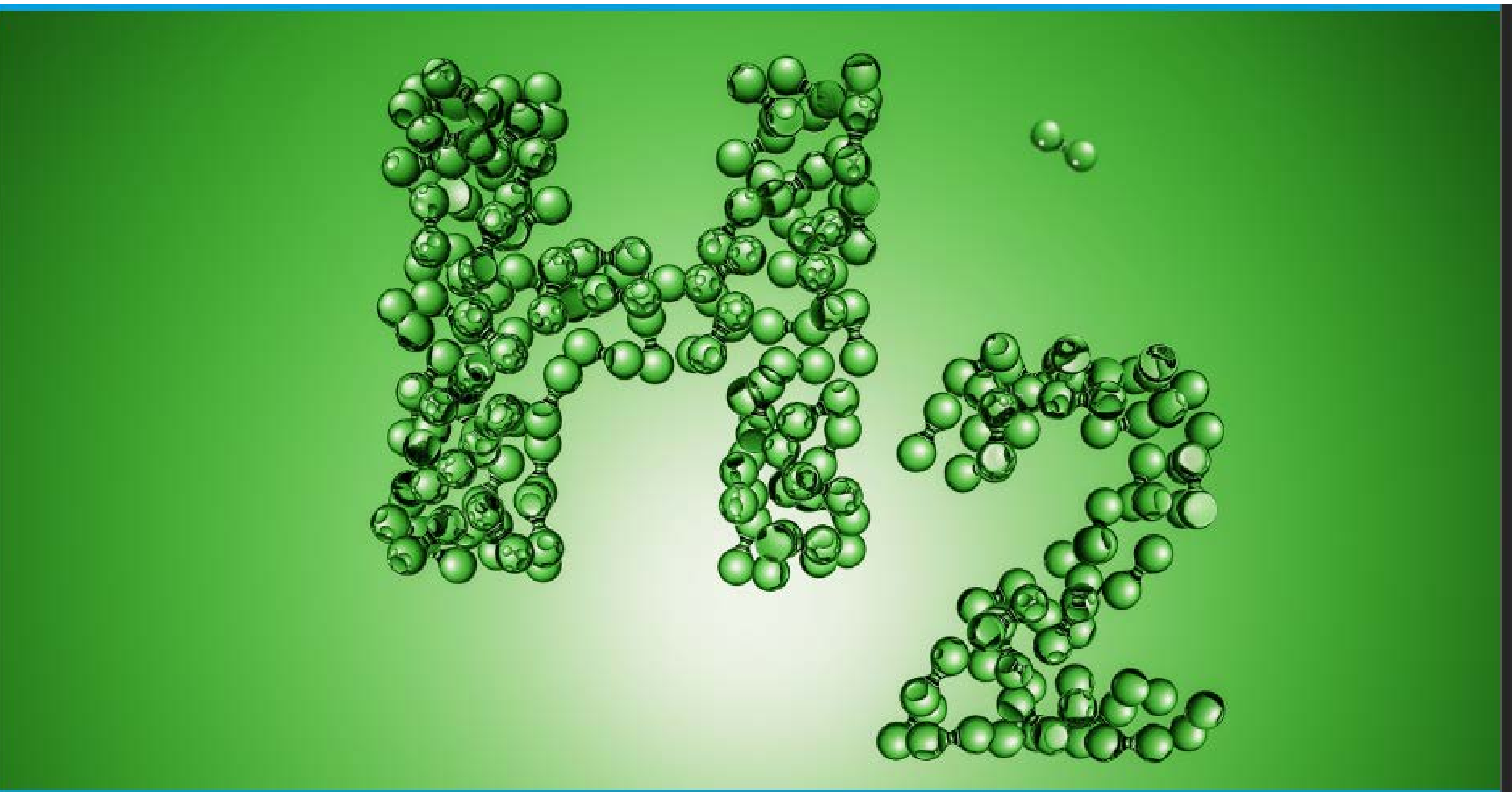
1. What are the projected future volumes of green hydrogen applications in Africa?

		Low	Medium	High	Irrelevant for the African case
1	Steel Making	[]	[]	[]	[]
2	Chemicals (ammonia and methanol)				
3	Maritime (mainly cargo)				
4	Industrial heat				
5	Glass production				
6	Fertilizer				
7	Heavy-duty vehicles				
8	Mining and Quarrying				
9	Oil Refineries				
10	Power Generation				
11	Light duty vehicles				
12	Off-grid Applications				
13	Rails				
14	Buildings				
15	Seasonal storage				
16	Backup Power				

2. In which applications do you see green hydrogen playing a key role in Africa in the short, medium, and long term? (Please tick as many as apply)

		Short-term (2030)	Medium (2040)	Long-term (2050)
1	Steel Making	[]	[]	[]
2	Chemicals (ammonia and methanol)			
3	Maritime (mainly cargo)			
4	Industrial heat			
5	Glass production			
6	Fertilizer			
7	Heavy-duty vehicles			
8	Mining and Quarrying			
9	Oil Refineries			
10	Power Generation			
11	Light duty vehicles			
12	Off-grid Applications			
13	Rails			
14	Buildings			
15	Seasonal storage			
16	Backup Power			

Please feel free to comment or add any missing point



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