INNOVATIVE RENEWABLE ENERGY TECHNOLOGIES FOR CLIMATE CHANGE MITIGATION AND ECONOMIC DEVELOPMENT IN AFRICA: THE POTENTIAL OF GREEN HYDROGEN IN KENYA

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by

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ABSTRACT

Emerging economies can grow and simultaneously reduce and avoid greenhouse gas emissions (CSIS, 2020). However, energy poverty and the adverse effects of climate change continue to hinder rapid economic growth in developing countries. The current green hydrogen momentum presents opportunities for developing countries to accelerate and expand progress in ensuring universal access to clean, affordable, and reliable energy while protecting the environment. This study seeks to explore how Kenya, a regional leader in renewable energy development and deployment, can adopt the use of green hydrogen to diversify its fuel sources, create jobs, and offer energy systems stability while supporting economic development goals. It provides policy recommendations to support the sustainable development and deployment of green hydrogen in Kenya.

BIOGRAPHICAL SKETCH

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Disclaimer: While I strived to ensure accuracy, any errors and omissions are my own and do not represent the views of the above experts.

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LIST OF ABBREVIATIONS

AfDB	African Development Bank
AHA	Africa Hydrogen Alliance
AHP	African Hydrogen Partnership
CCS	Carbon Capture and Storage
EACC	Ethics and Anti-Corruption Commission
ETAF	Energy Transition Accelerator Financing
GH2	Green Hydrogen Organization
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GW	Gigawatts
JICA	Japan International Cooperation Agency
kWh	Kilowatt per hour
LCPDP	Least Cost Power Development Plan
Mt	Million tons
MW	Megawatts
PPPs	Public-Private Partnerships
SDGs	Sustainable Development Goals
UNECA	United Nations Economic Commission for Africa
USAID	United States Agency for International Development

1 INTRODUCTION

Climate change, one of the grand challenges of our time, is one of the major hindrances to sustainable development globally. Developing and emerging economies particularly face unique challenges. On the one hand, these countries need to increase access to modern energy to end energy poverty and, on the other hand, do so without expanding their GHG footprint, even though it is significantly low (less than 2% of global emissions) compared to developed countries. Without urgent collective action and investment, by 2060, 75% of global emissions will come from developing countries (GEAPP, 2022). For these countries, tackling poverty, including energy poverty, remains a top priority, and considering the impacts of climate change and vulnerability levels, these countries need to accelerate energy access while limiting greenhouse gas (GHG) emissions.

The current global proliferation of renewable energy makes this possible. African countries can meet electricity demand to advance economic growth and still meet the carbon dioxide emissions goals using renewables as a sustainable route (AbouSeada & Hatem, 2022). Kenya, East Africa's most advanced economy, has seen renewable energy production grow over the years (Takase, Kipkoech, & Essandoh, 2021) currently at 92% of the country's energy mix (MoE, 2022). This backs the Kenyan government's commitment to transform the energy sector towards a low-carbon economy that serves the growing needs of the increasing population. Kenya is also keen to be a global investment choice for clean energy-powered industries (MoE, 2022).

Green hydrogen provides Kenya with low carbon market-oriented economic growth opportunities. Green hydrogen is hydrogen produced from surplus renewable energy (IRENA, 2020; GH2, 2022) and has been identified as a critical contributor to the global clean energy transition. It can be used as both a commodity and as an energy source (Tractebel Engineering GmbH, 2022). Experts refer to green hydrogen as a “gamechanger in the fight against climate change” (Nelson, et al., 2020, p. 44). It can be used to decarbonize the hard-to-abate sectors such as transportation, industry, agriculture, and mining. It is one of the most promising technologies that can be integrated into global energy delivery infrastructure owing to its high energy content (AbouSeada & Hatem, 2022).

As renewable energy continues to shift the energy map, green hydrogen opens new opportunities for developing and emerging countries to play a critical role in the clean energy transition. In Africa, countries such as Kenya, South Africa, Morocco, Namibia, Mauritania, and Egypt, through the Africa Green Hydrogen Alliance (AGHA), are committed to a high-energy future powered by green hydrogen (GH2, 2022). This new alliance seeks to position Africa as a green hydrogen hub operating in the domestic, regional, and international markets (Tractebel Engineering GmbH, 2022).

The Centre for Strategic and International Studies observed that it is hard for "an emerging economy to lead—but there is a difference between being an early or a late adopter" (CSIS, 2020). They further note that emerging countries must have the ability to adopt these emerging technologies once they have matured and not necessarily take up leadership in research and development. Kenya, as a clean energy leader, is well placed to lead the region in developing a thriving green hydrogen economy.

This paper explores green hydrogen as a new emerging clean fuel that can help countries increase access to clean energy while limiting GHG emissions. The author explores opportunities for Kenya and suggests a pathway to green hydrogen in the country, discussed in chapter four.

1.1 Background and Problem Identification

Climate impact

Many developing countries are most vulnerable to climate change (Lyes Bouchene, 2021), posing disproportionate risks to people and systems (United Nations Climate Change Secretariat, 2018). As a result, these vulnerable countries are taking steps to address climate change and lead climate response (UNFCCC, 2021). Despite a low emitter, Kenya remains one of the most vulnerable countries to the effects of climate change. In response to this, the government of Kenya has aligned its current policies and programs to the country’s adaptation and mitigation commitments, including energy sector plans.

As noted in the country’s updated Nationally Determined Contributions (NDC), there has been an increase in the frequency and intensity of extreme weather events in Kenya over the last ten years (MoEF, Kenya, 2020). This has exacerbated the negative impact on the lives of the affected population, including loss of life, assets, migration, and conflict. In response to this rising climate challenge, the country envisions a low carbon and climate-resilient economy through various adaptation and mitigation strategies. These strategies include afforestation, reforestation, **clean energy development,** and climate-smart agriculture.

Clean energy development

Kenya is one of the leaders in clean energy use globally, generating 92.3% of its energy from renewable resources (KNBS, 2021). Over the last decade, the country has made significant progress in increasing access to electricity. Currently, more than 70% of the population has access to electricity as of 2019 data and up to 71.4% in 2020 (The World Bank, 2020). This is a significant growth compared with 2010, when only 19.20% of the population had electricity access (Our World in Data, 2022).

Despite the high growth in electricity access, over 25% of the population still lack access to clean, affordable, reliable, and sustainable electricity, with millions relying on dirty fuels for basic energy needs such as cooking and heating. The country still has a low per capita electricity consumption at 164 Kilowatt-hours (kWh) compared to other middle-income countries, such as South Africa at close to 4000 KWh per capita (MoE, 2022). The energy ladder places energy access levels for basic human needs at 50 to 100 kWh, productive uses such as agriculture, and processing at 500 to 1000 kWh, and modern society level, which is domestic appliances use, cooling, and heating at 2000 kWh (Sovacool, 2012). This puts Kenya on the low level on the energy ladder, and equity used to measure energy poverty, meaning a significant portion of the population is energy poor. Therefore, efforts to increase access to modern energy are critical. This will, in turn, help lift millions of Kenyans out of poverty by improving the citizens' access to education, healthcare, and security and enabling them to run equipment with clean, modern energy and expand their businesses. Additionally, affordable, and reliable energy is essential in supporting the achievement of all development goals (Sovacool, 2012).

Looking at this in totality, tackling energy poverty and ensuring access to affordable and reliable, sustainable, and modern energy to all citizens remains the country’s priority. Doing so while limiting emissions is critical and possible though challenging. New emerging clean energy technologies create opportunities to bridge clean energy access, protect the environment and spur economic growth through green jobs and industries. Green hydrogen is one such technology that is undergoing increased attention from governments and businesses as an alternative fuel in the decarbonization agenda. It creates opportunities for Kenya to develop innovative clean energy solutions and support a climate-smart economy.

This study explores the extent to which green hydrogen can support Kenya in achieving a high-energy, low-carbon future. It is based on the energy sector growth trajectory showing that Kenya is on track to transforming its power sector to reach its goal of 100% electrification by 2030 (Ministry of Energy, Kenya, 2015) (World Bank, 2018) and increase per capita consumption to above 3000 kWh by 2040 from the current 164 kWh. To meet this goal, Kenya is committed to increasing green energy production and consumption toward a low-carbon industrialized economy (Ministry of Energy, Kenya, 2022).

1.2 Purpose

This study aims to analyze the potential of green hydrogen in supporting sustainable economic development while protecting the environment and seeks to offer a pathway and policy recommendations supporting the development of green hydrogen in Kenya.

1.3 Objectives

The study aims to address the following objectives:

1. To identify opportunities for green hydrogen development and deployment in Kenya
2. To explore areas in which Kenya is well poised to develop green hydrogen
3. To identify possible pathways for Kenya's green hydrogen economy and offer recommendations suitable for Kenya's national context policy making and project design.

1.4 Scope

Green hydrogen is gaining momentum as a fuel for the future owing to its potential to decarbonize hard-to-abate sectors such as long-distance transport, mining, agriculture, and industries (IRENA, 2020). This paper therefore focuses on green hydrogen's potential to protect the climate while powering green economy for Kenya and the region. The study aims to provide a green hydrogen pathway for Kenya as well as build contextualized knowledge at a time in which we do not have enough research on green hydrogen in developing countries.

Geographically, the study narrows down focus on Kenya, a country with high renewable energy use and potential. The country also recently launched the baseline study on green hydrogen opportunities and challenges in the country indicating government alignment to the growing recognition of green hydrogen (Tractebel Engineering GmbH, 2022). The baseline offers a starting point for Kenya's green hydrogen economy. It details possible industrial pathways; possible production locations based on existing renewable resources and infrastructure and further provides an action plan for deployment, which are further discussed in this study.

The paper also contributes to the field of energy transition systems policies for emerging and developing countries by investigating this new and emerging clean alternative fuel for the future. The study does not focus heavily on the technology needed for green hydrogen production which continue to mature over the years.

The paper is organized in to five chapters, introduction which covers the problem, scope, assumptions, and methodology. Chapter two looks at Kenya's energy profile and general country operating environment; political, economic, social, and technological overview. Chapter three looks at green hydrogen in general and chapter four narrows down to green hydrogen in Kenya. Chapter five offers conclusions and recommendations to advance green hydrogen in Kenya drawn from the literature review, interviews, and conferences

1.5 Significance

This paper is timely given the growing interest and investments going into green hydrogen globally including in Africa. The African Hydrogen Partnership (AHP) which aims to lay the foundation for hydrogen economies and societies in Africa identifies green hydrogen as a cutting-edge technology with great social economic benefits for Africa (AHP, 2021). GHG notes that more research is needed to support the development and deployment of green hydrogen (Nelson L. L., 2020) particularly as green hydrogen markets grow, and pilot projects kick start.

Currently, there is little research about the potential of green hydrogen in Africa with most studies focusing on Europe and North America. This study aims to contribute to the body of research in green hydrogen, particularly for Kenya, granted its production and market opportunities potential. Additionally, as the country seeks to expand its manufacturing sector particularly in steel and iron production, the paper presents ideas on how green hydrogen presents unique opportunities for clean industries.

The paper is also aligned with the UNFCCC Paris Agreement NDC plans to meet zero emissions and Kenya’s development blueprint vision 2030, which seeks to grow the economy through industrialization.

1.6 Assumptions

This paper assumes that Kenya has growing political will and drive to ensure 100% clean energy and meeting its nationally determined contributions to mitigate the adverse effects of climate change. The study assumes that renewable energy will proliferate to support industrial growth while protecting the environment (Takase, Kipkoech, & Essandoh, 2021).

The study assumes that the government of Kenya is committed to green hydrogen production and deployment as a strategic decarbonization intervention. This assumption is supported by the recent launch of the baseline study on green hydrogen in Kenya prepared for the Ministry of Energy by Tractebel Engineering GmbH with support from Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, which seeks to guide the green hydrogen development work in Kenya. This baseline report is discussed further in this study and referenced extensively as the initial green hydrogen research on Kenya.

Kenya recently joined the Africa Green Hydrogen Alliance (AGHA) during the May 2022 Green Hydrogen Organization Forum in Barcelona (Climate Champions, 2022) which helped the author draw the assumption that the country is committed to supporting the global clean energy transition through partnerships. The author also assumes that Kenya will benefit from more local expertise while developing and deploying the green hydrogen projects. The baseline by Tractebel Engie identifies capacity building to help build a local green hydrogen workforce as key factor in driving success.

This study assumes that there will be capital flows going towards the development of green hydrogen projects in the next five years for short-term projects and 15-20 years for a longer time. The report also assumes that green hydrogen will pick up globally to support market growth and enable Kenya to penetrate the green hydrogen export space in future.

A green hydrogen economy while new is vast and multidimensional; this study narrows down to 3 critical pathways; agriculture, industry, and transport, which have been informed by scientific and industry research and from interviews with subject matter experts.

1.7 Methods and Literature

This study which is situated in the field of global development, international development economics, and policy, seeks to explore a pathway for green hydrogen production in Kenya. The study analyzed secondary data which is noted as a cost-efficient approach (Xylia & Silveira, 2016) given the time limitation to conduct the study. The study used recent scientific papers, grey literature on green hydrogen, and reports on Kenya. The study focuses mainly on papers written between 2015 and 2022 on green hydrogen. However, the history section covers older literature. The author picked 2015 as the key year to link the grown of alternative fuels to the Paris Agreement commitment. As observed in several literature reviewed by the author during the Energy policies or systems transformation course (Silveira, 2022), Paris Agreement was critical moment in the energy and climate ecosystem.

The paper also includes presentations from conferences attended during the study period particularly the Africa Green Hydrogen Forum organized by the Africa Hydrogen Partnership in November 2021, the Powering Africa Summit which took place in March 2022, Green Hydrogen Standard and Certification forum and other virtual energy transition events. The author also conducted interviews with subject matter experts with national and international profiles from institutions listed in annex one with guiding questions highlighted in annex two, however, names have been left out to maintain confidentiality for all stakeholders. While the author recognizes the value names would have added to the paper, anonymity is preferred as this is a new and emerging technology. Conclusions and recommendations have been drawn from the literature, conferences, and interviews.

In line with Cornell university IRB requirement, the research body was informed that the study does not involve human subjects and therefore authorization was not required.

2 OVERVIEW OF THE KENYA ENERGY SECTOR

2.1 Kenya's Energy Profile

Kenya has one of the most developed power sectors in sub-Saharan Africa with a 71.4% electricity access as of 2020 (World Bank) as illustrated in figure 6 compared to overall Sub-Saharan Africa access currently at 48.4% World Bank 2020. This indicates the country's commitment to achieve Sustainable

Development Goal (SDG) seven on ensuring access to affordable, reliable, sustainable, and modern energy for all its citizens.

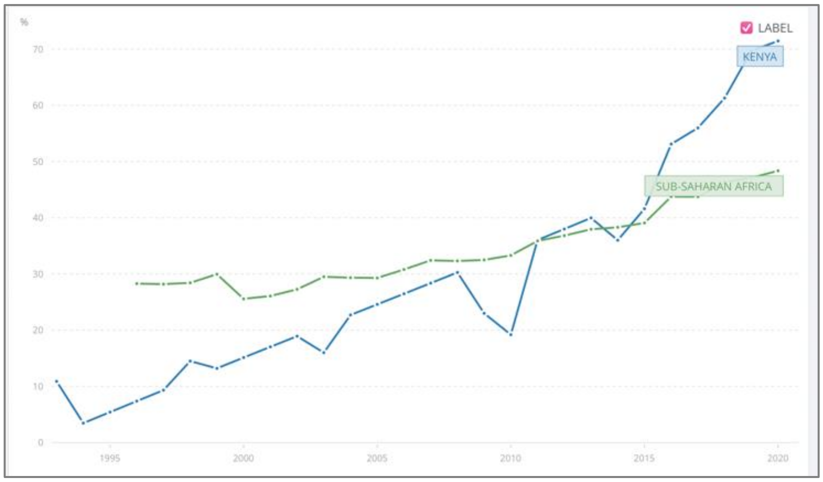


Figure 1: Access to electricity in Kenya, and Sub-Saharan Africa. Source World Bank

The country's energy mix has grown over the last decade with 92.3% coming from renewable sources (KNBS, 2021). Geothermal (863MW), hydro (834MW), and wind (336MW) sources are leading in Kenya's current installed electricity (KNBS, 2021) of the 2836.7 installed[1] capacity as illustrated in figure two below.

[1] Kenya's effective capacity is 2,705.3MW. Effective capacity is the maximum electric output capacity a power station can give in the context of its operating challenges. (KNBS, 2021)

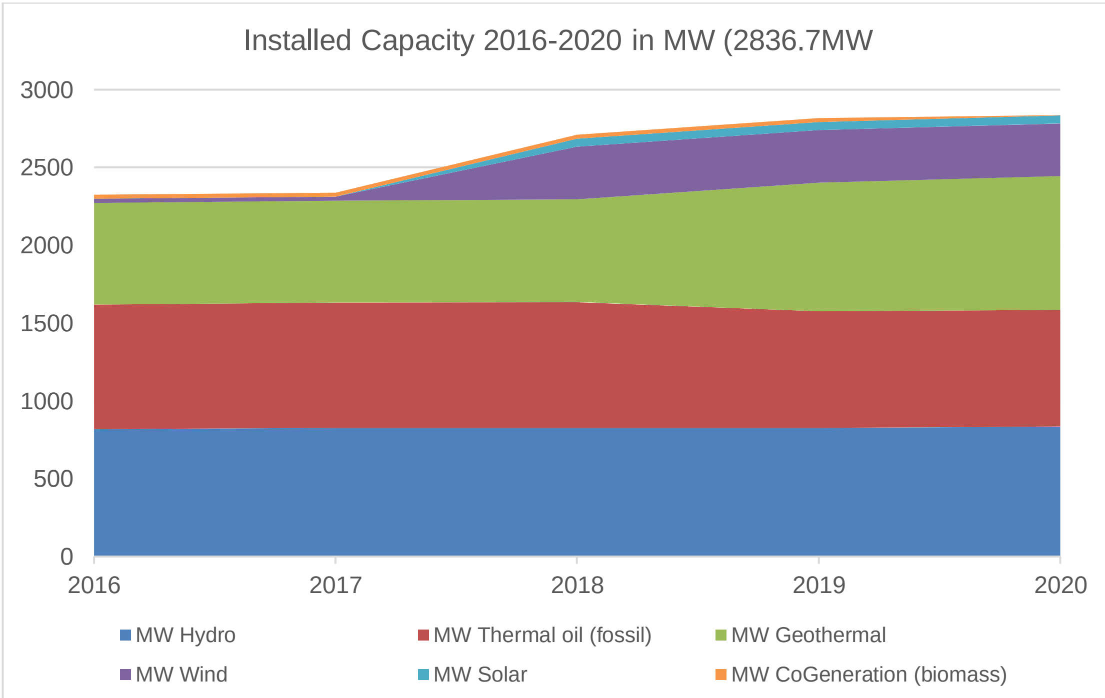


Figure 2: Kenya's energy mix

Source and notes: KNBS economic survey 2021

- 2020 numbers provisional from Kenya Power & Lighting Company (KPLC)
- Installed capacity is the maximum theoretical electric output a power station could produce on 100% operation

Solar energy has been increasing with a notable 3% increase in 2020 to 52.5MW. New projects such as the Lake Turkana Wind Project (LTWP), the largest wind farm in Africa adds 17% of renewable capacity to the national grid through its 365 wind turbines with a total capacity of 300 MW (AfDB, 2015). Kenya's energy sector strategic plan has set a target of increasing energy production to 100GW by 2040 (MoE, 2022). However, Kenya is only using 2% of its renewable energy capacity as shown in figure three, the 98% (MoE, 2022) unused capacity places Kenya at an advantageous position to lead the region in green energy production and consumption.

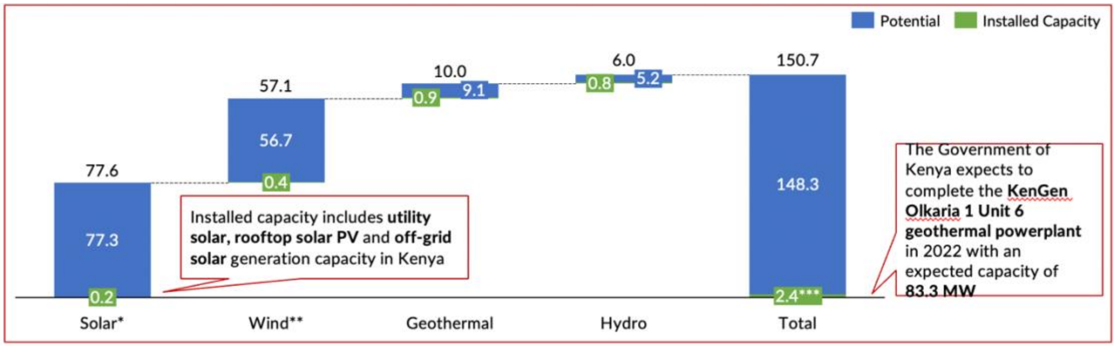
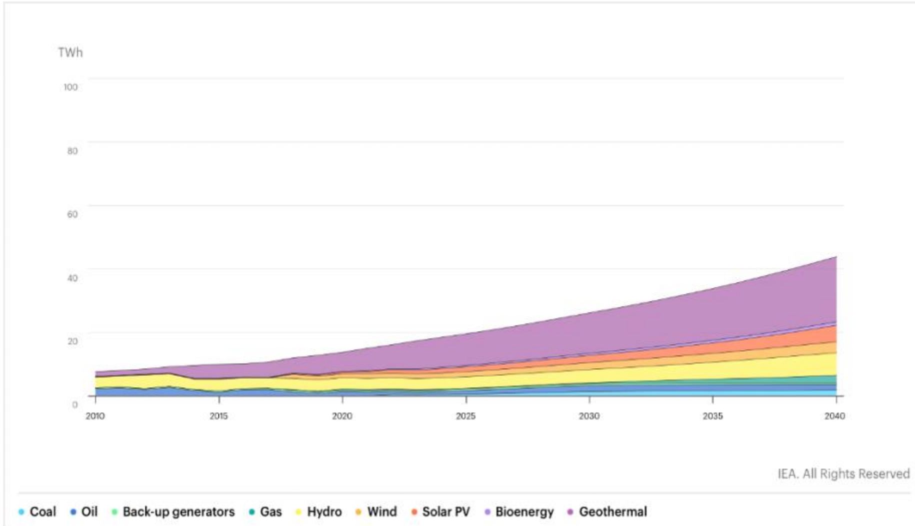


Figure 3 Kenya's RE installed vs potential capacity. Source MoE

Additionally, the International Energy Agency *(IEA, 2020)* projects a rise in renewable energy with geothermal, solar, and wind expected to have the highest growth in Kenya's electricity generation by technology in stated policies scenario 2010-2040 projects as illustrated in figure four below. Geothermal will account for nearly 50% of Kenya's generation mix *(IEA, 2020)* with an estimated potential of 10GW which strengthens Kenya's case in production of green hydrogen from this unexplored capacity.



Appears in
Kenya Energy Outlook

Figure 4 Kenya Electricity Generation by Technology. Source IEA

This growth will enable Kenya to increase energy[2] consumption per person which is currently low compared to other middle-income countries as illustrated in figure five below (Our World in Data, 2022).

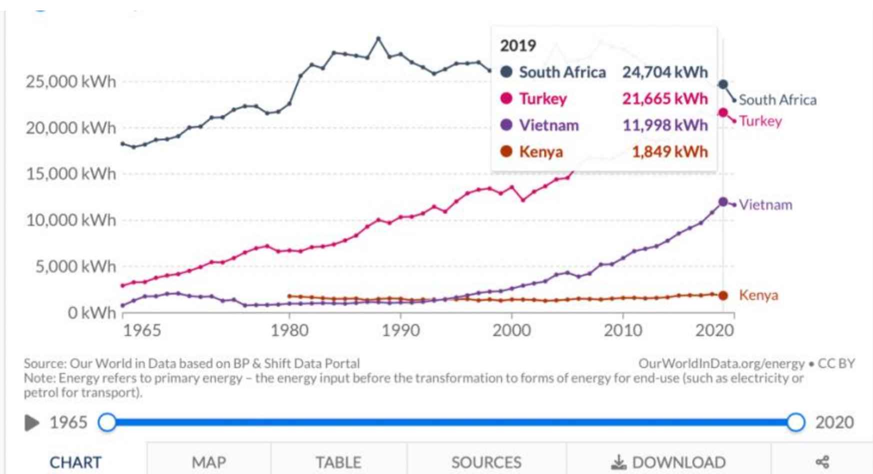


Figure 5 Energy use comparison. Source Our World in Data

[2] The energy use accounts for electricity and other needs such as heating, cooking and transport (Our World in Data)

Notably, only 13.42% of Kenyans have access to clean cooking fuels (Our World in Data, 2022). Bioenergy/solid fuels such as charcoal, dung, crop waste and firewood currently lead as the main source of cooking energy for the highest percentage of the population as indicated in figure six below. However, the government is committed to a clean cooking transition by 2040 with a targeted 5% reduction every year (MoE, 2022)

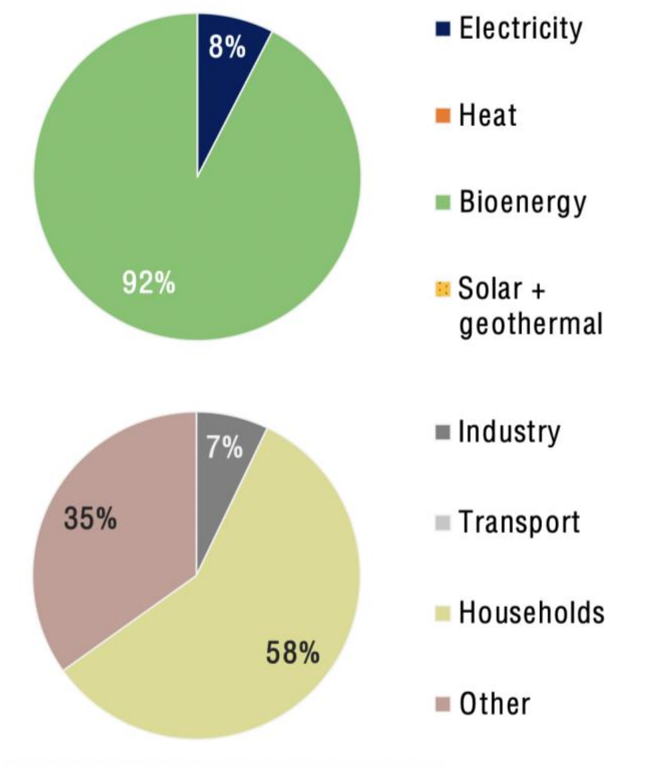


Figure 6 Renewable energy consumption 2018. Source IRENA

This commitment toward clean energy use in Kenya is aligned to the country's energy and climate priorities. Alternative fuels such as green hydrogen would require surplus renewable energy for its production which Kenya is endowed with. Therefore, the increase in renewables will be pivotal in first increasing consumption of clean energy for all, attaining the 100% electrification goal and increasing per capita consumption to ensure productive use and venturing into production of green hydrogen as the country continues to invest in low carbon energy sources over the next two decades (IEA, 2020).

To meet the 2040 goal of 100GW generation capacity, Kenya needs to attract 300 billion USD. While the investments exist as further discussed in this paper, Kenya will need to fast track the planned reforms to address existing challenges highlighted below.

2.2 Challenges facing the Kenya Energy Sector and Key Reforms

In 1991, soon after Kenya amended its constitution to allow multi-party democracy, donors placed the country under a six-month aid embargo after corruption allegations emerged (New York Times, 1991). The allegations were linked to procurement irregularities in the Turkwel Gorge 106 Mega Matt (MW) hydro project. Twelve donor organizations, including the United States, Germany, Japan, and Britain, required political and economic reforms before lifting the aid ban.

To increase the confidence of the donor community and private sector to invest in the country, Kenya committed to power sector reforms. These reforms included unbundling the sector by separating functions, ensuring power projects were based on the least-cost investment plans, creating a competitive power market through competitive tariffs, improving demand and supply of electricity (EPRA, 2018). Over the years, the country has continued implementing the reforms, albeit with slow progress.

Kenya opened its power sector to private sector investment in the mid-1990s introducing Independent Power Producers (IPPs), who currently represent a third of Kenya's total installed capacity – 937 MW (Power Africa). Kenya currently has 34 signed Power Purchase Agreements with IPPS who have played a significant in development large scale renewable energy projects such as the LTWP, Kipeto wind.

While Kenya has made substantial headway in increasing access to electricity from renewable energy sources, reliability affordability remains low (Mutiso, 2018). Kenya's electricity cost is high at 0.16USD per KW/H compared to compared to the average price which is 0.11 as illustrated in figure seven below. South Africa has lower prices at 0.08 USD and India at 0.09 USD (MoE, 2022).

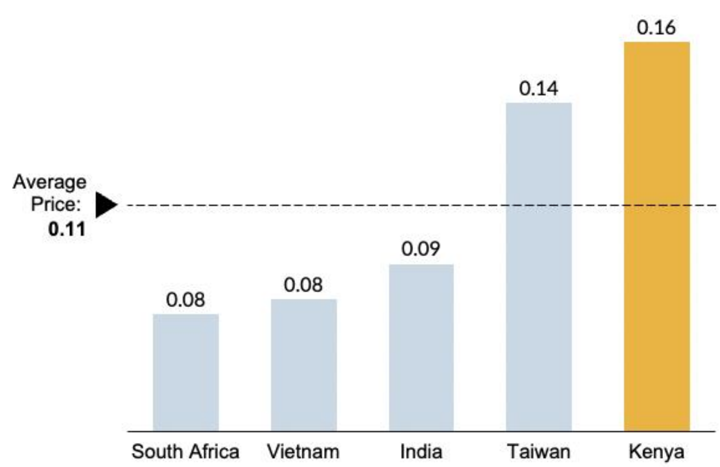


Figure 7 Electricity cost comparison of 1KW/H. *Source MoE Sector Roadmap 2022*

This high cost of electricity in Kenya makes the country's manufacturing cost uncompetitive (AfDB, 2021). For Kenya to meet its manufacturing vision, there is need to bring the costs of energy down. Expanding renewable energy projects to the 100GW goal will be critical in creating a supportive environment for large and small industries. Additionally, new, and emerging technologies such as green hydrogen and battery storage make this renewable energy future feasible.

This unreliable supply system, and high levels of outages due to weaknesses of the distribution network have contributed to slow and low industrialization (World Bank, Power Africa). Commercial and industrial power customers now have at least one back generator. Use of back-up power generators has been increasing with a steady 4.6% increase between 2015 and 2022 (MoE, 2022) as illustrated in figure eight below.

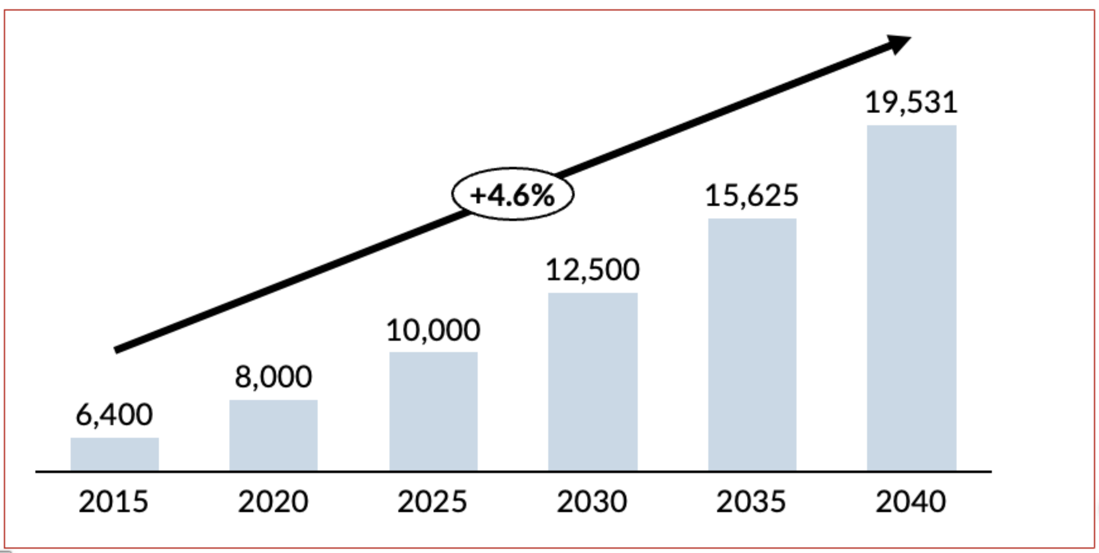


Figure 8 Demand met by back-up generators. Source MoE Kenya

These generators are a significant contributor to GHG emissions with high health and environmental risks. Replacing the use of back-up generators with stable renewable energy creates an opportunity for green hydrogen particularly in industrial processes. These alternative fuels such as green hydrogen present an opportunity for the country to stabilize its energy supply and attract more industries which will further stimulate economic growth. This in turn support the country's vision 2030[3] which recognizes the role of energy in driving economic development.

2.3 Country Context

2.3.1 Political Context

The Republic of Kenya, guided by its landmark 2010 constitution continues to strengthen its sovereignty as a democratic state since gaining independence on December 12, 1963. The 2010 constitution provided a framework for a decentralized government which brought in a devolved system of governance (World Bank Group, 2019). Under this framework, Kenya has the national and 47 county government systems of ruling, revenue-raising, and sharing, a tenured judicial and electoral body. The country has often experienced political violence around national elections fueled by tribalism. The country is currently in an election phase as leaders prepare for the upcoming 2022 transitional government after President Kenyatta completes his two-term Presidency. As

[3] Kenya Vision 2030 aims for a "newly industrialized, middle-income country providing quality life to all its citizens by 2030 in a clean, secure environment."

national campaigns take center stage, the country is planning to implement the controversial Building Bridges Initiative (BBI) constitutional amendment, which aims to improve governance to meet the country's vision. The key BBI pillars include addressing corruption, divisive elections, safety and security, ethic-antagonism, and competition. While the plan has attracted support from the international community, a significant number of citizens are concerned with the cost of implementation with the sentiment that this is yet another corrupt agenda and not the people's priority.

According to the Transparency International Corruption Index, in 2020, Kenya ranked 124/100 with a 31/100 score, a warning that corruption is still a looming crisis in the country. The country's Ethics and Anti-Corruption Commission (EACC) notes that Kenya lost one-third of its annual budget averaging USD 6 billion in 2016, to corruption (IEA, 2021). Recent reports from the Presidency indicate that 2 billion KES per day is lost to corruption. This is nearly 7% of the country's Gross Domestic Product (GDP), according to IEA Kenya. Tackling corruption is fundamental to sustainable development and needs to be a priority moving forward.

2.3.2 Economic Context

Kenya is one of the fastest-growing economies in Sub-Saharan Africa, with an average economic growth of 5.7% over 2015-2019 (World Bank). Kenya's economic growth is informed by Vision 2030, which serves as a long-term development blueprint. Vision 2030 aims to "*transform Kenya into a newly industrializing, middle-income country providing a high quality of life to all its citizens by 2030 in a clean and secure environment."* (Vision 2030, P1). Further to this, Kenya is currently implementing the Big-Four Agenda, a five-year development plan entailing: enhancing manufacturing, food security and nutrition, universal health coverage, and affordable housing (The Presidency, Kenya). The big four agenda action plan identified priorities for the current national government. Agriculture and the service sector are the leading economic activities in the country, with the service sector contributing 56% of the GDP in 2017 (AfDB, 2019). As the sector grows, there is an opportunity for the country to decarbonize the agriculture sector using green fertilizers produced from green hydrogen.

In addition, the government has an ambitious plan to expand the energy sector to support the achievement of this ambitious development blueprint in recognition of energy as an enabler for sustainable development. In its manufacturing pillar, Kenya aspires to have 15% of the Gross Domestic Product (GDP) coming from the manufacturing sector, up from 8.5% (President's delivery unit). Kenya's identified opportunities in manufacturing which include agro-processing, textile, apparel and leather, heavy industry, oil and gas, mining, and iron and steel exploration, exploitation, and production are sectors that could go green using the renewable energy hydrogen.

In the 2021/2022 financial year, Kenya anticipates a 6.3% GDP expansion (IEA, 2021) as it seeks to fund its ambitious KES 3.4 trillion (USD 34 billion) fiscal year 2021-2020 budget. According to the International Monetary Fund (IMF, 2016), Kenya's debt had been rising over the years from 48.6 in 2015 to 69% in 2020. The IMF further notes that the debt is manageable. Kenya has allocated Ksh 1.17 trillion to debt servicing which is 88% of the Consolidated Fund Services (CFS) expenses (IPFK).

As noted by the Institute of Public Finance Kenya (IPFK) in the 2021/2022 budget, the infrastructure, energy and Information Communication and Technology (ICT) sector received an allocation of Kenya shilling 332.86 billion, as indicated in table one below.

Table 1 Kenya Budget estimates 2021/22 KSH billion. Source Treasury

	SECTORS	2021/22 BPS ceilings	2021/22 Budget Estimates	Deviation (Kshs. Billion)	Deviation	Remarks on Deviation in Programmes
1	Agriculture, Rural and Urban Development	70.05	69.69	-0.35	-0.5%	▪ Reduction of Kshs. 1.56 B for Livestock Resource management
2	Energy, Infrastructure and ICT	334.78	332.86	-1.92	-0.6%	▪ Reduction of Kshs. 1.18 B for Power Generation ▪ Reduction of Kshs. 1.45 B for Power Transmission and Distribution ▪ Increase of Kshs. 1.41 B for ICT Infrastructure Development
3	General Economics and Commercial Affairs	23.39	21.54	-1.85	-7.9%	▪ Reduction of Kshs. 2.12 B for Tourism Development and Promotion
4	Health	112.57	121.09	8.52	7.6%	▪ Increase of Kshs. 6.49 B for Preventive, Promotive & RMNCAH
5	Education	508.59	509.20	0.61	0.1%	▪ Increase of Kshs. 1.16 B for Secondary Education
6	Governance, Justice, Law and Order	216.53	217.09	0.55	0.3%	▪ Increase of Kshs. 1.06 B for General Admin under the State Department for Interior
7	Public Administration and International Relation	356.62	350.41	-6.21	-1.7%	▪ Reduction of Kshs. 17.48 B for General admin and Kshs. 4.06 B for Marine Transport under the National Treasury ▪ Increase of Kshs. 5.98 B for Public Financial Management
8	National Security	170.01	162.29	-7.72	-4.5%	▪ Reduction of Kshs. 7.72 B for Defence
9	Social Protection, Culture and Recreation	71.32	71.97	0.66	0.9%	▪ Increase of Kshs. 314.82 M for Gender Empowerment Kshs. 284.67 M for Social Development & Children Services
10	Environmental Protection, Water and Natural Resources	102.84	103.52	0.69	0.7%	▪ Increase of Kshs. 2.55 B for Water Storage & Flood Control ▪ Reduction of Kshs. 1.23 B for Forests & Water Towers Conservation
	Grand Total	**1,966.70**	**1,959.67**	**-7.03**	**-0.4%**	

Source: Analysis of Treasury documents by PBO

The government reduced investment in the energy budget in the 2021/2022 budget and increased health to help the country cope and recover from the COVID-19 pandemic. However, the country's new clean energy roadmap creates a conducive investment space for the private sector. Kenya plans to attract $300billion to advance renewable energy projects to reach a capacity of 100GW from the current approximately 2.8GW. Global projections estimate that $75 trillion will be set aside for clean energy projects by 2050. Kenya needs to be ready to tap into these resources as they become available. Having a clear strategic direction and interest to be an early adopter of the emerging clean energy technologies brings unique positive attributes to Kenya's economic profile.

2.3.3 Social Context

The 2019 Kenya population and housing census indicates an enumerated population of 47.5 million, of which 50.5% were female (KNBS, 2019). Of these, 71.8% live in rural areas, while 28.2% are urban dwellers. Kenya continues to experience high poverty levels, rising inequality, lack of access to essential services for all Kenyans, and high youth unemployment and gender inequality (AfDB, 2019) (World Bank Group) Kenya has "less than 0.1% of the population (8300) own more wealth than the bottom 99.9% more than 44million people." (Oxfam International, 2017, p. iv) Reducing inequality and poverty can help the country transform the lives of its citizens.

Majority of the population continue to use dirty cooking fuels with only 13% having access to clean cooking fuels such as electricity, and gas (Our World in Data, 2022). Accelerating clean energy development will unlock economic opportunities for all, create green jobs and uplifting the poor and underserved.

2.3.4 Technological Context

The advanced information and technology market in Kenya has earned it the name Africa's "Silicon Savannah." The country has Kenya has one of the most developed internet and mobile network penetration in Sub Sahara Africa, including a robust digital economy (ITA, 2021). Kenya's smart city, Konza, which is currently under construction, gives Kenya a competitive advantage for global enterprises to set up shop. However, the lack of stable, reliable energy limits this attractiveness, and it is vital to advance the sector in tandem.
This will consequently unlock large technology businesses such as data centers which can help digitize the energy sector for instance growth of smart meters and grids to support a high clean energy future for Kenya and the region.

2.3.5 Environmental Context

Kenya intends to reduce greenhouse gas (GHG) emissions by 32% by 2030 relative to Business as Usual (BAU) at the cost of USD 62 billion. This is as detailed in 2020 NDC. This is critical because Kenya is highly vulnerable to the effects of climate change owing to the increase in the frequency and intensity of extreme weather events. Kenya's land area is over 84% arid and semi-arid, while Kenya's economy is dependent on climate-sensitive sectors such as agriculture, water, and energy (NDC, 2020). As a renewable-rich resource, Kenya's hydropower resource is greatly threatened by the adverse droughts experienced in the country. There is, therefore, a need to think of other renewable energy sources such as geothermal, solar, and wind. Additionally, environmental factors require stakeholder attention as they influence fuel choices (Xylia & Silveira, 2016).

3 GREEN HYDROGEN OUTLOOK

3.1 The Technology

Hydrogen (H_2) is the most abundant element on earth discovered in 1766 by Henry Cavendish (IRENA, 2020) indicating that a hydrogen economy has existed for decades. Hydrogen, in its natural form is colorless, odorless, and the lightest of all molecules (Nelson, et al., 2020). Hydrogen is a versatile product which can be used in multiple ways (CMS Legal Services, 2020); it is used as a source of power and a feedstock in various sector such as oil refining, steel production, ammonia, and methanol production (IEA, 2019).

Demand for hydrogen has been growing over the years, as illustrated in figure ten below, which has mainly been used in refining and ammonia production. In 2020, hydrogen demand was approximately 90 million tons (mt), and it is expected to continue growing, leading to increased CO2 emissions from its production, emitting 830 million tons per year (IEA, 2019).

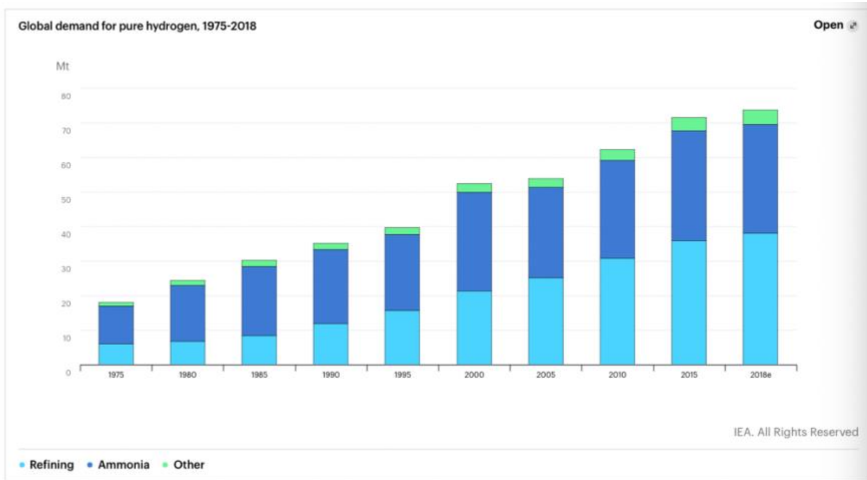


Figure 9 Global demand for Hydrogen 1975-2018. Source IEA

With this rising demand and the consequent rising emissions from hydrogen, there is a need to transition to the use of clean hydrogen aligned to global decarbonization goals. Clean hydrogen is critical to 2050 net-zero emissions. IEA notes that clean hydrogen will help avoid up to 60 Giga Tons (Gt) of CO2 emissions, which is a 6% reduction of total cumulative emissions (IEA, 2019). The 2022 IRENA World Energy Transitions Outlook (WETO) indicates that hydrogen could contribute to 10% net emissions reductions up from IEA's 6%, demonstrating the growing recognition of hydrogen's role in the global decarbonization agenda. The report highlights the other major contributors to the 2050 emissions reduction as renewables at 25%, energy efficiency at 25%, electrification at 20%**,** renewable energy-based CO_2 removals at 14%, and fossil fuel CO_2 carbon capture and storage (CCS) at 6% (IRENA, 2022)

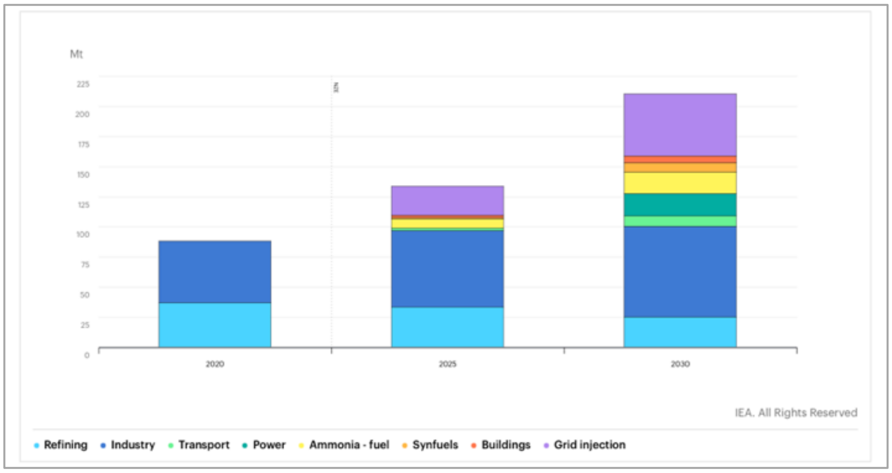


Figure 10 Hydrogen demand by sector in the net-zero scenario, 2020-2030

IEA projects an uptake of hydrogen in new sectors such as synthetic fuels, use in building, grid injection, and uptake in power and transport use, as shown in figure 11 above. The IRENA WETO report recommends that green hydrogen to move to mainstream use to ensure hydrogen contributes meaningfully to a climate-friendly future (IRENA, 2022). Therefore, the hydrogen economy needs to go green as stakeholders adopt more uses and more investments go into its production, helping lower its costs. According to the Hydrogen Council, hydrogen technologies have matured and can be rolled out at scale (Hydrogen Council, 2019) creating a sustainable green hydrogen economy.

3.2 Hydrogen color codes

Hydrogen is produced in different way, from diverse resources which has led to the color coding to differentiate hydrogen production as illustrated in figure 12 below.

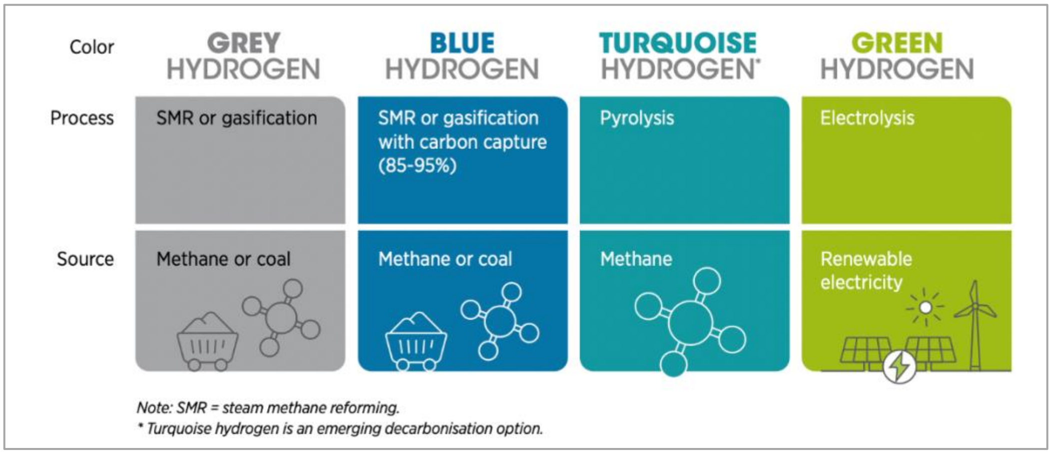


Figure 11: Different hydrogen production. Source: IRENA 2020

Grey hydrogen is produced from fossil fuels mainly natural gas (methane) and coal which has higher CO2 emissions, accounting for over 70% (natural gas) and 23% from coal (CMS Legal Services, 2020), of the hydrogen in use currently as shown in figure 13 below. Some experts have labeled hydrogen produced from coal (bituminous) as black hydrogen or brown (lignite) (WEF, 2021) due to its significantly high CO_2 emissions, a major contributor to climate change. Grey hydrogen is relatively cheap and is commonly used in industries thus a need to ensure green hydrogen price points are competitive as technologies mature.

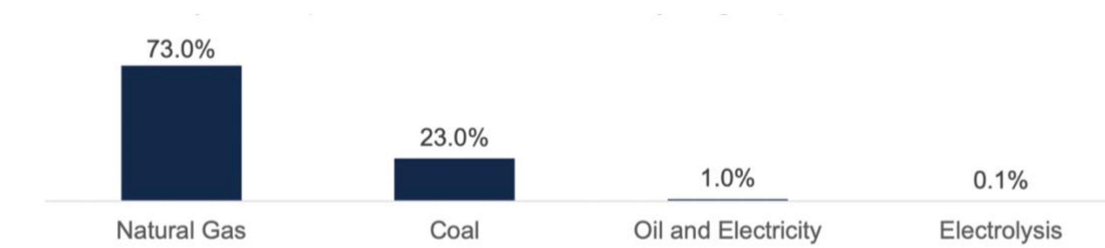


Figure 12 Hydrogen by source.

Blue hydrogen is a low carbon alternative produced from fossil fuels with carbon capture and storage (CCS). It is mainly produced from natural gas through steam reforming (IRENA, 2020). Experts have often referred to this hydrogen as carbon neutral however this has been challenged because 10-20% of the generated carbon is not captured (WEF, 2021) making the low carbon reference more acceptable across the energy and climate sectors.

Green hydrogen is hydrogen produced through the electrolysis of water with 100% renewable energy with close to zero greenhouse gas emissions (GH2, 2022, p. 5). Green hydrogen "*created from renewable energy sources such as solar, wind, hydropower, biomass, biogas, or municipal waste"* (Nelson, et al., 2020, p. 2) and has increasingly become a critical element in the decarbonization agenda (IRENA, 2020) (Nelson, et al., 2020). Green hydrogen is used both as an energy carrier and industrial feedstock (Tractebel Engineering GmbH, 2022). Currently, green hydrogen accounts for only about 0.1% of hydrogen in use (IEA, 2019; CMS Legal Services, 2020). Green hydrogen is also referred to as clean hydrogen and this paper seeks to explore its potential as an alternative fuel in Kenya, a renewable energy rich country.

Other emerging hydrogen color differentiations include **yellow** for hydrogen produced through electrolysis from solar, **pink** generated through nuclear powered electrolysis and **turquoise** from methane pyrolysis and has potential to be a low carbon fuel (National Grid, n.d.).

The color-coding practice creates a need for standardization to ensure all stakeholders agree on what really constitutes green hydrogen which is important in supporting the decarbonization agenda. This is particularly critical because hydrogen in the global marketplace is greatly influenced by different national and regional standards, political and economic priorities, and interests. This present one challenge which can be addressed with harmonization of the existing certification standards to increase acceptance of green hydrogen in the marketplace (Tractebel Engineering GmbH, 2022).

The GH2 standard can help build confidence between investors and producers (GH2, 2022). This involves the creation of certificate of origin to ensure the hydrogen economy is contributing to decarbonization by clearly defining green hydrogen and setting it part from other types with high emissions.

3.3 Production of Green Hydrogen

Electrolysis: Electrolysis approach involves an electric current from renewable energy splitting water into oxygen and hydrogen (U.S. Department of Energy, n.d.) using an electrolyzer. This approach which uses electricity from renewable sources such as solar, wind, hydropower, and geothermal has in the recent years shown potential to be scaled (Nelson L. L., 2020) and is so far the most established production approach (IRENA, 2020).

In 2021, the capacity of installed electrolyzer was at 0.5GW with an anticipated growth to 350GW by 2030 (IRENA, 2022). As of 2019, the global electrolyzer market was worth USD 321.65 million with a projected growth of 6.3% to the period leading to 2027 rising to USD 467.39 million in 2017 (Fortune Business insights, 2021). Key players already producing commercial electrolyzer include Siemens AG (Germany), Nel (Norway), Hydrogenic (US) and ITM Power (UK) with others listed in annex three.

Electrolysis is anticipated to grow significantly as the technology matures, and capacity increases and cost of renewable energy reduce. Africa hydrogen plans also recognizes electrolysis as the most viable route owing to its simplicity and technology maturity (AbouSeada & Hatem, 2022).

Steam Methane Reformation (SMR) of Biogas: This approach is like SMR from natural gas, but it is a clean option because it uses biogas produced from biomass (Nelson L. L., 2020). The feedstock comes from landfill, wastewater and animal and waste which is critical in helping local government manage their waste by producing a valuable product (Nelson L. L., 2020). Communities can also generate revenue from the upcycling of the waste.

Biomass Gasification: This is a waste to energy. (EIA, n.d.) approach involving passing high heat or pressure to the organic matter (Nelson L. L., 2020). Other technologies under development: Renewable liquid reforming

3.4 Distribution, Transmission and Storage

Green hydrogen can either be consumed on site or transported by road or pipelines. Of the hydrogen produced currently, 85% is used on site while 15% is transported via road, pipelines, rail or marine (CMS Legal Services, 2020) (Nelson L. L., 2020). It can be transported in existing infrastructure, creating added benefits because it does not require new infrastructure where it exists. In the Kenya case as a developing country with limited infrastructure there is need for need infrastructure. Additionally, green hydrogen can be stored for long periods of time for future use which add value to renewable energy.

3.5 Green Hydrogen Uses

Green hydrogen can be produced for domestic, regional, and international markets. It is a versatile multi use product which can help decarbonize hard to abate sectors. Some of its common uses include:

- As a commodity in chemical industry. Derivatives such as ammonia and methanol can be used in industrial processes. It can be used in the production of steel, and iron processing. Green ammonia is also used in the production of green fertilizers
- Petrochemical industry in refining crude oil
- Larger scale mobility uses in shipping, long-haul trucking, and aviation. Green hydrogen has been proposed as a viable fuel for short haul flights in hydrogen propelled crafts (ATAG, 2021). Airbus is currently

doing research and development for the world's first hydrogen powered commercial aircraft anticipated to be operational in 2035 (Airbus). The aircraft market leader has started the technology tests showing promising in decarbonizing the aviation sector coupled with sustainable aviation fuels.

- It can be used as an energy career (Tractebel Engineering GmbH, 2022). Stephen Lamm from Bloom Energy notes that green hydrogen's flexibility is fundamental to the planned advanced energy systems which will help country save energy that would otherwise be lost when supply from the renewables is higher than the demand given that current technologies do not support energy storage.
- For heating and cooling to replace the overreliance of natural gas particularly in countries experiencing winter and extreme summer temperatures.

This study narrows down its scope to green hydrogen use in agriculture, industry and transport which are key sector in the country's development blueprint.

3.6 Barriers and Challenges

High production costs remain on the major barriers to the scale up of green hydrogen. As illustrated in figure 16 below, hydrogen produced from renewable sources is significantly high compared to hydrogen from fossil fuels such as natural gas and coal (IEA, 2019). However, the cost is anticipated to become competitive particularly with natural gas as the cost of electrolyzer and renewable energy goes down (Wouters, 2021).

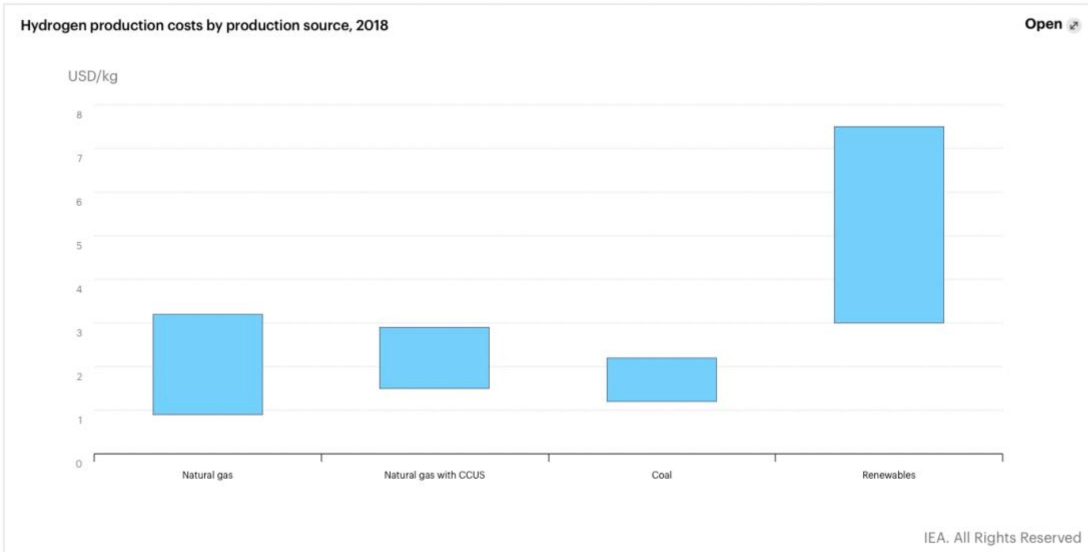


Figure 13 Hydrogen production costs. Source IEA

Global prices put green hydrogen costs at US $2.5 per kg while fossil-based cost USD 0.7 (Tractebel Engineering GmbH, 2022). In the EU, a Kg of fossil-based hydrogen was 1.5EUR (US $1.53), fossil-based hydrogen with carbon captures 2 EUR (US $2.03) per kg while green hydrogen ranged between 2.5 and 5.5 Euros (US 2.54 -$5.6) per KG as of 2020 data (CMS Legal Services, 2020). South Africa aims to produce green hydrogen at a cost of US $1.60 per KG by 2030 which will make it one of the lowest costs globally (Salma, 2022) However, this cost is expected to reduce significantly, as costs of electrolyzers go down, and capacity goes up. Notably, electrolyzers costs have gone down by 60% in the last 10 years (CMS Legal Services, 2020).

Experts agree that green hydrogen is most viable in areas where electrification is technically not possible as electricity is cheaper than green hydrogen and will be for the short to medium term (Tractebel Engineering GmbH, 2022, p. 29)

Limited financing for developing and emerging countries: while investments in transitional technologies such as green hydrogen have continued to increase in recent years, they are still concentrated in developed countries. IRENA notes that 84% of the investments are still concentrated in countries such as China, Europe, United States, Japan, and India while East Africa accounts for about 2% (IRENA, 2022). There is need to support these countries with the financial resources and enabling policies that address the financing barriers.

Limited infrastructure and technical capacity: while electrolyzer capacity is growing as discussed earlier with planned capacity of 350GW by 2030 (IRENA, 2022), the technology has not yet penetrated in developing and emerging economies with the potential to produce green hydrogen.

Other challenges include water resources competition with other sectors such as agriculture. Policy makers need to factor in environmental factors to ensure that basic human needs are prioritized. As this is a new and emerging technology, there is still limited information about the value and benefits. There is a need for more national level research and knowledge products on green hydrogen which this paper aims to contribute towards.

3.7 Key Enablers and Policy Priorities for Green Hydrogen Acceleration

A green hydrogen future is within reach globally. It is a viable decarbonization pathway that has been gaining attention in recent years owing to its ability to reduce emissions in hard to abate sector. Various critical steps will be needed to facilitate the development of green hydrogen.

Supportive and targeted policies will be critical in promoting a successfully green hydrogen economy and scale up projects. Increasingly, more countries are developing policies to support green hydrogen. Globally, several policies exist, and they cut across the green hydrogen value chain from production, distribution and uses illustrated in figure 15 below (IEA, 2019).

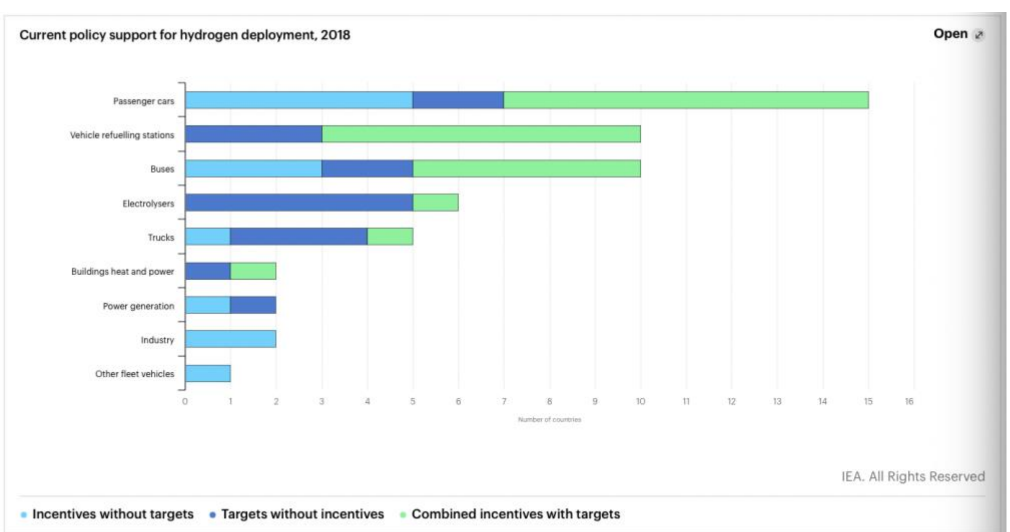


Figure 14 Green Hydrogen Support Policies. Source IEA

Policies will play a critical role in helping countries meet their ambitious targets as well supporting a fair and progressive global marketplace. Policies need to focus on bringing costs down to ensure green hydrogen is competitive with hydrogen from fossil fuels. Policies should unlock more investments particularly to support developing and emerging economies with the potential to produce green hydrogen but with limited national resources.

Additionally, green hydrogen projects need to protect the environment and natural resources (Wouters, 2021). Clear guidance needs to be given to prevent competition for water as feedstock and land which should not be in competition with basic human rights and food security.

Green hydrogen policies need to ensure standardization. The Green Hydrogen Organization is currently working on the GH2 standard earlier discussed under color codes which establishes a global definition of green hydrogen. The standard also includes a registry of projects which issues, tracks, and cancels Guarantee of Origin Certificates (GH2, 2022).

3.7.1 National Strategies and Market Opportunities

Countries are increasingly designing their national level strategies to guide the development of green hydrogen. So far, over 16 countries have their defined strategies (Beagle, 2021) which outline their priorities and targets. While most of the projects are currently concentrated in developed countries, there is opportunity for emerging and developing countries to benchmark as they venture into production. Increased political will create the enabling environment needed to attract funding. These national strategies need to create a clear roadmap to guide the growth of a hydrogen sector with defined market opportunities at a local, national, regional, and international level to drive cost competitiveness.

3.7.2 Financing and Partnerships

Public-Private Partnerships (PPPs) will help in raising the funds needs for demonstration projects, tap into global expertise and most mature technology in the market. These PPPs are well positioned to de-risk projects and kick start pilot projects and unlock capital for long term projects.

The table below lists some of the climate finance funds available for green hydrogen projects that Kenya could attract though most of these are early-stage funds.

Table 2 Summary of some of the available funding

Fund	**Mechanism**
EU Global Gateway	• EURO 300 billion up to 2027Climate and energy
Green Climate Fund	• Offers low interest long tenor loans, credit to banks, equity, guarantee to de-risk and capacity building initiatives
Global Energy Alliance for People and Planet	• $10 billion partnership that seeks to unlock $100 billion for clean energy transition for developing and emerging economies
Breakthrough Energy	• Long term capital investments to start ups

NAMA Facility	• Financing for innovative projects tackling climate challenges • The facility supports NDCs implementation for a green recovery
Energy Transition Accelerator Financing (ETAF) By IRENA & the United Arab Emirates (UAE)	• A multi stakeholder climate finance solution aimed at advancing the clean energy transition in developing countries • ETAF aims to mobilize $1 billion by 2030

The figure below gives an overview of some possible funding mechanisms that Kenya could explore to finance green hydrogen projects. Possible financing mechanisms needs to include a combination of loans, grants,

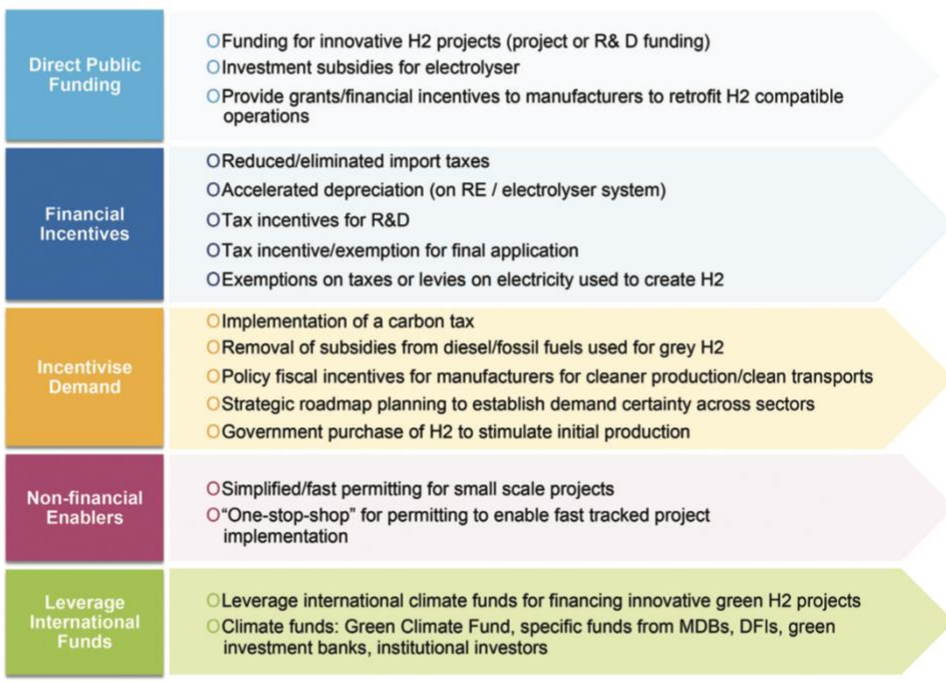


Figure 15 Policy and financial incentives mechanisms

Source: (Tractebel Engineering GmbH, 2022)

3.7.3 Co-Benefits of a green hydrogen ecosystem

Innovative energy technologies have the potential to help developing countries leapfrog to clean technologies (IISD, 2020) in the context for need for more energy in these energy-poor countries that are more vulnerable to climate change to support climate adaptation efforts (Mimi Alemayehou, 2021). Some of the notable co-benefits of investing in clean innovative energy technologies include creation of green jobs for local talent, powering sustainable economic development, technology, capacity, and skill transfer. GEAPP estimates that the clean energy transition will unlock over 150 million green jobs (GEAPP, 2022) which will in turn improve the lives of the poor and underserved in developing and emerging economies.

In the Africa case, green hydrogen is offering more benefits above domestic use to the global the marketplace (AbouSeada Nour, 2022). In South Africa, which aims to capture 4% of the global hydrogen market by 2050 by deploying 10GW of electrolysis capacity aims to create 20,000 jobs annually by 2030 and 30,000 by 2040 (Salma, 2022). Namibia is planning to install 3GW of electrolyzer capacity through a planned USD 9.4 billion green hydrogen project (Tractebel Engineering GmbH, 2022).

As an economic hub for East Africa and a renewable energy resources rich country, Kenya is well positioned to be a green hydrogen hub for Africa together with South Africa and Namibia. Kenya has positioned itself as a leader in Africa through the baseline study on the potential of green hydrogen developed by Tractebel for the Ministry of Energy through financial support from GIZ. This is discussed further in the next chapter.

Kenya also needs to improve the ease of doing business to attract more private sector investment and support for development partners as it develops a green hydrogen market space. These investors and partners include foreign governments, financial institutions, exploration companies, technology companies, and other investors interested in the energy sector. Some of the strategic development partners include Africa Development Bank (AfBD), World Bank, Japan International Cooperation Agency (JICA), United States Agency for International Development (USAID), Power Africa, and GIZ. Attracting new investment injection will power infrastructure projects that can help increase generation capacity and stimulate demand for electricity to support development priorities.

4 GREEN HYDROGEN PATHWAY FOR KENYA

This chapter presents and interprets findings from the various interviews with subject matter experts, information from conferences and analysis of existing scientific and industry literature. It aims to narrow down the priority opportunities for Kenya that can be realized in the short-medium and long term. The chapter analyses green hydrogen as a new clean energy technology that can support Kenya's energy sector roadmap for sustainable economic development while protecting the environment, people, and the planet.

4.1 Green Hydrogen opportunities for Kenya

Although Kenya is endowed with renewable energy resources and is well positioned to explore the production and deployment of green hydrogen, the country does not have a defined green hydrogen strategy, unlike its peers Namibia and South Africa who have already defined strategies. However, the country in on track towards the development of green hydrogen projects and this could be the starting point for developing a country strategy. Through the ministry of energy and its membership in the Africa Green Hydrogen (AGHA) steered by the Green Hydrogen Organization, Kenya shows commitment to the technology in the coming years. Kenya recognizes the role hydrogen can play in boosting the economic particularly through the manufacturing sector which remains a top priority in the country development blueprint. Additionally, green hydrogen can deliver higher energy independence without the need for fossil fuels (GH2, 2022). The Kenya green hydrogen baseline states that Kenya could produce approximately 500MW electrolysis capacity produced in the medium term and between 3000-4000MW in the long term (Tractebel Engineering GmbH, 2022).

Green hydrogen makes it possible for the country to grow its industrial sector at the same contributing to the NDC goal of lowering emissions by 32%

relative to business as usual by 2030. A new and operative green hydrogen economy for Kenya while a possibility within reach, it will certainly be a massive undertaking that will require political will and national ownership of projects by both the governments, project producers and the communities and international support for the right skills, technology, and investment mechanism. If these align, Kenya could be on the way to materializing the goal to be an early green hydrogen market leader in Africa.

The Power to X baseline study creates scenarios for Kenya's energy mix that will support the production of green hydrogen between 2025- 2040 with geothermal and wind energy contributing the greatest supply for the production (see Figure 17).

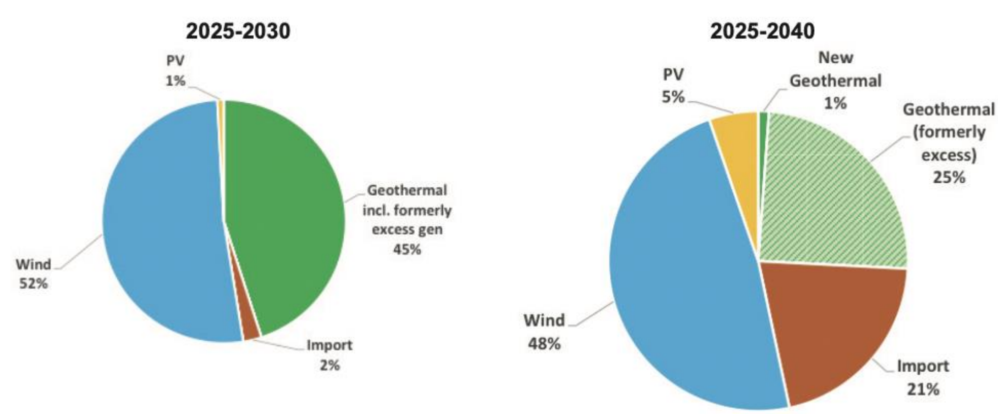


Figure 16: Kenya's Energy Mix Projection for GH Production. Source Tractebel Eng

Additionally, the country has ample land and water resources making Kenya a potential competitive hydrogen producer (Wouters, 2021). Additionally, as desalination technologies continue to develop, Kenya could use water from its salty lakes which include Lake Nakuru, Elementaita, in the Rift Valley region which is a potential green hydrogen production area and Lake Turkana which is close to another potential spot near the largest wind project Lake Turkana wind project, another potential hydrogen production location.

This section highlights the potential pathways for Kenya as it develops its green hydrogen strategy. As noted in the green hydrogen outlook chapter, green hydrogen can be used to decarbonize multiple sectors, this paper only focuses on three critical opportunities for Kenya based on their relevance to the country's context from the research conducted. These opportunities are highlighted in the table below informed by IRENA, IEA, GHC, GH2, Tractebel and discussed in detail in this chapter.

Table 3: Green hydrogen opportunities for Kenya. Source Tractebel Eng

Sector	**GH2 Use**	**Time frame**	**Scale**	**Geographic focus**
1. Agriculture	Fertilizer production from ammonia	Medium term	Large use	Central Kenya, Nairobi, Rift Valley - Olkaria
2. Manufacturing -Light	Food processing, semiconductors & electronics, and	Medium – long term	Large use	Nairobi, Thika, Kisumu

industry, methanol	materials processing (textile, wood, leather, and pulp)			
-Heavy industry	High temperature industrial processes such as steel and cement production, and metal processing	Long term	Large use	
3. Transport	Biofuels for public transport and rail fuel, trucking and shipping	Short-medium	Large use	Mombasa port access

4.1.1 Green hydrogen for agriculture

As discussed in chapter one, Kenya's economy is heavily dependent on rain-fed agriculture, a climate sensitive sector (MoEF, Kenya, 2020). Agriculture contributed to nearly 22% of the country Gross Domestic Product (GDP) (World Bank Data, 2021), employing 54% of the population (World Bank Data, 2019). On the flip side, an indicated in the country NDC, in 2015, the sector contributed 40% of the country's emissions which was the highest emitter (MoEF, Kenya, 2020). These emissions were mainly from fertilizer application and livestock enteric fermentation.

Several studies reach the consensus that nutrients from fertilizers are important in boosting agricultural productivity and consequently reducing food insecurity and lifting people out of poverty. According to the 2021 economic survey, value of purchased fertilizers was Ksh 16.2 billion in 2020 (approximately usd143 million), which is a 3.2% increase, demonstrating its importance in the sector. However, majority of fertilizers in use are produced from chemical processing using fossil fuels. Particularly, ammonia nitrate (AN) fertilizers are produced by mixing nitrogen with hydrogen from fossil fuels (natural gas) at high temperature to create ammonia. The ammonia is then used to make nitric acid which is used in making the AN fertilizer (Fertilizers Europe, n.d.). Green hydrogen opens a new opportunity to produce clean fertilizers from ammonia. 85% of fertilizers in use are produced from ammonia (Ammonia, n.d.) (AbouSeada Nour, 2022)

Kenya is currently importing most of its fertilizers. Domestic fertilizer production from domestic green hydrogen production could help the country save money from imports and high shipping costs and thus boost local economy while also decarbonizing the agricultural sector.

The Power-X baseline study identifies Olkaria, Mombasa, Nairobi, Lamu-Lamu Port South Sudan Ethiopia Transport (LAPSSET) location, Thika and Western Kenya as possible hubs for fertilizer production. This is from the renewable resources' availability in these locations and their proximity to the country's food baskets and road and rail infrastructure.

Establishing the fertilizer production plants will be a capital-intensive endeavor which will require public and private financing. Additionally, public, and private partnerships will de-risk the project thus raising investor appetite. Additionally, fertilizer use is still low in Kenya compared to developed countries. This creates a need for government and stakeholders to boost supply and demand of affordable fertilizers. As the cost of renewables reduces, and adoption of decentralized local production using green hydrogen, prices will significantly reduce over the years thus increasing demand.

In summary, agriculture will continue to power Kenya's economy and its regional and green fertilizers present a clean low carbon alternative which the ministry of energy, agriculture, environment, and forestry should work together with the private sector to explore and actualize. Kenya could lower its emissions from the agricultural sector while still feeding its growing population and promoting sustainable development.

4.1.2 Green Hydrogen in Manufacturing

Kenya's development blueprint, Vision 2030 aims to create wealth and employment through the manufacturing sector and aims to increase manufacturing sector contribution to the GDP by at least 10% per year (industrialization, n.d.). The country has set an ambitious goal of developing a steel and iron industry as well as industrial parks. Green hydrogen will play a critical role in ensuring the country sets up clean industries from the start. A report by McKinsey suggests that Africa's economic growth and decarbonization of the manufacturing sector and industrialization efforts need to be linked to ensure prosperity (Lyes Bouchene, 2021).

Kenya has an opportunity to produce green hydrogen with the off-peak power produced from its renewable sources for both heavy and light industry. At the same time, the country needs to ensure it meets the 100% electrification goal to achieve energy security.

As discussed in chapter one on energy levels, Kenya must strive to increase per capita energy consumption from the current 170 kilowatt per hour (kWh) to the proposed modern energy minimum of 1000 kWh per person per year (Energy for Growth, 2020) for both household and non-household uses. Kenya aims to increase the per capita consumption to about 5594 kWh by 2040 which is aligned with the goal of increasing its electricity capacity generation to 100 Giga Watts (GW) by 2040 (MoE, 2022) up from the 2020 total electricity of 2.7[4] GW (Energy for Growth Hub, 2020) 11,603.6 GWh (KNBS, 2021).

As the country works on balancing demand and supply of the power generated, Kenya currently has ‘idle’ renewable power produced during off peak hours 11pm to 6am which can be used to decarbonize the industrial processes. The country's take-or-pay tariff dictates that the utility, Kenya Power, must still pay the producers even though they cannot consume or take

[4] MOE put this baseline at 3GW

on the power. This surplus/idle power which would otherwise go to waste can be used in light and heavy industries.

In **light industries** green hydrogen can be used in food processing and preservation where ammonia is used as a refrigerant. This can be realized in both the medium term and long term as technologies mature and costs go down. Other potential light industries uses of green hydrogen include textile, wood, leather, rubber, and pulp processing. Additionally, it can replace natural gas in burners for high temperature processing in glass production. Baseline study by (Tractebel Engineering GmbH, 2022) identifies Nairobi, Thika, Ruiru, Coast as possible project location for light industries powered by green hydrogen.

In **heavy industry** manufacturing, experts note that green hydrogen can be used in steel production, metal processing, cement and as a base chemical. Kenya needs to particularly look at launching steel production demonstration projects in medium term building on the ongoing momentum for viable pilot projects and interest from investors such as the Breakthrough Energy, GIZ, and Fortescue Future Industries among others. Additionally, as the country endeavors to grow its manufacturing sector, Kenya can consider engaging in other aspects of the green hydrogen value chain and consider for instance production on electrolyzers for regional markets.

4.1.3 Green Hydrogen in the Transport Sector

Kenya can decarbonize its public transport sector using green hydrogen as a fuel for buses and trucks which can be rolled out across all regions. Green hydrogen can also be used as fuel for ships for cargo as the country grows its industries for export markets. Kenya's decarbonization plans aim for half of all light vehicles to be zero emissions (Tractebel Engineering GmbH, 2022). Green hydrogen can help the country achieve this goal through clean fuel development. Notably, high green hydrogen costs limit its capability to compete with fossil fuels currently, but experts anticipate that this could change in the medium to long term and therefore important to stay up to date with the innovation.

As a first step, Kenya needs to invest in feasibility studies to determine the extent to which domestic production of green hydrogen can be used in both long and short distance transport including road, raid, maritime and aviation to guide the sector. One of the aerospace market leaders, Airbus is already working on a demonstration commercial flight that uses 100% green hydrogen. If this technology is viable for the market, Kenya can be a hub for supplying this alternative aviation fuel.

4.2 Recommended Next Steps for Kenya

In charting a path for Kenya, several steps will lead to successful projects.

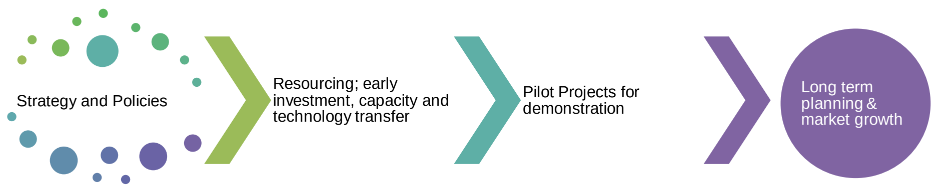


Figure 17 Next steps for Kenya

Design a strategy and develop relevant policies. To complement the Power-to-X baseline, Kenya needs to initiate a strategy paper that clearly defines projects that can be launched immediately. This can also help the country identify which parts of the value chain to venture into. For instance, given the increasing demand in electrolyzers, Kenya can explore if it has the potential to manufacture electrolyzers for regional use in partnership with one of the global manufacturers to help the region increase in production capacity.

Additionally, the country needs to **advance its current renewable energy policies to support an enabling environment** that will in turn **unlock investment.** Advancements in policy, technology, and infrastructure are necessary to make green hydrogen more viable for widespread use. An integrated policy approach will be critical for the growth of green hydrogen production where different government departments work together to accelerate green hydrogen production and use. This particularly would involve the energy sector, transport and infrastructure trade and investments, agriculture, and finance among others. Continued efforts to enhance an enabling environment will help attract targeted private sector and development finance institutions investments.

Pilot green hydrogen projects: With the current 'idle' load, Kenya can start producing green hydrogen. The Kenyan government just declared their intention to start pilot projects (Green Building Africa, 2022). As pointed out by Tsafos (2020) from the Centre for Strategic and International Studies (CSIS), "*it is hard for an emerging economy to lead (in innovating)—but there is a difference between being an early or a late adopter."* Kenya must be an early adopter to better benefit from technology companies and investment injection in these emerging technologies soon and this is demonstrated in the commitment to start project soon. As stated earlier, Kenya has potential to explore other areas of the value chain such as electrolyzer production which can help accelerate green hydrogen projects in Kenya. The decision to join the Africa Green Hydrogen Alliance will also be instrumental in helping the country learn fand exchange best practices from its counterparts such as Namibia and South Africa who are also members of the alliance.

Smart partnerships and global collaboration will help catalyze finance, technology, and capacity transfer. These supportive partnerships will help upskill local talent in the new emerging technology and ensure scale up and de-risking of projects. **Kenya also needs to improve the ease of doing business to attract more private sector investment and support from development partners** as it develops a green hydrogen market. These investors and partners include foreign governments, financial institutions, exploration companies, technology companies, and other investors interested in the energy sector. Some of the strategic development partners include Africa Development Bank (AfBD), World Bank, United Nations Economic Commission for Africa (UNECA), Japan International Cooperation Agency (JICA), United States Agency for International Development (USAID), Power Africa, and GIZ. Attracting new investment injection will power infrastructure projects that can help increase generation capacity and stimulate demand for electricity to support development priorities.

5 CONCLUSION

Kenya, an economic hub of East Africa, has a grand long-term development blueprint, Kenya Vision 2030, to be a "*newly industrialized, middle-income country providing quality life to all its citizens by 2030 in a clean, secure environment*." (P.1 vision 2030). To meet this vision, the energy sector will play a vital role in providing clean stable, reliable, and affordable modern energy for household and commercial use. While tackling energy poverty remain a key priority for the country, Kenya also needs to invest in green energy as a way of mitigating and preventing negative effects of climate change and power green industries and economies and create green jobs.

Kenya has been making great progress in expanding its energy sector, currently, renewable energy resource makes up 92% of the electricity produced, with plans to reach 100% clean energy production and consumption. To meet this goal, adoption of new and emerging technologies such as production of green hydrogen will help accelerate this sector growth. Integrating these emerging technologies into existing energy systems and plans will help bring the costs of renewables down while increasing energy access.

Green hydrogen presents incredible opportunity for the country to increase its energy production to power the country's economy. Green hydrogen can be used in the production of ammonia which can be used as a base material in fertilizer production, or in marine transport or moved easily over long distances for export market (Tractebel Engineering GmbH, 2022) (Wouters, 2021). It can also be used in both light and heavy industries to help decarbonize the manufacturing sector particularly, steel and cement. Currently, non clean hydrogen in mainly used in industrial processes oil refining, ammonia production, methanol production, steel production (CMS Legal Services, 2020) (IRENA, 2020) (Nelson L. L., 2020). Substituting grey and blue hydrogen with green will be critical in decarbonizing these industrial processes thus accelerating the journey to a net zero emission.

According to the Hydrogen Council, hydrogen technologies have matured and can be rolled out at scale (Hydrogen Council, 2019) creating a sustainable green hydrogen economy. While green hydrogen is a promising alternative fuel and demand is growing globally as projects come into the pipeline, some hurdles exist such high costs of electrolyzer, and low to limited technical capacity in developing markets.

Despite the challenges, green hydrogen is a promising technology for developing countries to enhance energy security and industrialize while contributing to the reduction of greenhouse emissions. Kenya's strategy moving forward should include pathways and supportive policies for successful development of green hydrogen and models to scale up implementation. The clean energy transition and the pressure to mitigate the adverse effects of the looming climate crisis validate this push for clean alternatives.

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7 ANNEXES

Annex 1: Interviews, industry and conference papers

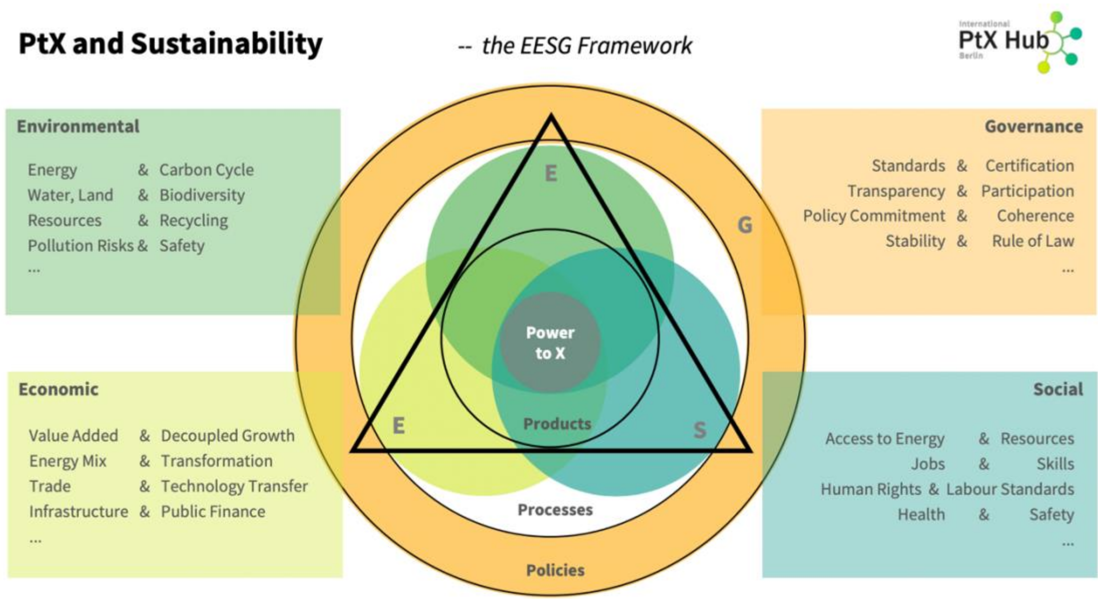
1. Ministry of Energy Kenya
2. Green Hydrogen Organization (GH2)
3. African Climate Foundation (ACF)
4. African Hydrogen Partnership (AHP)
5. African Green Hydrogen Alliance (AGHA)
6. UNFCC Climate Champions
7. Power2X Hub
8. Bloomberg
9. Cornell University

Annex 2: Subject Matter interviews Guiding Questions

1. How can green hydrogen support the clean energy transition in sub-Saharan Africa as a preferred fuel source?
2. How can Kenya build smart high-energy solutions using renewables?
3. How can Kenya embed climate into its economic priorities?
4. Creating sustainable jobs, how fast we can realize gains
5. What does a green hydrogen roadmap for Kenya look like?
6. Impact in numbers – production quantities and economic value
7. What does an enabling environment for success look like? Key aspects
8. How soon can we expect green hydrogen prices to be competitive?
9. Which price points are producers targeting?

Annex 3: Electrolyzer production companies

- Nel (Proton On-Site) (Norway)
- Asahi Kasei (Japan)
- Hydrogenics (US)
- Areva H2gen (France)
- Shandong Saikesaisi Hydrogen Energy Co., Ltd. (China)
- Teledyne Energy Systems (US)
- Siemens AG (Germany)
- Kobelco Eco-Solutions (Japan)
- McPhy (France)
- Yangzhou Chungdean Hydrogen Equipment Co., Ltd (China)
- Suzhou Jingli (China)
- TianJin Mainland (China)
- ITM Power (UK)
- 718th Research Institute of CSIC (China)
- Idroenergy Spa (Italy)
- Erredue SpA (Italy)
- MVS Engineering (India)
- GreenHydrogen .dk (Denmark)
- Enapter (Italy)
- Giner Inc. (US)
- ShaanXi HuaQin (China)
- Next Hydrogen (Canada)
- H-Tec Systems GmbH (Germany)
- Beijing Zhondian (China)


PtX and Sustainability
-- the EESG Framework
Environmental
Energy & Carbon Cycle
Water, Land & Biodiversity
Resources & Recycling
Pollution Risks & Safety
...
Governance
Standards & Certification
Transparency & Participation
Policy Commitment & Coherence
Stability & Rule of Law
...
Economic
Value Added & Decoupled Growth
Energy Mix & Transformation
Trade & Technology Transfer
Infrastructure & Public Finance
...
Social
Access to Energy & Resources
Jobs & Skills
Human Rights & Labour Standards
Health & Safety
...
E
G
E
S
Power to X
Products
Processes
Policies