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Sector Analysis – Kenya

Green hydrogen for the C&I sector

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Abbreviations/Acronyms

AC Alternating Current
AEL Alkaline electrolysis
AEM Anion exchange membrane
AHK German Chambers of Commerce Abroad
ASU Air Separation Unit
barg Absolute pressure and gauge pressure
BMWK German Federal Ministry of Economics and Climate Action
CAPEX Capital Expenditures
CCF National Climate Change Fund
CH_3OH Methanol
CO Carbon
CO_2 Carbon dioxide
DAP Diammonium phosphate
DC Direct Current
EFTA European Free Trade Association (Iceland, Liechtenstein, Norway, Switzerland)
EIB European Investment Bank
EPRA Energy Regulatory Commision of Kenya
ESMAP Energy Sector Management Assistance Program
EU European Union
EU ETS European Union Emissions Trading System
FEC Fuel Energy Charge
FERFA Foreign Exchange Rate Fluctuation Adjustment
FFI Fortescue Future Industries
FIT Feed-in-Tariff
FOB Free on Board
GDP Gross domestic product
GHG Greenhouse Gases
GIS Geographic information system
GIZ Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
H_2 Hydrogen
H2-PDP Project Development Programme for Green Hydrogen Projects
H2Uppp International Hydrogen Ramp-up Programme
HFO Heavy Fuel Oil
HPP Hydro Power Plant
IPP Independent Power Producer
KEPSA Kenya Private Sector Alliance
Ketraco Kenya Electricity Transmission Company
KFW Kreditanstalt für Wiederaufbau)
km Kilometer
KPLC Kenya Power
kV Kilovolt
kWh Kilowatt-hour
LCoA Levelized cost of Ammonia
LCoH Levelized Cost of Hydrogen
LCPDP Least Cost Power Development Plan
LEDS Low Emission Development Strategy
LOHC Liquid organic hydogen carriers
LTS Long Term Low Emission Development Strategy for Kenya
m^3 Cubic metre
MoE Ministry of Energy
MoU Memorandum of understanding
Mt Million tons
MTHP Maximum Technical H2 Potential
MW Mega Watt
N_2 Nitrogen
NCCAP National Climate Change Action Plan
NDC Nationally determined contributions
NH_3 Ammonia
NPK Nitrogen, phosphorus, and potassium
OPEX Operational expenditures
PDP Project Development Programme
PEM Proton Exchange Membrane
PPA Purchase Power Agreement
PPP Public-Private Partnership
PtX Power-to-X
PV Photovoltaics)
R&D Research and Development
R&D&I Research & Development & Innovation
RE Renewable energy
REAP Renewable Energy Auction Policy
RFP Request for proposal
SDGs Sustainable Development Goals
SERC Strathmore Energy Research Centre
SGR Standard Gauge Railway
SME Small and medium-sized enterprises
SOEC Solid oxide electrolysis
TIC Total installed cost
tpa Tons per annum
tpd Tons per day
TWh Terawatt-hour
UETCL Uganda Electricity Transmission Company Limited
VAT Value Added Tax
W2W Water to Water
WARMA Water Resource Management Authority Levy

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Currency Units

EUR Euro
USD United States Dollar
KES Kenyan Shilling

Conversion 17.11.2022: EUR 1 = KES 126.9665
Source: Central Bank of Kenya
https://www.centralbank.go.ke/rates/forex-exchange-rates/

The German Energy Solutions Initiative

Energy solutions – made in Germany

Launched in 2002 by the German Federal Ministry for Economic Affairs and Climate Action (BMWK), the German Energy Solutions Initiative is primarily aimed at small and medium-sized enterprises (SMEs) and supports suppliers of climate-friendly energy solutions in finding new markets abroad. The initiative is active in around 140 countries and aims to disseminate German and European energy technologies more extensively across the globe.

The initiative includes the Project Development Programme (PDP) which is carried out by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and promotes climate-friendly energy solutions in selected emerging and developing countries in sub-Saharan Africa, South and Southeast Asia and the Middle East. Since 2007, the PDP has been supporting the energy transition in its cooperation countries by developing concrete renewable energy and energy efficiency projects. The focus was recently expanded to include green hydrogen projects through the Project Development Programme for Green Hydrogen Projects (H2-PDP), as the German Energy Solutions Initiative is increasingly promoting green hydrogen as a crucial energy carrier for achieving a climate-neutral economy.

Project Development Programme for Green Hydrogen Projects (H2-PDP)

Green hydrogen (H2) is needed to reduce the industry carbon footprint. At present, however, countries such as Ghana, Kenya, Jordan and Vietnam primarily use 'grey hydrogen' derived from fossil fuels. The sustainability of a product and its carbon footprint will play a greater role in determining its competitiveness in future, so it is worthwhile for companies to switch from grey to green hydrogen at an early stage. This solution is hardly cost-effective at the moment, but it is expected to become more competitive with the ramping up of this new market. Moreover, German and European technology suppliers and project developers are not currently particularly active in the selected countries. The market is still being established.

The objective of the project is to enable Ghana, Kenya, Jordan and Vietnam to progressively produce green hydrogen at competitive prices. In order to achieve this, the project identifies local companies that are able to switch from producing or consuming grey hydrogen to producing green hydrogen within a short period. It advises them on plant design, financial models and how they can cover the funding gap when compared with grey hydrogen. With a view to accelerating the transition to green hydrogen, the project facilitates access to funding instruments such as the public-private partnership (PPP) under the International Hydrogen Ramp-up Programme (H2Uppp), international funds and to suitable technology partners from Germany and elsewhere.

The project analyses industry segments that would be suitable for pilot projects and facilitates contact with German/European companies. Additional training sessions raise awareness among local hydrogen consumers, producers and project developers with the involvement of German solution providers. Local companies gain access to suppliers, who are made aware of specific opportunities. Due to their pioneering role, they may profit from financial support measures for pilot projects.

The project is thus supporting the energy transition in the partner countries. At the same time, German and European companies can benefit from this approach as it supports the better understanding of markets and the study project opportunities whilst strategic contacts are also acquired in developing countries and emerging economies.

The series of sector analyses available explore the green hydrogen market potential of Ghana, Kenya, Jordan, and Vietnam and can be downloaded from GIZ's H2-PDP project website:
Changing from grey to green hydrogen production – giz.de

Executive summary

Why start a hydrogen business in Kenya?

The objective of this sector analysis is to outline, from the perspective of German and European business the hydrogen market in Kenya and provide simplified cost estimations for producing green hydrogen using photovoltaics (PV) and orientations for starting a new business in the country. This report is intended for companies looking to partner with local companies that use hydrogen as the main feedstock for their industrial processes. The country offers many opportunities for international investors, such as political stability, a strategic location in East Africa, well-established trade links, tax incentives and an investment protection guarantee supported by the Kenyan government.

Starting a business in Kenya has several benefits, including building new partnerships with Kenyan companies and developing decarbonised solutions for industry by utilising the country's vast renewable resources – including geothermal, hydro, wind and solar – providing an affordable and carbon-free source of energy for green hydrogen production. Locally produced hydrogen is an attractive alternative to reduce the country's current imports of fossil-based hydrogen commodities and build on its energy independence. Additionally, market opportunities for green hydrogen are expected to increase as technology costs for electrolysis lessen and the market of customers willing to pay a premium for decarbonised products increases.

Green hydrogen and ammonia opportunities

Green hydrogen and its derivatives offer multiple benefits such as the decarbonisation of processes and end products, energy storage, renewable energy integration, energy security and economic opportunities. These technologies can play an essential role in the transition to a sustainable and low-carbon economy. The analysis explains, in detail, green hydrogen and ammonia production processes, input product requirements and the associated costs. Additionally, a brief overview describing the import and export balance of hydrogen-based commodities in the country is provided. Furthermore, local industries with the greatest potential to transition to green hydrogen applications are also highlighted.

Zusammenfassung

Warum sollte man ein Wasserstoff-projekt in Kenia starten?

Diese Sektoranalyse skizziert, welche Perspektiven der Wasserstoffmarkt in Kenia deutschen und europäischen Unternehmen bietet. Sie liefert vereinfachte Kostenschätzungen für die Herstellung von grünem Wasserstoff mit Photovoltaik (PV) und Orientierungshilfen für die Umsetzung eines Projekts in Kenia. Dieser Bericht wendet sich an deutsche und europäische Firmen mit Interesse an einer Partnerschaft mit kenianischen Unternehmen, die Wasserstoff als Hauptrohstoff für ihre industriellen Prozesse nutzen. Kenia bietet internationalen Investor*innen gute Voraussetzungen wie politische Stabilität, eine strategisch günstige Lage in Ostafrika, gut etablierte Handelsbeziehungen, Steueranreize und eine von der kenianischen Regierung unterstützte Investitionsschutzgarantie.

Ein Projekt in Kenia umzusetzen, ermöglicht den Aufbau von Partnerschaften zu lokalen Unternehmen. Zudem bieten die umfangreichen erneuerbaren Ressourcen des Landes gute Voraussetzungen für die Entwicklung kohlenstoffarmer Lösungen für die Industrie. Die reichlich vorhandene Erdwärme sowie Wasser-, Wind- und Sonnenenergie sind erschwingliche und kohlenstofffreie Energiequellen für die Produktion von grünem Wasserstoff. In Kenia produzierter grüner Wasserstoff ist eine attraktive Alternative zu Importen von Wasserstoff aus fossilen Rohstoffen und stärkt die Energieunabhängigkeit des Landes. Darüber hinaus dürften die Marktchancen für grünen Wasserstoff steigen, da die Technologiekosten für die Elektrolyse sinken und immer mehr Kunden bereit sind, einen Aufpreis für kohlenstofffreie Produkte zu zahlen.

Chancen für grünen Wasserstoff und Ammoniak

Grüner Wasserstoff und seine chemischen Derivate bieten zahlreiche Vorteile, darunter die Dekarbonisierung von Prozessen und Endprodukten, Energiespeicherung, Integration erneuerbarer Energien, Energiesicherheit und neue wirtschaftliche Chancen. Diese Technologien können eine wesentliche Rolle beim Übergang zu einer nachhaltigen und kohlenstoffarmen Wirtschaft spielen. Die Analyse erläutert im Detail die Verfahren zur Herstellung von grünem Wasserstoff und Ammoniak, die Anforderungen an die Ausgangsprodukte und die damit verbundenen Kosten. Außerdem gibt sie einen kurzen Überblick über die Import- und Exportbilanz von wasserstoffbasierten Produkten in Kenia. Darüber hinaus stellt die Sektoranalyse die lokalen Industrien mit dem größten Potenzial für grüne Wasserstoffanwendungen vor.

Benefiting from Kenyan solar energy sources to produce green hydrogen

Kenya possesses abundant renewable energy resources, including solar, wind, hydro and geothermal, which could be used to produce renewable hydrogen. A specific focus is placed on green hydrogen produced from solar PV with cost details presented in the case studies. Interviews with local manufacturers in Kenya supplemented by informal discussions and a detailed sector analysis were conducted to gauge any potential interest in producing their own green hydrogen. Business cases were developed based on the interviews and represent typical sector scenarios for replacing grey hydrogen with green hydrogen. The business cases focus on current grey hydrogen consumers, where hydrogen is either a production feedstock or an element in the current manufacturing process. The analysis estimates the system sizing, cost including the electrolyser system and solar PV plant, as well as calculating the levelised cost of hydrogen (LCoH) as per the local solar resource. Two business cases are presented for illustrative purposes, where green hydrogen is used for green ammonia and food production.

Establishing hydrogen policies to support investments

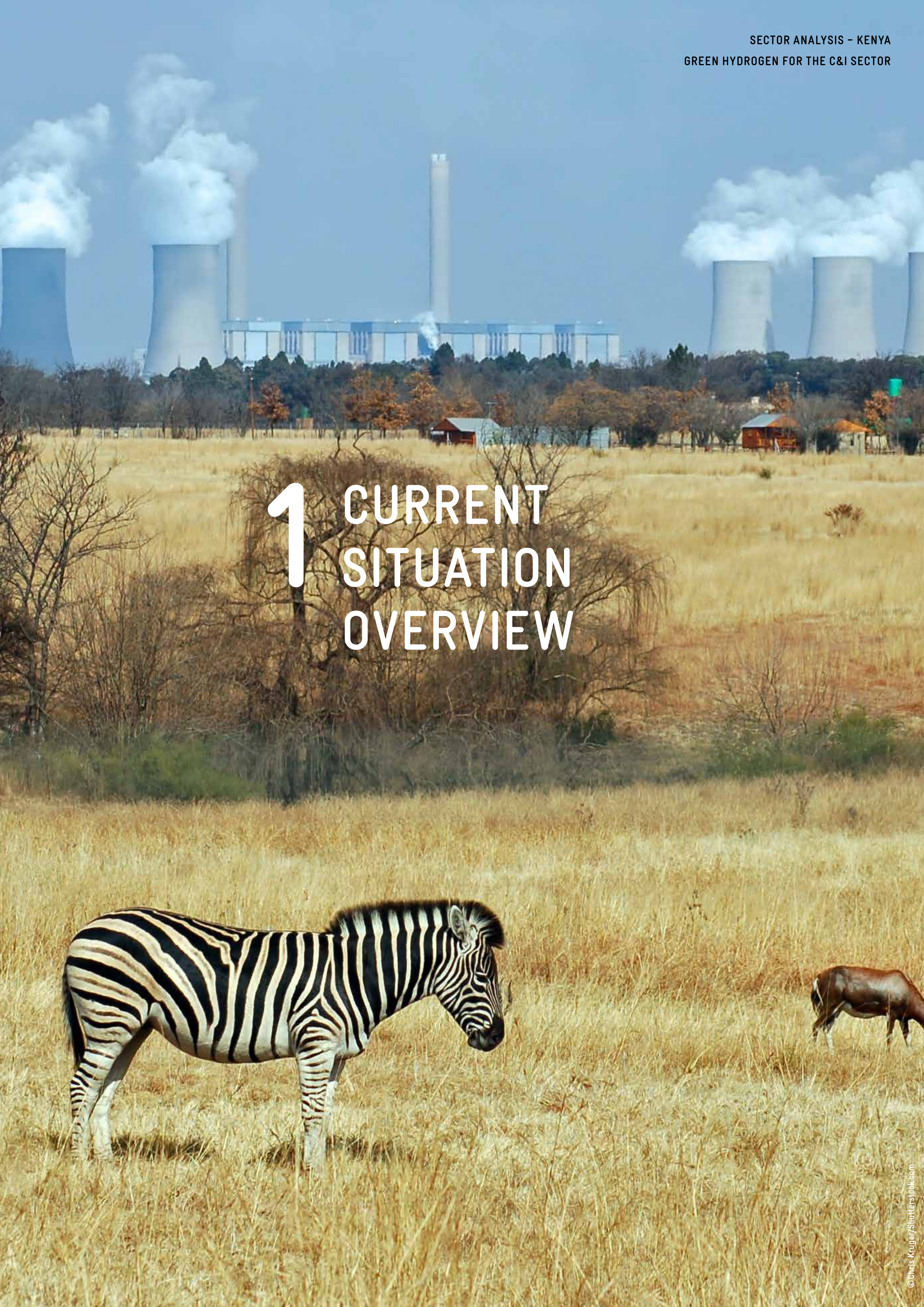
The hydrogen sector in Kenya is an area of growing interest and has the potential to contribute to the country's energy security, reduce its reliance on fossil fuels and help meet its climate change commitments. By implementing green hydrogen and its derivatives, industries can reduce their greenhouse gas emissions and contribute to the decarbonisation of their operations. The country is currently in the process of developing legislation to promote the use of renewable powered hydrogen as part of its efforts to transition to a low-carbon, sustainable economy. The National Climate Change Action Plan (NCCAP) is Kenya's primary policy document on climate change. Furthermore, the Low Emission Development Strategy (LEDS) is a long-term strategy with the objective of decarbonising the electricity system and the industry's transition towards the use of clean electricity sources, including hydrogen.

Nutzung der kenianischen Solarenergie zur Herstellung von grünem Wasserstoff

Kenia verfügt über reiche erneuerbare Energieressourcen, darunter Solar-, Wind-, Wasser- und geothermische Energie, die zur Herstellung von erneuerbarem Wasserstoff genutzt werden können. Ein Schwerpunkt liegt auf grünem Wasserstoff, der mithilfe von PV hergestellt wird. Die entsprechenden Kosten werden in Fallstudien dargestellt. Interviews mit lokalen Herstellern, informelle Gespräche und eine detaillierte Sektoranalyse geben Aufschluss über das Interesse an der Produktion von grünem Wasserstoff. Auf der Grundlage der Interviews entstanden Projekte, die typische Branchenszenarien für den Ersatz von grauem durch grünen Wasserstoff repräsentieren. Die Projekte konzentrieren sich auf die derzeitigen Verbraucher von grauem Wasserstoff, bei denen Wasserstoff entweder ein Produktionsrohstoff oder ein Element im Herstellungsprozess ist. Die Analyse liefert eine Einschätzung der Systemgröße und der Kosten. Berücksichtigt werden dabei auch die Kosten für das Elektrolyseursystem, die PV-Anlage und die nivellierten Wasserstoffkosten (LCoH) in Abhängigkeit von den lokalen Solarressourcen. Zwei Fallbeispiele machen die Nutzung von grünem Wasserstoff für die Herstellung von grünem Ammoniak und Lebensmitteln anschaulich.

Einführung einer Wasserstoffpolitik zur Förderung von Investitionen

In Kenia wächst das Interesse an grünem Wasserstoff, denn dieser Energielieferant hat das Potenzial, zur Energiesicherheit beizutragen, die Abhängigkeit von fossilen Brennstoffen zu verringern und das Erreichen der Klimaziele des Landes zu unterstützen. Durch grünen Wasserstoff und seine chemischen Derivate kann die Industrie ihre Treibhausgasemissionen reduzieren und Betriebe dekarbonisieren. Kenia erarbeitet derzeit Gesetze zur Förderung von Wasserstoff aus erneuerbaren Energiequellen. Dieses Engagement ist Teil der Bemühungen des Landes um den Übergang zu einer kohlenstoffarmen, nachhaltigen Wirtschaft. Der National Climate Change Action Plan (NCCAP) ist Kenias wichtigstes politisches Dokument zum Klimawandel. Von Bedeutung ist darüber hinaus die Low Emission Development Strategy (LEDS), eine langfristige Strategie mit dem Ziel, die Stromversorgung zu dekarbonisieren und die Industrie auf saubere Stromquellen umzustellen – einschließlich Wasserstoff.



1 CURRENT SITUATION OVERVIEW

1. Current Situation overview

Hydrogen is a promising energy carrier with the potential to play a significant role in Kenya's low-carbon transition. While the hydrogen sector in Kenya is still in its early stages of development, the country has taken steps to explore its potential as a clean energy source and to link it to its energy and climate policies. Kenya is in a unique position of already having more than 90% renewable energy (RE)-based electricity generation with a diversified mix of technologies – primarily hydro and geothermal generation followed by wind and solar. The country's electricity system is also characterised by excess baseload energy production during the night derived from geothermal power plants that could be further used to produce green hydrogen.

The country is currently in the process of developing legislation to promote the use of renewable powered hydrogen as part of its efforts to transition to a low-carbon, sustainable economy. The NCCAP is Kenya's primary policy document on climate change. It aims to guide the country's efforts to mitigate and adapt to climate change and to promote low-carbon, climate-resilient development. Furthermore, the LEDS is a long-term strategy plan with the objective of decarbonising the electricity system and the industry's transition towards the use of clean power sources, including hydrogen. The country has also established a Green Hydrogen Working Group and is part of the African Green Hydrogen Alliance to promote the use of green hydrogen in the country.

Overall, the hydrogen sector in Kenya is an area of growing interest and has the potential to contribute to the country's energy security, reduce its reliance on fossil fuels and help meet its climate change commitments. By using green hydrogen and its derivatives, industries can reduce their greenhouse gas emissions and contribute to the decarbonisation of their operations.

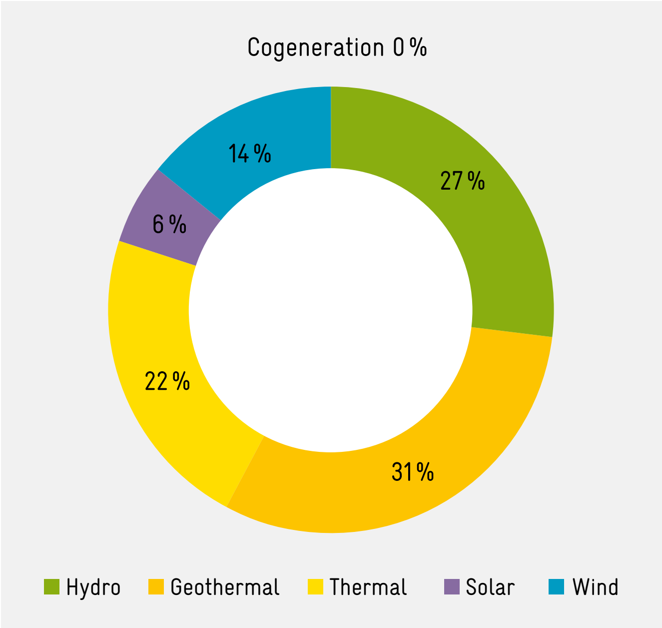
1.1 Assessment of the energy landscape

Kenya's energy system has several distinct characteristics, including the high diversification of energy sources with most of the generation coming from renewable sources. The energy sector in Kenya is unbundled (separate generation, transmission and distribution companies). The utility companies are predominantly state-owned, though there is private participation in the generation sector. Kenya Electricity Transmission Company (Ketraco) operates the bulk electricity transmission and high-voltage network of 132 kV and above and is designated as the system operator. Kenya Power (KPLC) is the operator of the transmission and distribution systems below 132 kV. KenGen, the state-owned electricity generator, accounts for 60% of the effective generation capacity in the country (Kenya Power, 2022).

1.1.1 Electricity generation

There is 3,081 MW installed generation capacity in Kenya. The system is dominated by 27% hydro and 31% geothermal capacity. In addition, there is around 250 MW installed captive capacity (Kenya Power, 2022).

FIGURE 1. INSTALLED GENERATION CAPACITY IN 2022

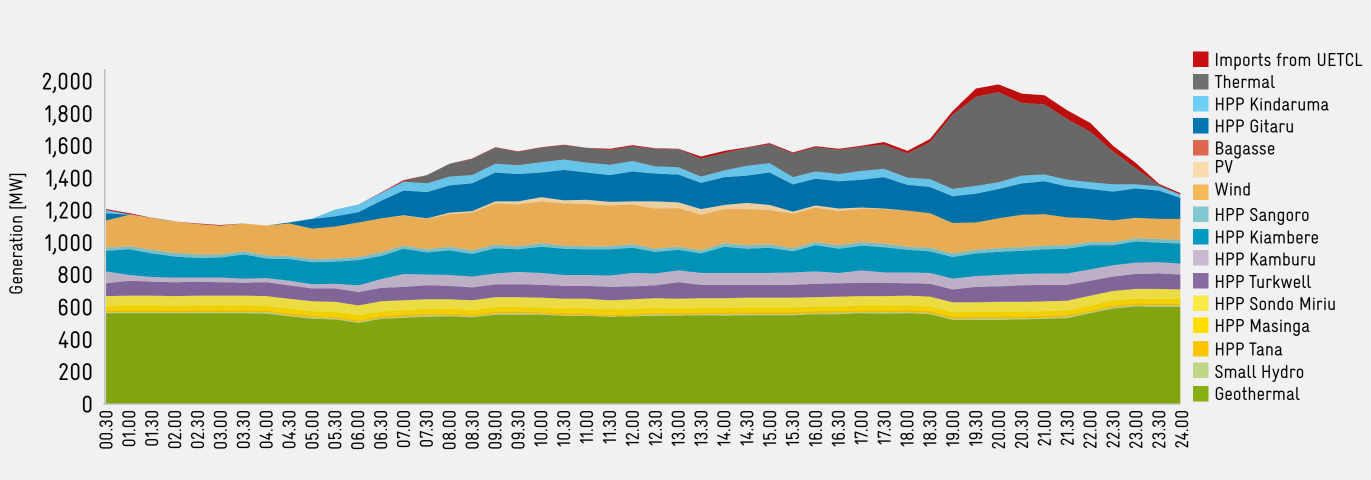


Source: Authors' representation based on (Kenya Power, 2022)

Commercial and industrial users accounted for 53% of electricity demand in 2021/22.

The Kenyan electricity system is characterised by excess baseload, provided by geothermal energy at night, but under capacity during peak times, particularly in the dry season. In the following a sample operation of the Kenyan electricity system on Wednesday 10 December 2020 depicts this phenomenon, with each colour representing a power plant or generation source. Geothermal plants provide baseload at around 600 MW. Most hydropower plants (HPP) also provide baseload with some minor load increase within the peak. Wind power is rather constant at around 180 MW, although this declines during the evening peak period. PV power provided electricity from around 7 am – 5 pm of up to 43 MW. The HPPs Gitaru and Kindaruma provided intermediate power starting at 4.30 am until past midnight. On this day, a significant amount of additional thermal power had to be sourced, around 100 MW between 8 am – 5 pm and up to 500 MW in the peaking evening hours. During the evening peak, up to 60 MW were also imported from the Uganda Electricity Transmission Company Limited (UETCL) (Tractebel Engineering GmbH, 2021).

FIGURE 2. KENYAN SYSTEM DISPATCH EXAMPLE

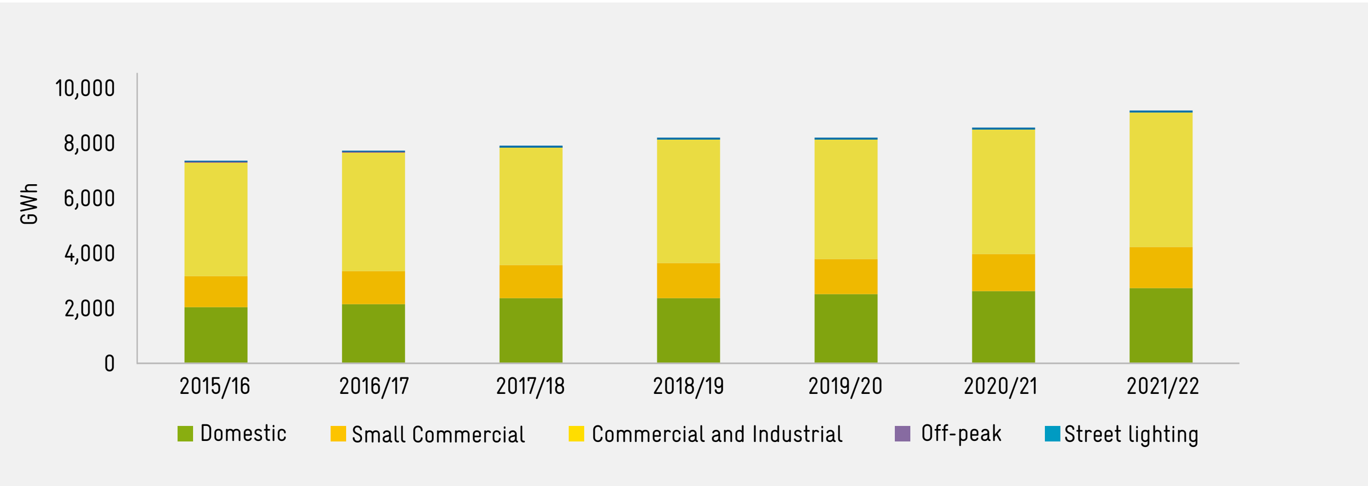


Source: (Ministry of Energy, Kenya, 2021)

1.2 Electricity demand

Total electricity demand in Kenya in 2021 was roughly 12.3 TWh. Generally speaking, demand for electricity in Kenya is fairly predictable: no considerable seasonal variations, demand curve with low demand during the night (below geothermal must-run capacity), fairly even shoulder demand throughout the day and distinctive evening peak (+20% of daytime demand) between 6 pm and 9 pm, main peak from 7 pm to 8 pm. The 20 largest consumers of electricity contribute some 20% of the total commercial/industrial consumption. Historic energy consumption by user type is depicted in Figure 3.

FIGURE 3. ELECTRICITY CONSUMPTION BY USER TYPE



Source: Authors' representation based on (Kenya Power, 2022)

1.3 Energy prices

1.3.1 Electricity prices

Electricity tariffs (on- and off-grid) in Kenya are set by the Energy Regulatory Commission of Kenya (EPRA). Retail tariffs vary by client type and volumes vary between approx. EUR 0.04/kWh and EUR 0.10/kWh, plus a demand charge for industrial customers as shown in Table 1.

Electricity retail tariffs include several monthly pass-through tariff adjustments. These are:

- Fuel Energy Charge (FEC)
- Water Resource Management Authority Levy (WARMA Levy)
- Inflation adjustment (adjusted on a semi-annual basis)
- Foreign Exchange Rate Fluctuation Adjustment (FERFA)

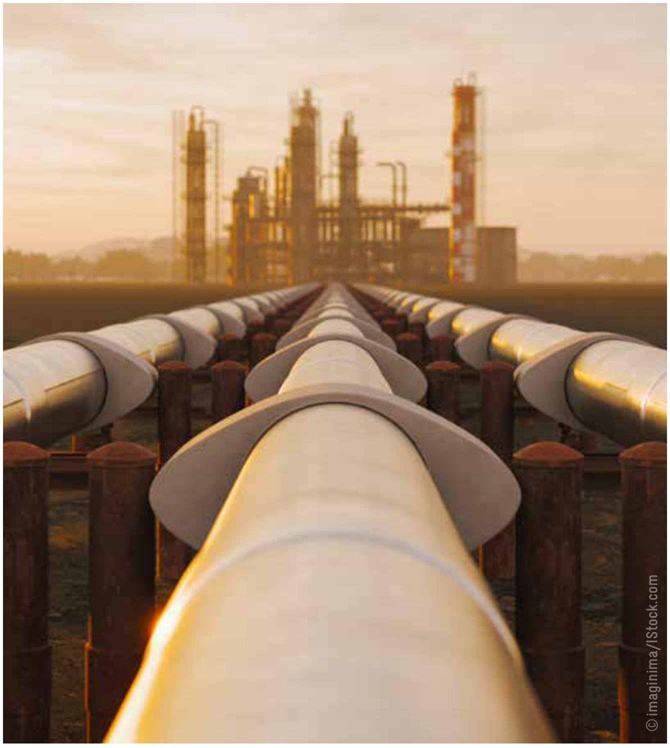
TABLE 1. ELECTRICITY TARIFFS, EFFECTIVE DATE 1 JANUARY 2022

Customer Category	Energy Limit (kWh/Month)	Charge Rate (KES/kWh)	Demand Charge (KES/kVA)	Charge Rate (EUR/kWh)	Demand Charge (EUR/kVA)
DC-Lifeline	0-100	7.7	-	0.061	
DC-Ordinary	>100-1,500	12.6	-	0.099	
Small Commercial SC-1	0-100	7.7	-	0.061	
Small Commercial SC-2	>100-15,000	12.4	-	0.098	
Commercial and Industrial CI 1	No limit	8.7	800	0.069	6.301
Commercial and Industrial CI 2	No limit	8.1	520	0.064	4.096
Commercial and Industrial CI 3	No limit	8	270	0.063	2.127
Commercial and Industrial CI 4	No limit	7.8	220	0.061	1.733
Commercial and Industrial CI 5	No limit	7.6	220	0.060	1.733
Street Lighting	No Limit	5.5	-	0.043	

Souce: Authors' calculation based on (Kenya Ministry of Energy, 2021) EUR 1 = KES 126.9665

1.3.2 Gas prices

Kenya does not have a domestic supply of natural gas. The natural gas price is the global market commodity price, plus transport. In the Least Cost Power Development Plan (LCPDP) planning, international transport costs are estimated at 4% markup on free on board (FOB) for gas oil and 13% markup on FOB for heavy fuel oil (HFO). EPRA approved a tariff of KES 4.61/m³/km/ (EUR 0.036/m³/km) in 2021/22 for the use of domestic pipelines (Kenya Power, 2022).



1.4 Legislative and regulatory framework

1.4.1 Renewable energy incentive mechanism

Feed-in tariff

Kenya's Feed-in-Tariff (FIT) system for RE has been in place since 2008. The RE policy for the power sector was updated by the Ministry of Energy in 2021 by means of:

- the FIT policy on renewable energy resource-generated electricity (small hydro, biomass and biogas), 3rd revision of January 2021 ("FIT"),
- the Renewable Energy Auction Policy, January 2021 ("REAP").

These policies are applied together; FIT is applicable to installations up to 20 MW and REAP applies to solar PV, wind power projects as well as other RE power projects greater than 20 MW. Auctions will be announced by the Ministry of Energy (MoE) on the appropriate timing and targeted capacity.

Another policy change currently being discussed is the shift to "take-and-pay" from the previous "take-or-pay" clause in Power Purchase Agreements (PPA's) for Independent Power Producers (IPP's), which allowed generators to ensure bankability through guaranteed payment for providing capacity, whether it was evaluated or not. "Take-and-pay" will shift the risk of bottlenecks in transmission capacity or oversupply to the IPP, which will likely severely hinder the bankability of future renewable energy project selling to the grid.

Taxes

Solar and wind generation equipment has been exempt from 16% Valued Added Tax (VAT) since the Finance Act of 2021 (removing the VAT which was imposed in the Finance Act of 2020) (Green Hydrogen Organisation, 2021). According to the VAT Act 2013, wind generation equipment is not subject to import duty or value added tax.

TABLE 2. SUMMARY OF RENEWABLE ENERGY POLICY INSTRUMENTS

RE policy instruments	Description
Mechanisms to support renewable energy	FIT up to 20 MW (excluding PV and wind) REAP PV, wind and RE projects greater than 20 MW
Tax	The exemption from VAT for specialised equipment for the development and generation of solar and wind energy, including deep cycle batteries which use or store solar power wind generation equipment, is not subject to import duty or value added tax

Source: Authors' representation

1.4.2 Hydrogen incentive mechanisms

There are currently no hydrogen-specific incentive mechanisms in Kenya. However, the Government of Kenya is in the process of developing a financial incentive policy framework with the aim of incentivising investments in green production. The task force is currently working on the draft; however, it is expected that one main focus area will be manufacturing.

Hydrogen is also starting to play an important role in long-term planning for industry decarbonisation, as demonstrated in the Long-Term Low Emission Development Strategy for Kenya (LTS). In the LTS it is forecasted that Kenya can achieve net-zero carbon emissions if the electricity system is successfully fully decarbonised and energy consumption in industry and transport shifts from traditional carbon-based fuels towards clean electricity sources including hydrogen fuel, specifically:

- in industry, increase share of final energy demand coming from hydrogen in the cement industry. Replace 40% of coal with hydrogen in the production of cement;
- increase the use of green hydrogen in large industries, including chemicals, paints, steel, pharmaceuticals;
- in food and beverage manufacturing, replace 15% of heavy fuel oil used with electricity and hydrogen. In other industries, hydrogen replaces 70% of heavy fuels;
- in transport, transition from fossil fuel to electric and hydrogen-fuelled vehicles, with 30% of all vehicles to be electric or hydrogen-powered by 2050. With the extension of the Standard Gauge Railway (SGR) to Malaba, it is assumed that most of the freight shall shift from truck to train. It is assumed that 90% of truck transport will transition to train and the remaining 10% will consist of state-of-the-art trucks on hydrogen fuel cells.

The current interest in green hydrogen is driven by manufacturers and industries wishing to use it to decarbonise their own operations. A list of hydrogen norms and standards currently in place used by industries can be found in the Appendix.

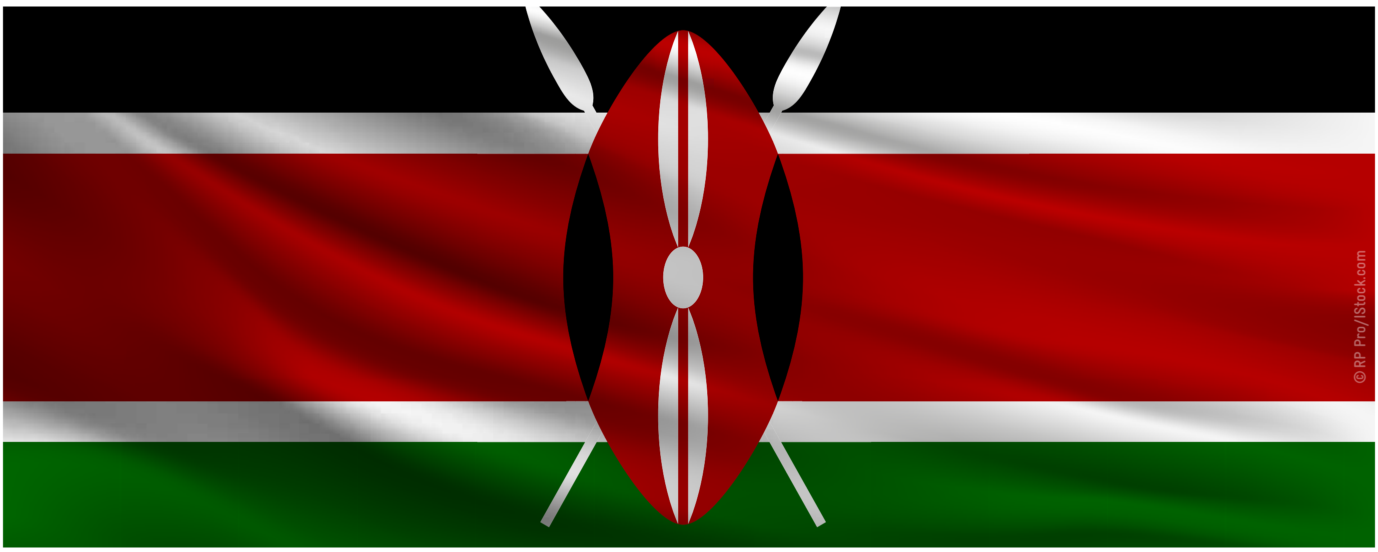
1.5 Pilot projects and enabling infrastructure

The Government of Kenya is actively developing its hydrogen programme to promote the use of green hydrogen in the country. Its recent initiatives include:

- the establishment of the Green Hydrogen Working Group by the Ministry of Energy with representatives from industry, government, energy infrastructure utilities and international development agencies to address challenges to green hydrogen;
- commissioning of the Baseline Study on the Potential for Power-to-X / Green Hydrogen in Kenya (Ministry of Energy, Kenya, 2021);
- Kenya is one of six countries which formally launched the African Green Hydrogen Alliance in May 2022 to help link existing green hydrogen initiatives to leadership efforts (African Green Hydrogen Alliance, 2022);
- KenGen has published an RFP (request for proposal) for a feasibility study for fertiliser production using green hydrogen.

Several green hydrogen pilot projects have been announced, a couple of which are currently under development. These include:

- Fortescue Future Industries (FFI) and the Kenya Private Sector Alliance (KEPSA) have signed a Memorandum of understanding (MoU) to help facilitate their members' participation in new large-scale green energy projects in Kenya. FFI is currently assessing a proposed integrated large-scale green hydrogen and green ammonia production facility, which would be powered by renewables. Through the partnership with KEPSA, FFI is expected to co-develop green hydrogen project(s) with Kenyan private sector firms (Green Hydrogen Organisation, 2021);
- Project – power-to-fertiliser plant by Maire Tecnimont S.p.A. (Maire Tecnimont, 2021). Maire Tecnimont S.p.A., an Italian group of 50 companies, through its subsidiaries MET Development, Stamicarbon and NextChem, has announced its interests in a commercial-scale renewable power-to-fertiliser (nitrate fertiliser) plant in Kenya. In this regard, the company has signed an agreement with Oserian Development Company – an owner and operator of the Oserian Two Lakes Industrial Park – for the development of a new 150-hectare sustainable industrial development in Nakuru County, Kenya. Located close to the country's largest geothermal energy basin, it is planned to be partly powered by solar energy sources produced on-site. The project is expected to reduce dependency on imported nitrogen fertilisers and substitute around 25%, of which the total accounts for around 800 kt/a.
- Research and Development (R&D)/demonstration project on zero-emission energy generation and storage technology by Strathmore Energy Research Centre (SERC) and Steamology in Kenya (Strathmore University, 2020). The concept of the Water to Water (W2W) system will be used in closed-loop energy generation and storage. The system will use a renewable energy source to split water into hydrogen and oxygen gases through electrolysis. The gases will be then compressed and stored in pressurised cylinders where they can be recombined, on demand, to produce steam in order to generate electricity.



2 GREEN HYDROGEN TECHNOLOGY AND ESTIMATION OF COSTS IN THE KENYAN CONTEXT

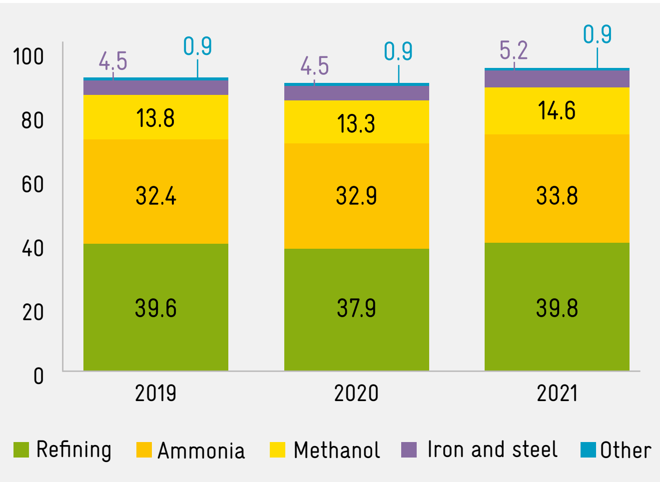
2. Green hydrogen technology and estimation of costs in the Kenyan context

2.1 Introduction to hydrogen-based products

Hydrogen is the most abundant element on earth and an important chemical building block for numerous production processes, including the refining of petrochemicals, industrial processes such as glass and semi-conductor production and in food production. Hydrogen is also a feedstock used in the production of downstream products such as ammonia and methanol.

Hydrogen has been produced on a significant industrial scale for decades. Currently, 95% of global hydrogen is produced using fossil fuels (grey hydrogen) (IRENA, 2018), primarily through the natural gas-based steam reforming process which is used to produce around 69 million tons of hydrogen annually (Statista). For the production of hydrogen, a typical natural gas-based steam reforming plant with 607 t/d capacity results in a H_2 production cost of USD 1.22/kg, depending on natural gas prices (A.O. Oni, 2022). The primary drawback to this process are the significant carbon dioxide (CO_2) emissions, which range on average between 8–9 kg CO_2/kg hydrogen (H_2). Global demand for hydrogen in 2021 was 94 Mt., a 5% increase compared to 2020 (IEA, 2022).

FIGURE 4. HYDROGEN DEMAND BY SECTOR



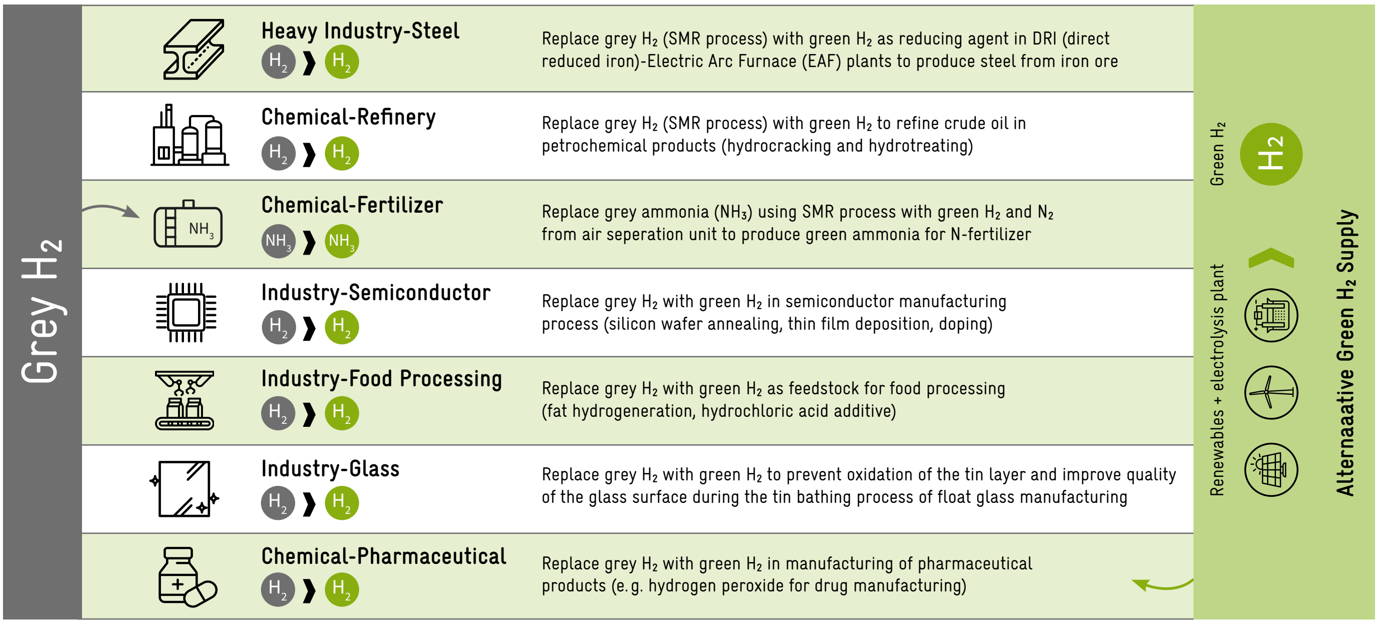
Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (IEA, 2022)

Hydrogen is predominantly used in refining as well as in the production of downstream products such as ammonia and methanol. Only about 6% of hydrogen produced is used for pure hydrogen demand (IEA, 2019). This share of hydrogen goes into the manufacturing processes of a wide variety of petrochemical products (PU foams, oxo-alcohols, nylon, etc.), pharmaceuticals, food production, electronics, etc. Hydrogen is mainly produced on-demand and on-site for treatment purposes or the production of chemicals.

In the context of decarbonisation of industrial processes, green hydrogen is one of the favoured commodities. There are several utilisation routes for green hydrogen. One is the replacement of fossil-based hydrogen in synthesis or treatment processes. It is also used as a reduction gas, for example, in the steel industry. Another is the replacement of fossil energy sources for heating purposes, as well as an energy carrier for electrical storage purposes.

Numerous sectors currently use hydrogen (or hydrogen-based products) as part of their production processes. These include heavy industry, for example, in steel production, in the chemical sector in refineries, for fertiliser production and pharmaceuticals and in the industrial sector, for example, in floating glass, semi-conductor or food production. Figure 5 shows a selection of the current industrial uses of hydrogen and how these can be replaced with carbon-free green hydrogen alternatives.

FIGURE 5. CURRENT INDUSTRIAL USES OF GREY HYDROGEN



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

As described above, hydrogen is extremely versatile and green hydrogen unlocks new possibilities for decarbonising industries as well as contributing to energy security. However, hydrogen is a gas under atmospheric conditions and therefore needs to be processed either through compression or conversion to make it suitable for transport. The most attractive options for shipping hydrogen are ammonia, liquid hydrogen and liquid organic hydrogen carriers (LoHC) (Blanco, 2022).

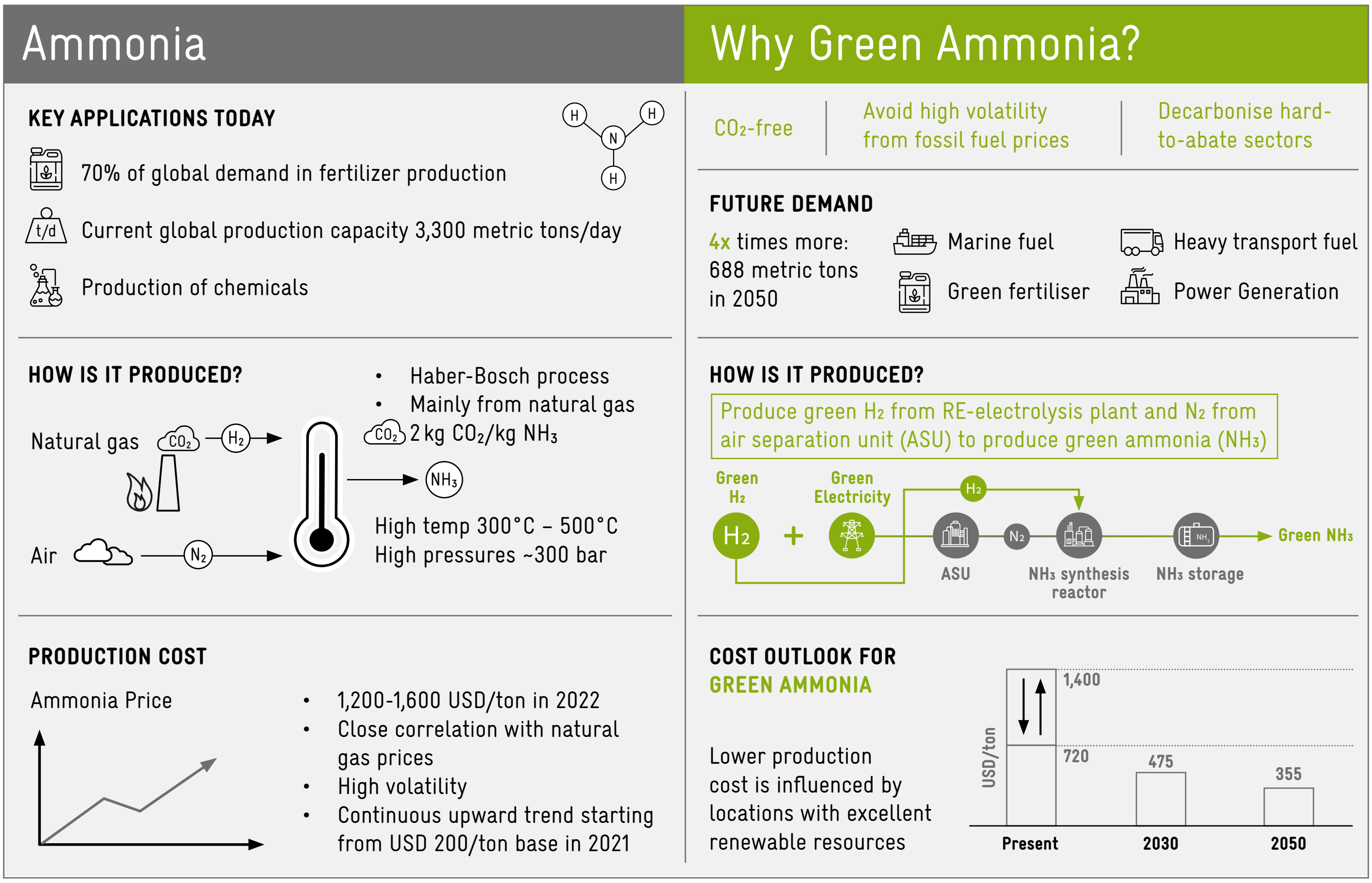
2.2 Hydrogen downstream products

The two primary downstream hydrogen-based products are methanol and ammonia. Methanol is a highly versatile commodity which is used as a fuel and in the production of plastics, silicone, acetic acid and formaldehyde, among others. Ammonia is primarily used as a chemical to create fertilisers, including urea and diammonium phosphate (DAP).

2.2.1 Ammonia

Ammonia ($NH3$) is the largest hydrogen-based downstream chemical by volume, representing around 43% of the global hydrogen demand, with around 236 million tons produced worldwide in 2021 (Statista, 2022) (IEA, 2022). It is the primary feedstock for nitrogen fertilisers, which account for around 70% of the global ammonia demand. The production of NH_3 involves a chemical synthesis process which requires H_2 and nitrogen (N_2), at a ratio of 18% H_2 and 82% N_2 as feedstock. As most of the current ammonia production is dependent on natural gas, ammonia prices are strongly correlated with those of natural gas. Conventional ammonia production is an emission-intensive process as it primarily relies on fossil fuels with over 70% of production using natural gas and the remaining 30% using coal. This most common fossil fuel-based Haber-Bosch process emits CO_2 in the order of USD 2 per kg of ammonia (Ghavam, 2021). Switching to green ammonia can significantly reduce greenhouse gas emissions in agriculture and transportation as it could be used as carbon-free fuel or fertiliser.

FIGURE 6. GREY AND GREEN AMMONIA PROPERTIES

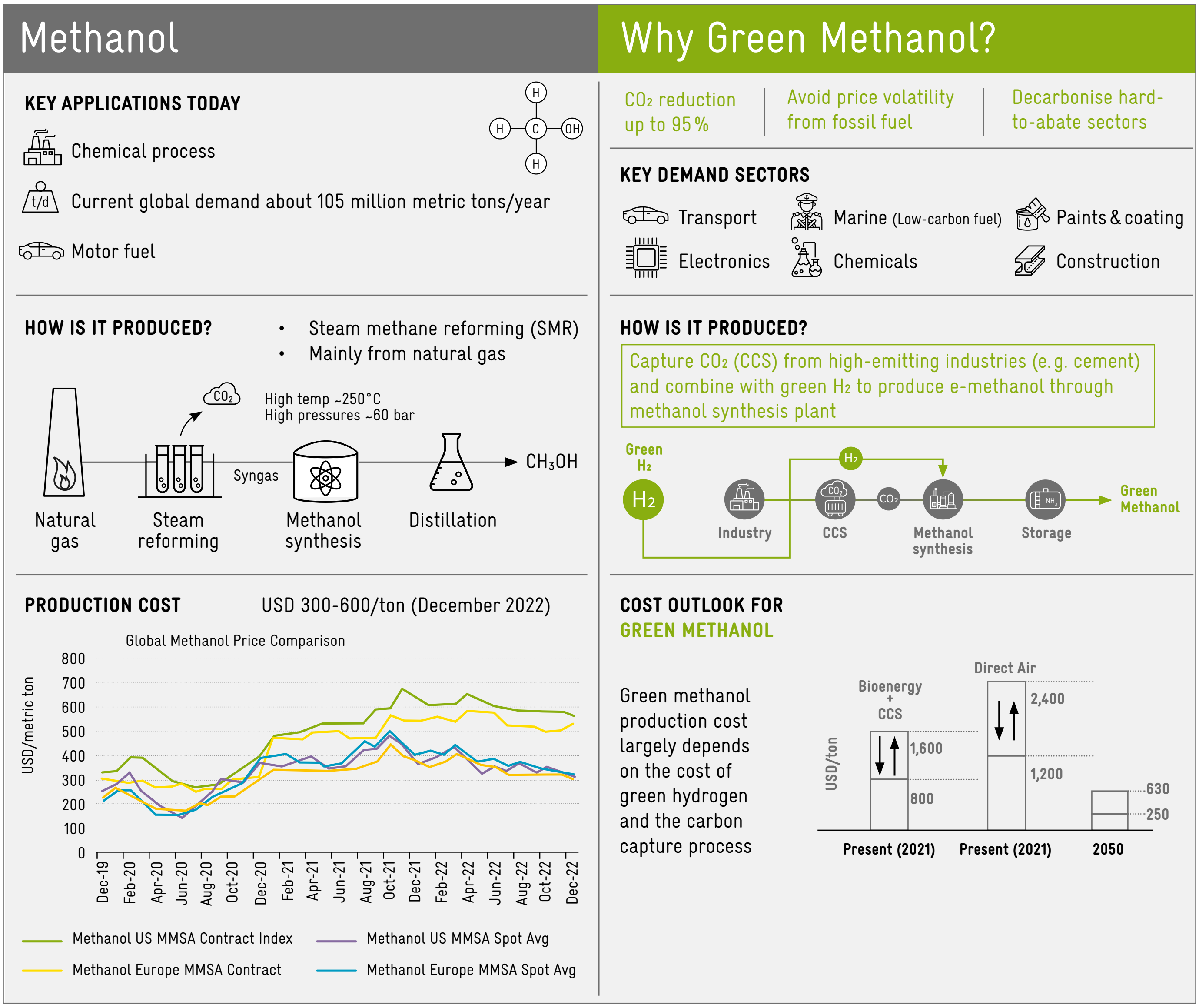


Source: Authors' own illustration, ENGIE Impact GmbH (2023)

2.2.2 Methanol

Methanol (CH_3OH) is a simple water-soluble alcohol which can be used as a fuel for combustion engines or in methanol fuel cells, as a solvent, an anti-freeze, and a base chemical in the production of various downstream chemicals such as polymers, formaldehyde and acetic acid. The predominant methanol consumer is the automotive sector where it is mainly used as a motor fuel offering multiple advantages due to its high-octane content, which improves engine efficiency. Methanol is typically produced through the process of catalytic reduction of carbon monoxide (CO) with H_2, called syngas, with a catalyst used at high pressures (up to 60 bar) and high temperatures (about 250°C), in a process known as "methanol synthesis". Green methanol is gaining significant interest as its production methods could cut up to 95% of CO_2 emissions compared to traditional methods (Methanol Institute, 2021).

FIGURE 7. GREY AND GREEN METHANOL PROPERTIES



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

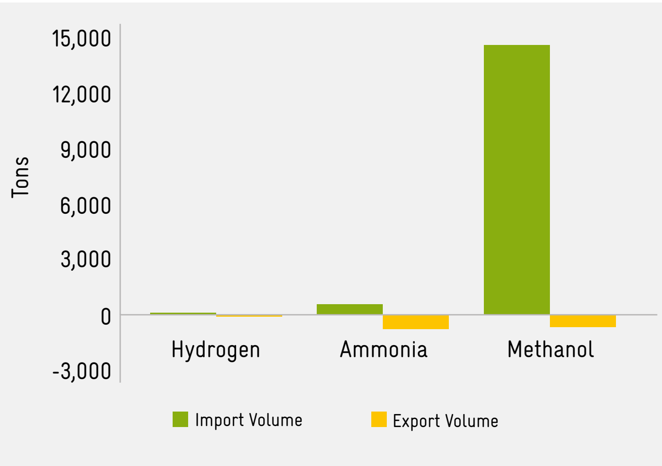
2.3 Industrial use of hydrogen in Kenya

The main hydrogen-consuming industry in Kenya is the chemical sector, primarily for fertilisers as well as to a lesser extent food production.

- Chemical - fertilisers. Between November 2021 and October 2022 an estimated 126,212 Mt of nitrogen, phosphorus, and potassium (NPK) fertiliser was imported into Kenya, with an apparent consumption of NPK in 2021 of 154,269 Mt. Several fertiliser plants are in the planning/under construction stage (AfricaFertilizer, 2023).
- Chemical – pharmaceutical.
- Industry – food processing.

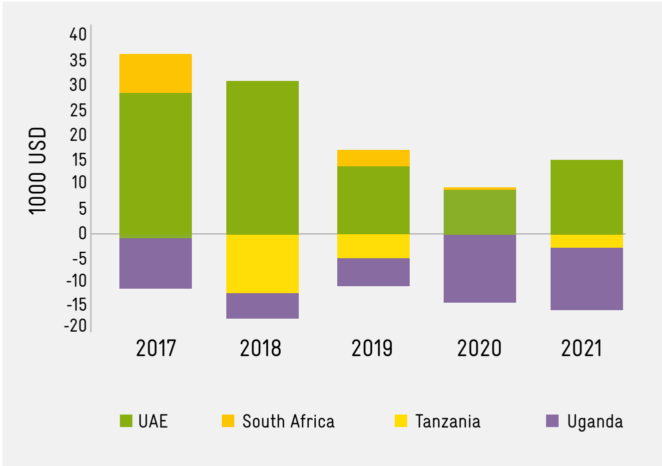
Kenya imports USD ~23 thousand p.a. of hydrogen, the equivalent of ~7 ton/year (assuming 3 USD/kg) with no growth trend. Kenya exports ammonia to neighbouring Tanzania and Uganda with imports primarily coming from India and South Africa at volumes of around USD 90 thousand p.a. Most importantly, Kenya is an importer of methanol, primarily from Egypt and Saudi Arabia, with an annual volume of around 5,000 tons, amounting to about USD 3 million p.a. with a slight growth trend.

FIGURE 8. KENYAN TRADE BALANCE BY FEEDSTOCK IN 2017–2021



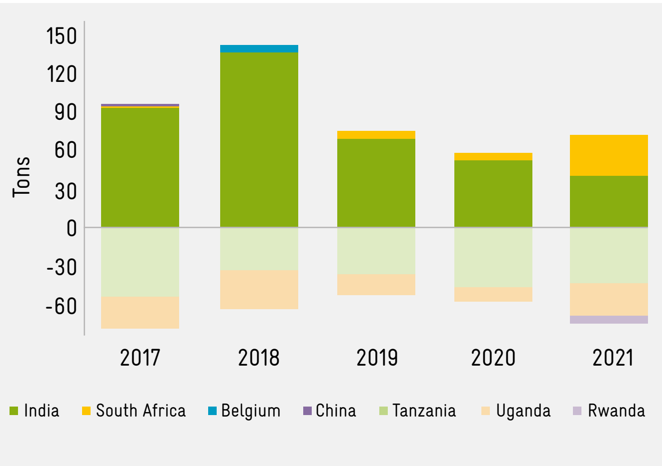
Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (World Bank, 2022)

FIGURE 9. HYDROGEN IMPORTS AND EXPORTS TO AND FROM KENYA BY COUNTERPARTY 2017–2021



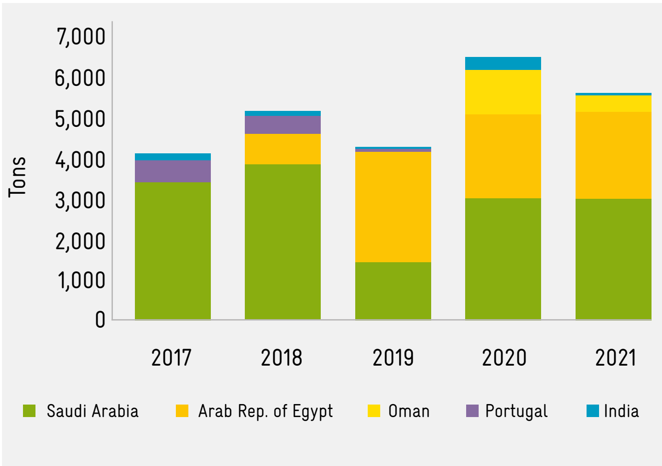
Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (World Bank, 2023)

FIGURE 10. AMMONIA IMPORTS AND EXPORTS TO AND FROM KENYA BY COUNTERPARTY 2017–2021



Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (World Bank, 2023)

FIGURE 11. METHANOL EXPORTS AND IMPORTS TO AND FROM KENYA BY COUNTERPARTY 2017–2021



Source: Authors' own illustration, ENGIE Impact GmbH (2023), based on (World Bank, 2023)

The consistent, if modest, import volumes of hydrogen and its derivative products indicate that there is potential for local production and deployment of Power-to-X (PtX) technologies, particularly for the introduction of green ammonia and methanol into Kenya's economy. Methanol is the primary hydrogen-based commodity imported into Kenya, accounting for the largest share in terms of volume and representing almost 95% of total imports. Replacing hydrogen commodity imports with green substitutes would enable the development of new industrial processes, reduce supply risks and mitigate risks associated with market price fluctuations. Furthermore, Kenya's almost 100% renewable energy-based power system could allow for cost-effective hydrogen production without negatively impacting existing power consumers.

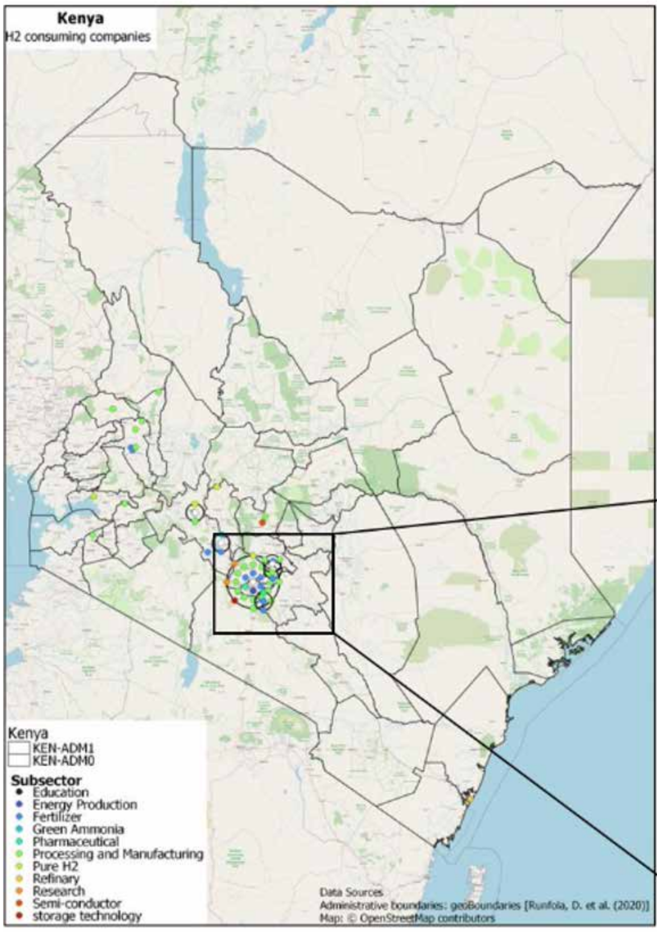
Agriculture is the second-largest contributor to Kenya's gross domestic product (GDP) and a significant source of employment, with fertiliser playing an essential role in sustaining the sector. The majority of fertiliser imports come from India, Europe and South Africa, and local production of green ammonia presents an opportunity to shift the value chain to Kenya and reduce supply risks. As shown in the graphs, Kenya is also a re-exporter of ammonia to neighbouring Tanzania and Uganda, and domestic production of green ammonia could lead to the development of new markets and strengthen the country's position as an export hub. Due to excess renewable power, established trade links and import/export costs, prices of green ammonia could become competitive in the near future. Benefits of moving to green ammonia for fertiliser production include improved food quality, supply chain security and job creation.

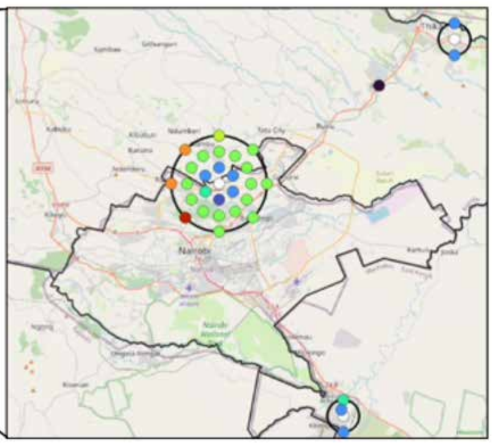
Introducing green methanol into Kenya's industry sector presents many opportunities, including its use as an energy carrier for storing the electricity generated by renewable resources, cooking fuel, an additive to conventional fuels, or as a fuel for direct methanol fuel cells. New hydrogen-based solutions could be used as an energy carrier for the off-grid supply of isolated grids or single consumers and serve as pilot schemes.

Green hydrogen and its derivatives have potential applications in light industry and the commodity sector, particularly in manufacturing. Hydrogen is a critical feedstock for refining, the chemical industry, pharmaceuticals and float glass production. In Kenya, several manufacturing industries rely solely on grey hydrogen, lacking a viable alternative. Green hydrogen presents an advantage over grey hydrogen due to the omission of possible contamination, potentially leading to improved quality of final products (Ministry of Energy, Kenya, 2021).

The key fossil-based hydrogen-consuming sectors are primarily clustered in three main locations: Nairobi, Mombasa, and the Great Rift Valley (see Figure 12). Each hub has its unique characteristics that may provide benefits to future hydrogen producers and consumers. Mombasa and surrounding coastal areas are close to the existing infrastructure (port, railway, handling, storage) and availability of water through desalination. The Rift Valley is located close to major power generation sources and power network nodes, while the centrally located Nairobi area is connected to major power network nodes, generation sources, infrastructure and industrial sites.

FIGURE 12. CURRENT INDUSTRIAL HYDROGEN USERS





Source: Authors' own illustration, ENGIE Impact GmbH (2023)

2.4 Power-to-X technology

In this sector analysis, the PtX technologies green hydrogen and green ammonia will be considered from a techno-economic perspective as they suit best to the current market in the country.

2.4.1 Green hydrogen production process

In the context of PtX systems, green hydrogen is produced via the electrolysis of water, using electricity and water as inputs to produce hydrogen as the main product. The electrolysis of water is an electrochemical process in which water is electrochemically dissociated into its molecular components – hydrogen and oxygen.

The main inputs for the electrolysis process are pure water – which needs to be supplied in demineralised quality – and electricity - which needs to be supplied as direct current either from a Direct Current (DC) power source or an Alternating Current (AC) power source after conversion. Depending on the electrolyser type, the average pure water demand is 14 litres of water per kg of hydrogen produced. The main product of the electrolysis process is hydrogen in gaseous form. Oxygen and waste heat are produced as by-products, which can be utilised for external applications.

There are different water electrolysis technologies, of which alkaline electrolysis (AEL) and proton exchange membrane (PEM) electrolysis are currently the most mature technologies for low-temperature systems. Other electrolysis technologies include anion exchange membrane (AEM) and high-temperature solid oxide (SOEC) electrolysis which are currently in the prototype (AEM) and demonstration phase (SOEC), respectively.

The electrolysis process itself is dependent on the technology and is characterised by different electrochemical and process parameters.

TABLE 3. OVERVIEW OF THE MAIN PERFORMANCE VALUES OF ALKALINE AND PEM ELECTROLYSIS

	Alkaline electrolysis	PEM electrolysis
Stack efficiency range at full load (LHV)	48–50 kWh/kg ˜67–70%	48–52 kWh/kg ˜64–70%
Operating temperature range	50–80°C	50–80°C
Operating pressure range	0.15–30 barg	0.15–40 barg
Operating range per module	20–100%	10–100%

Source: Authors' representation

The main hydrogen production process takes place in the electrolysis cell stacks, which are composed of multiple individual cell modules. At plant level, electrolysis plants include various subsystems for the supply of utilities to the cell stacks. These subsystems include, for example, water treatment, gas treatment, cooling, power conversion and distribution as well as instrumentation and control systems.

Electrolysis plants are characterised by a modular design approach, with current available designs in the range of 1 MW (small-scale) and 100 MW or more (large-scale). Small-scale electrolysis plants can be delivered as turnkey units based on standardised solutions, while large-scale electrolysis plants are developed as project-specific solutions based on predefined subsystems.

2.4.2 Green ammonia production process

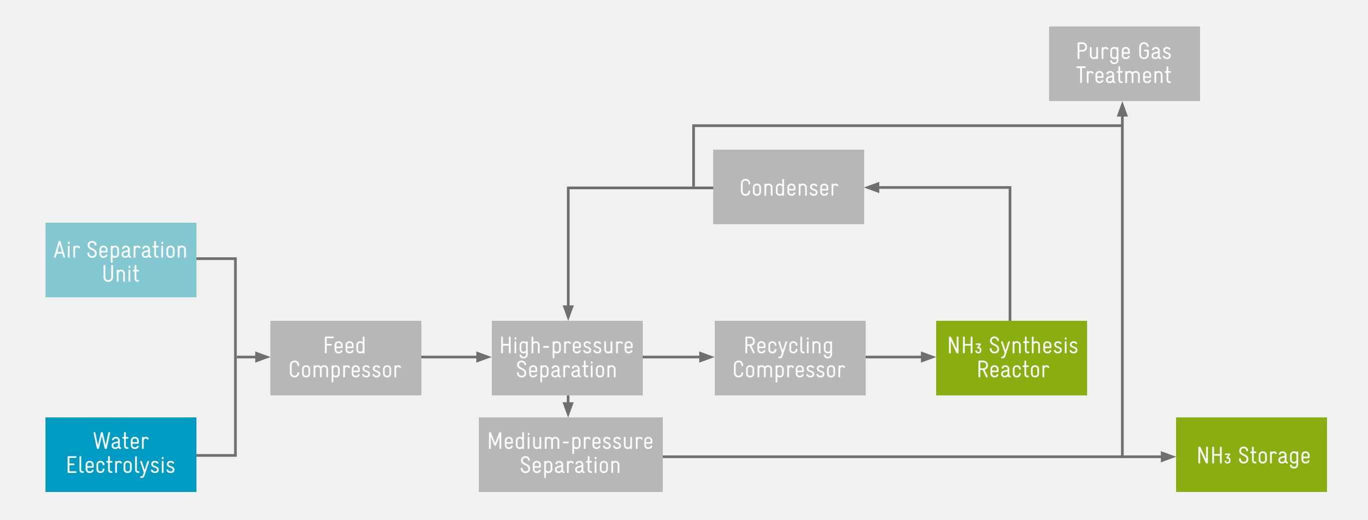
Wind- or solar-based green ammonia production requires the separate production of both hydrogen and nitrogen. Within the scope of this sector analysis, hydrogen is generated by electrolysis. Nitrogen is obtained from ambient air and, from a technical point of view, can be produced in three different ways: cryogenic distillation (ASU – air separation unit), pressure swing adsorption or separation using a membrane process. All processes are commercially viable and primarily require electrical energy. The process of cryogenic distillation has the lowest specific energy consumption. Hydrogen and nitrogen are then introduced downstream into an ammonia synthesis loop. With a starting material ratio of 18% of hydrogen by weight to 82% of nitrogen by weight, ammonia is produced by means of catalytic synthesis – also known as Haber-Bosch synthesis – at temperatures between 300°C and 500°C and high pressures of up to 300 bar. Full conversion to ammonia cannot be achieved in a single pass due to the equilibrium conditions of the Haber-Bosch reaction. Consequently, the overall yield of the plant can be increased by implementing a so-called recycling loop to recycle unreacted reactants.

TABLE 4. OVERVIEW OF HABER-BOSCH SYNTHESIS CONDITIONS

Technology	Reaction	Process conditions	Specific consumption for 1 kg NH_3
Haber-Bosch synthesis	$1.5\ H_2 + 0.5\ N_2 \leftrightarrow NH_3$	300°C to 500°C up to 300 bar	0.18 kg H_2 0.82 kg N_2

Source: Authors' representation

FIGURE 13. GREEN AMMONIA PROCESS



Source: Authors' own illustration, ENGIE Impact GmbH

During green ammonia production, attention should be paid to ensure that the Haber-Bosch synthesis is effected at a constant operating mode when possible. The same applies to cryogenic air separation for the supply of nitrogen. In contrast, PEM electrolysis can be "ramped up or down" under changing current loads. Therefore, when developing the overall system process, appropriate compensation of load changes on the upstream side must be taken into account. Consideration should also be given to how constant production quantities can be ensured for the consumer market. The figure below provides an overview of the green ammonia production process.

2.5 PtX costs

A set of technical and economic assumptions are defined for the calculation of the levelised cost of hydrogen, as well as for the business case calculations, which are summarised in Table 5 and Table 6. The cost assumptions are differentiated between medium- (5 MW) and large-scale (100 MW) system sizes in order to show economies of scale. Note that the CAPEX assumptions are based on the total installed cost (TIC), including direct costs for equipment supply and indirect costs for plant installation and design.

The technical assumptions are based on average values, common per technology, without differentiation between plant scale.

TABLE 5. TECHNICAL AND ECONOMIC ASSUMPTIONS FOR THE ELECTROLYSIS SYSTEM

		PEM		Alkaline		AEM	SOEC
		Large-scale	Medium-scale	Large-scale	Medium-scale	Small-scale	Small-scale
Spec. CAPEX	EUR/kW	1,300	2,700	840	1,900	4,683	3,650
Spec. fixed OPEX	EUR/kW/year	15	20	20	25	19	32
System efficiency	% LHV	62%	62%	62%	62%	62%	81%
Efficiency degradation	%/year	1.3%	1.3%	1%	1%	1.3%	4%
Stack operational lifetime	hours	65,000	65,000	60,000	60,000	35,000	20,000
Spec. tap water consumption	L/kg H_2	14	14	14	14	14	14
Operating pressure	barg	30	30	0.15	0.15	35	0.15

Source: Authors' representation based on generic assumptions

TABLE 6. TECHNICAL ASSUMPTIONS FOR THE HYDROGEN COMPRESSION AND STORAGE SYSTEM

		PEM		Alkaline		AEM	SOEC
		Large-scale	Medium-scale	Large-scale	Medium-scale	Small-scale	Small-scale
Delivery pressure	barg	100	100	100	100	100	100
Spec. compression power	kWh/kg	0.7	0.7	2.8	2.8	0.7	2.8
Max. storage pressure	barg	100	100	100	100	100	100
Max. storage autonomy	hours	72	72	72	72	72	72

Source: Authors' representation based on generic assumptions

2.5.1 Green ammonia production costs

The following provides an illustrative example of the cost of green ammonia production when considering the capacity of a 300 tons per day (tpd) ammonia synthesis plant. Table 7 summarises the technical assumptions. Based on the Haber-Bosch reaction, the hypothesis is that the complete conversion of hydrogen and nitrogen into ammonia takes place via the ammonia synthesis cycle. Green hydrogen is produced using PEM electrolysis with a specific consumption of 50 kWh/kg H_2. The total specific consumption for the ammonia synthesis loop including nitrogen generation is about 1.2 kWh/kg NH_3. Hence a total of around 10 kWh of energy is required to produce 1 kg of NH_3, of which H_2 production is a major component.

TABLE 7. TECHNICAL ASSUMPTIONS FOR GREEN AMMONIA PRODUCTION

Specific Technical Assumptions		
H_2 demand	0.18	kg H_2 /kg NH_3
N_2 demand	0.82	kg N_2 /kg NH_3
PEM electrolysis (50 kWh/kg H_2)	8.8	kWh/kg NH_3
NH_3 synthesis (incl. ASU)	1.2	kWh/kg NH_3
Total energy demand	**10** 36	**kWh/kg NH_3** MJ/kg NH_3

Source: Authors' representation based on generic assumptions

Table 8 summarises the capacity and price assumptions. To produce 300 tpd of ammonia, 53 tpd of hydrogen and 247 tpd of nitrogen are required. The production cost calculation considers levelised hydrogen production costs of EUR 8/kg H_2. The energy required for NH_3 synthesis including ASU is assumed to be provided via grid electricity at EUR 0.16/kWh. Due to the cryogenic process, the ASU cannot be "ramped up and down" depending on the availability of renewable energy; it must remain relatively constant 24 hours a day. The total investment cost for the NH_3 synthesis loop including ASU amounts to approx. EUR 82 million.

TABLE 8. GREEN AMMONIA CAPACITY AND PRICING ASSUMPTIONS

Capacity and Pricing Assumptions	
NH_3 capacity	300 tpd NH_3
H_2 demand	53 tpd H_2
N_2 demand	247 tpd N_2
CAPEX NH_3 synthesis (incl. ASU)	EUR 82 m
LCoH	EUR 8/kg
Grid electricity cost	EUR 0.16/kWh

Source: Authors' representation based on generic assumptions

Table 9 shows the specific production costs separated according to the shares for H_2 and NH_3 synthesis. Both shares consider operating costs and TIC. When calculating the specific cost shares for NH_3 synthesis, a depreciation period of 10 years and annual operating hours of 8,000 h are assumed.

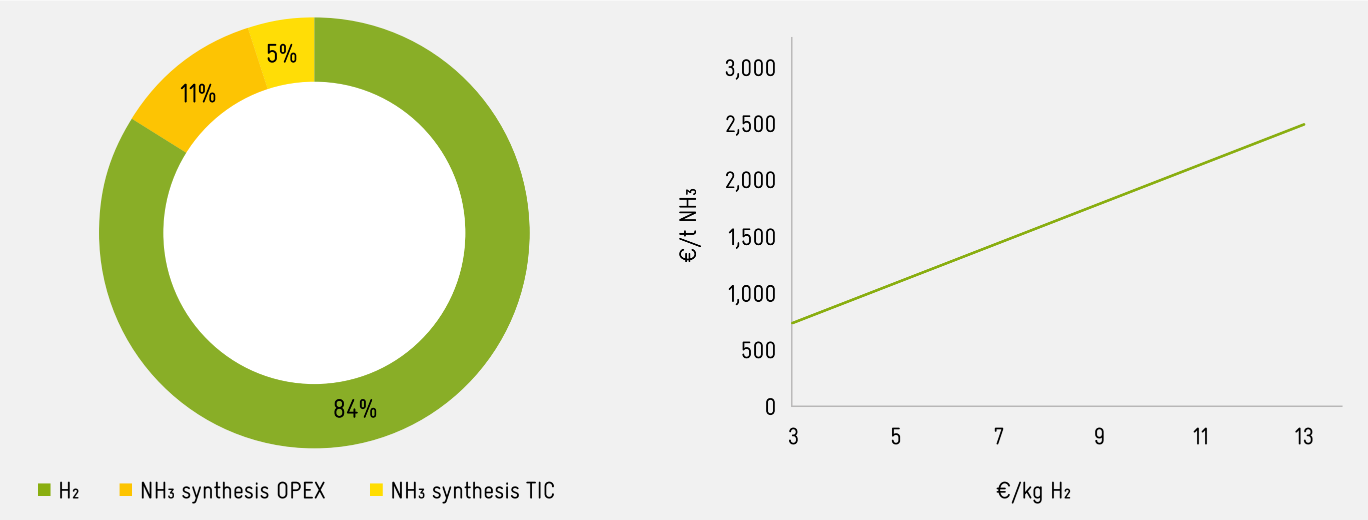
TABLE 9. GREEN AMMONIA SPECIFIC PRODUCTION COSTS

Specific Production Costs			
	H_2	NH_3 synthesis	Total
EUR/t NH_3	1,412	274	1,686
	84%	16%	100%

Source: Authors' representation based on generic assumptions

As with the specific energy requirement, the calculation shows that the main cost driver is hydrogen production. At around 84%, this is more than three quarters of the total production cost for ammonia. The 16% NH_3 synthesis cost comprises 11% operating costs and 5% TIC. The influence of the levelised cost of hydrogen on NH_3 production is shown in Figure 14. Impact of the H_2 price on the LCoA

FIGURE 14. H_2 PRICE IMPACT ON LCOA



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

2.5.2 Levelised cost of hydrogen in Kenya

The green hydrogen production potential from solar PV energy in Kenya and the associated levelised cost of hydrogen production were estimated. For this purpose, a high-level geographical analysis has been performed, estimating the regional hydrogen production potential and specific cost based on local solar potential. A map of the solar PV capacity factor with assumptions can be found in Figure 19 and Table 15 in the Appendix.

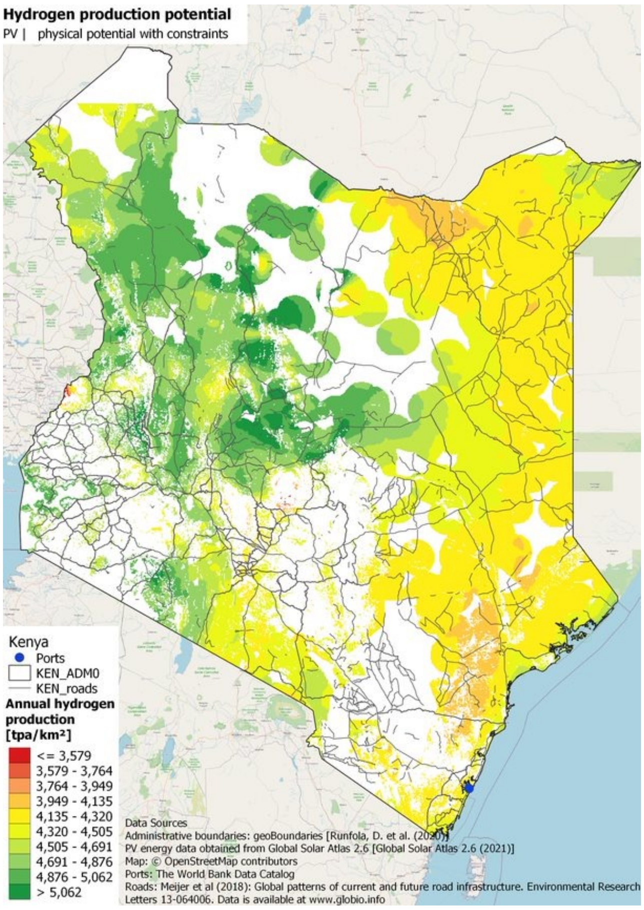
In the GIS analysis, the technical hydrogen production potential is estimated. The technical production potential describes the maximum annual hydrogen quantity that can be produced in a defined area, taking into account the local PV energy yield, conversion efficiencies (electrolysis) as well as land-use constraints. Land-use constraints are applied according to the level 2 constraints based on the Energy Sector Management Assistance Program (ESMAP) (ESMAP Global Solar Atlas, 2020), which considers areas with rugged terrain, extreme remoteness, built-up environments, dense forests and, additionally, cropland and conservation areas as exclusion areas for the installation of solar PV plants. Therefore, areas with these land-use constraints are excluded from the analysis and the overall production potential (for electricity and hydrogen) is reduced accordingly.

Due to the land-use constraints applied, in regions with high population densities, complex terrain or large nature reserve areas, locally large areas are considered unsuitable for the production of hydrogen. The exclusion areas are shown as white space in the following coloured maps. Due to the land-use constraints, several areas were not considered for hydrogen production, including large parts of the southern half (except Garissa, Kajiado, Kilifi and Kwale Counties) and of the Isiolo and Marsabit Counties.

Figure 15 gives an indication of the maximum technical H_2 potential (MTHP) for a specified area, taking into account the land-use restrictions. The average H_2 potential for Kenya is 4,509 tpa/km². The specific MTHP for the Uasin Gishu County is 4,891 tpa/km². Other areas with significant specific potential in the central part of the country are the Laikipia and Samburu Counties with an estimated specific MTHP of 4,887 tpa/km² and 4,865 tpa/km², respectively. Note that local water constraints are not considered in the hydrogen potential maps and must be assessed on a case-by-case basis.

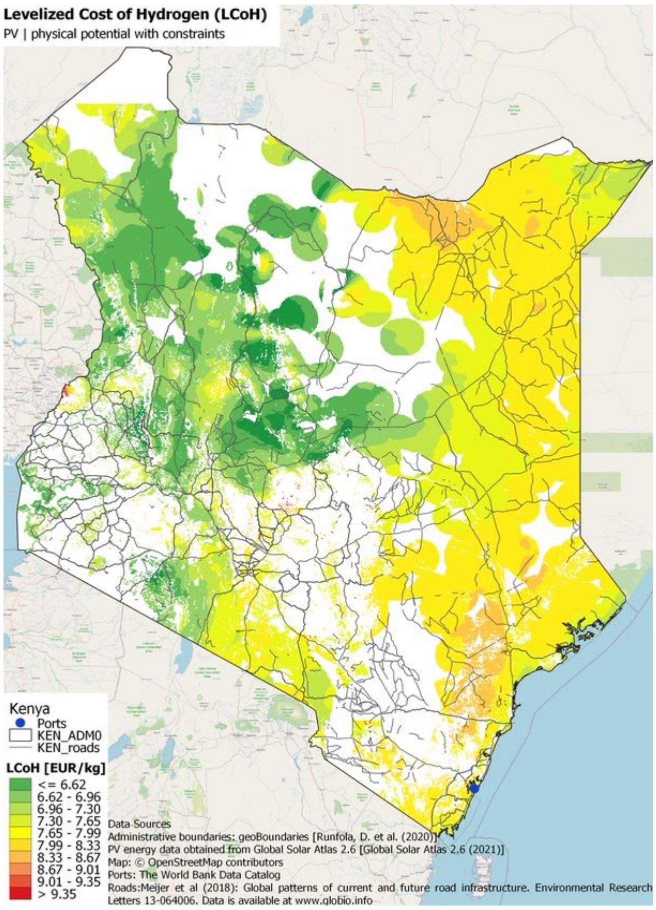
As can be seen on the maps, the areas with the greatest potential are located in the north-western (former Rift Valley Province) and eastern areas of the country. The proximity of the Lamu East Sub-county would be advantageous if a project were to be set up to produce green hydrogen for export. The areas with most land without constraints can be observed in the north-western region (Baringo, Laikipia, Samburu, Turkana and West Pokot Counties), western region (Garissa, Lamu, Mandera, Tana River and Wajir Counties) and Kajiado County.

FIGURE 15. SPATIAL DISTRIBUTION OF HYDROGEN PRODUCTION POTENTIAL IN KENYA



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

FIGURE 16. HYDROGEN PRODUCTION POTENTIAL



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

Figure 15 and Figure 16 show the spatial distribution of the levelised cost of hydrogen (in EUR/kg) in Kenya taking into account land-use constraints (level 2 constraints). The spatial distribution of the LCoH is directly proportional to the local irradiance and power yield of the PV plants.

The lowest LCoH level of EUR ≤ 6.62/kg can be observed in the central region (Laikipia, Meru and Samburu Counties), while the highest LCoH level of USD > 9.35/kg can be observed in the western region in Bungoma County (Mt. Elgon Sub-county).

In the Appendix, Figure 21 and Figure 20 show the H_2 production potential and LCoH without land-use constraints.

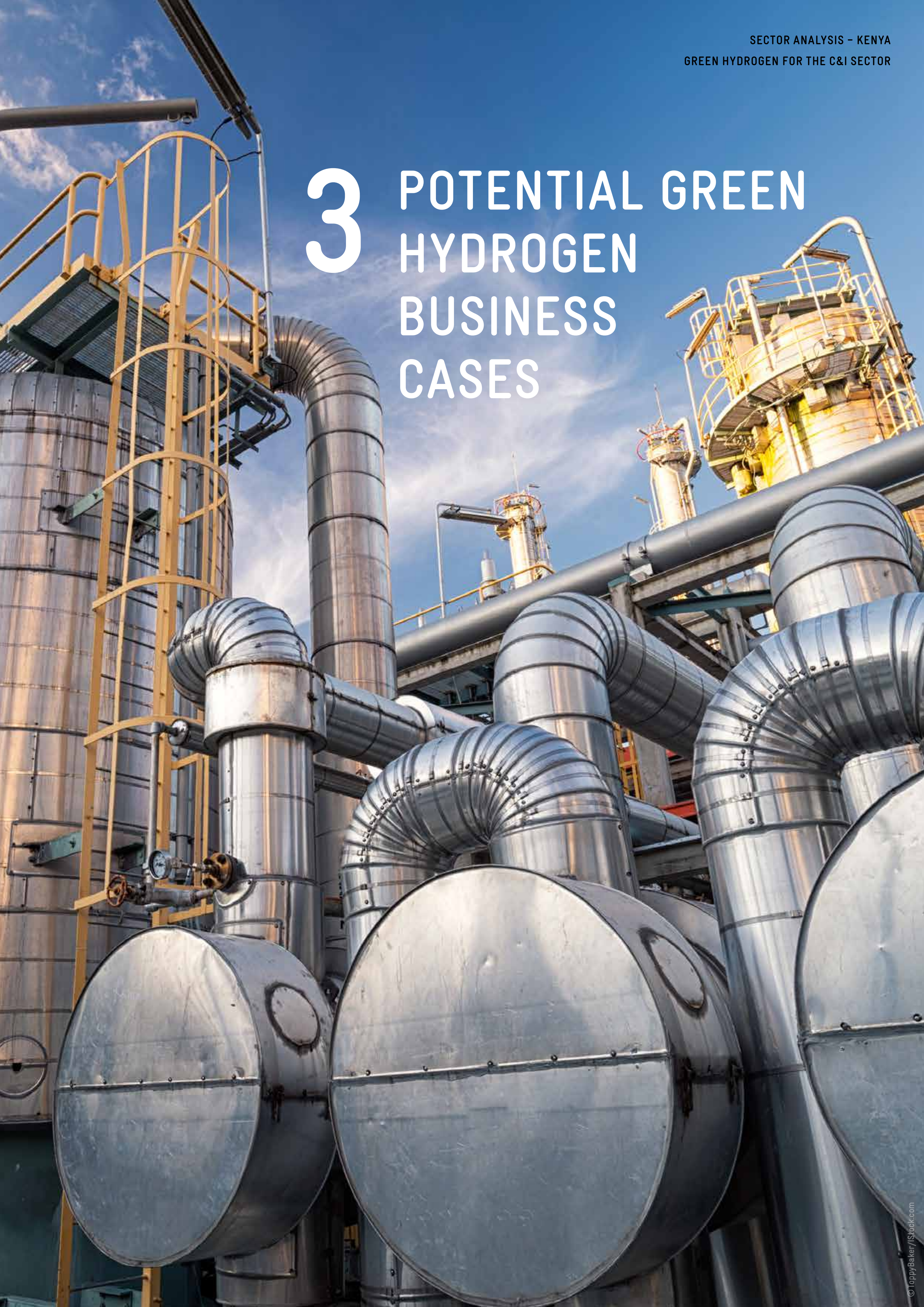
The top 5 locations in terms of renewable energy and hydrogen production potential in Kenya are shown in Table 10; the complete table with all locations can be found in the Appendix. The capacity factor for PV, the average specific hydrogen production potential per region, the total hydrogen production potential per region and the calculated average levelised cost of hydrogen per region are shown.

TABLE 10. SUMMARY OF PV AND GREEN HYDROGEN PRODUCTION POTENTIAL BY REGION

Kenya	PV capacity factor [%]	Theoretic green hydrogen production potential		LCoH
		Area-specific potential [tpa/km²]	Total potential [tpa]	[EUR/kg]
Laikipia	20.34%	4,887	34,211,485	6.75
Uasin Gishu	20.33%	4,891	7,487,619	6.75
Samburu	20.23%	4,865	62,654,639	6.78
Siaya	20.17%	4,878	3,561,199	6.76
Kisumu	20.11%	4,846	3,300,121	6.8

Source: Authors' representation

3 POTENTIAL GREEN HYDROGEN BUSINESS CASES



3. Potential green hydrogen business cases

To understand the potential interest of local businesses in Kenya in converting from current conventional hydrogen consumption to producing their own green hydrogen, detailed research was conducted with private sector representatives. The main sources of information were two industry interviews with current grey hydrogen users, during which they were asked about their hydrogen processes, motivation for interest in green hydrogen production, perceived challenges in converting to local green hydrogen production, hydrogen (or derivative product) demand and cost levels, land availability for PV and access to sufficient water. A complete list of questions included in the questionnaire could be found in the Appendix in Table 17. The attached list is not exhaustive and additional informal discussions, e-mail exchanges and literature reviews were used to gain a full picture of the private sector in Kenya and its willingness to switch to green hydrogen. The chosen method of research allowed the responders of this sector analysis the freedom of response that was further supplemented by a detailed industry sector analysis. Based on this information, illustrative business cases were developed, which represent typical sector scenarios replacing grey hydrogen used in the manufacturing process with green hydrogen.

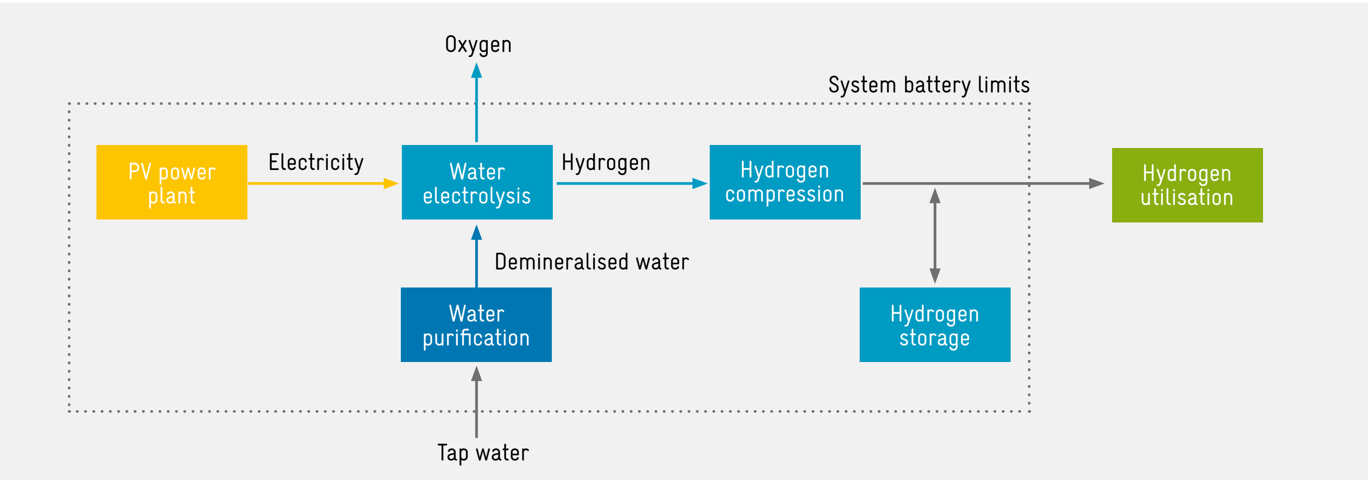
The premise of the business cases is the replacement of current grey hydrogen with locally produced green hydrogen which would be created solely using carbon-free electricity supplied from on-site solar PV. These business cases focus on current grey hydrogen consumers where the hydrogen, or hydrogen derivative product, is either a production feedstock or an element in the current manufacturing process (e.g. process gas). Use cases for hydrogen as a thermal or energy carrier or as a transportation fuel are not considered within this sector analysis. The production concept for the business cases is shown in Figure 17.

For each business case, a high-level cost-benefit analysis was carried out based on the estimated sizing and cost of the electrolyser system and solar PV plant, as well as the LCoH as per the local solar resource. To estimate the system cost, the PV and the electrolysis system are sized to meet the H_2 demand, and it is assumed that both are implemented as a combined greenfield project without pre-existing equipment. The methodology for the calculation is described in the Appendix and the key assumptions used are shown in Table 18.

When considering green hydrogen production powered solely by PV electricity, due to the variable nature of the solar resource the sizing of system components will be influenced by the operational mode of the H_2 used in the end production process. Although the same volume in annual tons of H_2 produced is the same, for business operations where a constant or baseload supply of hydrogen is required, the PV plant must be oversized to ensure a minimum baseload production even during non-peak solar resources. In cases where flexible production is possible, i.e. production scheduled following the solar resource, then PV plants could be significantly smaller, but the electrolyser would need to be oversized to fully utilise solar peak production. The choice of flexible and baseload H_2 production also has a significant impact on system costs and the resulting LCoH, particularly in cases where extra electricity from the PV plant can be sold back to the grid, which can account for substantial additional revenue. Please see the Appendix for a thorough explanation.

For each case, the complete LCoH is calculated. In addition, the "effective" LCoH is calculated by adding back the discounted value of electricity sales revenue and oxygen sales revenue, which are benefits which would not accrue without the project. Finally, the effective LCoH is also provided for informational purposes, also taking into account the value of avoided GHG emissions.

FIGURE 17. GREEN HYDROGEN PRODUCTION CONCEPT



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

The LCoH presented in the case studies varies from the global specific LCoH presented on the geographic information system (GIS) maps as the GIS maps represent simplified costs of production, which is a common standard methodology, and are comparable to what is found in the LCoH in literature and other studies. The LCoH in the business cases, on the other, hand include additional costs that the company will likely incur, for example, import taxes (when applicable), inflation on OPEX, capitalised financing costs and increased capital expenditures (CAPEX) and operational expenditures (OPEX) related to system sizing (or oversizing) required to achieve the specified H_2 production profile as well as additional oversizing of the PV field to ensure a minimum level of annual production taking into account the degradation of both the PV and the electrolyser system over time which requires adding significant additional PV capacity. Together, these result in an LCoH which can, in some cases, vary significantly from the simplified specific production costs.

Given the comparatively low plant utilisation rates, due to the variable solar resource and lack of economies-of-scale production, small-scale local green hydrogen is not currently cost-competitive with conventional sources on a specific cost-of-production basis. However, as electrolyser technology costs come down and the decarbonisation of industry takes on a more important role with financial consequences, for example, through carbon tax, this could change. Therefore, the business cases set out to determine what it would take in terms of financial support to make the local production of green hydrogen, powered by solar PV, cost effective for local businesses in Kenya.

Note: the business cases are intended for illustrative purposes only and do not represent an actual company.

3.1 Case 1. Green hydrogen for ammonia fertiliser production

A fertiliser production company located near Nairobi, Kenya, which currently imports all raw materials for fertiliser mixing is considering expanding to include local green H_2 production. In the first phase, the ammonia demand would be ~7,400 tpa. Given that ~18% hydrogen and ~82% nitrogen is required to produce ammonia, for 7,366 tons/year of NH_3 production, 1,300 tpa H_2 is required.

Given the solar resource in the Nairobi region of Kenya, to produce 1,300 tpa of H_2 in baseload operational mode, a 111 MW PV plant and a 27 MW electrolyser would be required. In flexible operation mode the PV plant would only need to be 60 MW and the electrolysis system would need to be sized at 46 MW. Both systems have almost the same upfront investment cost of around EUR 150 m. About 10,400 tons of oxygen per year would be produced as a by-product of the hydrogen production process, which could be sold to industrial users (assumed price EUR 0.40/kg). The table below shows the system sizing for both flexible and baseline operational modes.

TABLE 11. BUSINESS CASE 1. H_2 FOR AMMONIA PRODUCTION SYSTEM SIZING

System Sizing	Flexible Operation	Baseload Operation
Installed PV power (kWp)	60,982	111,358
Design power electrolysis (kW)	45,870	27,380
Annual net electricity generation PV (kWh/year)	92,908,702	169,659,123
Annual net electricity consumption EL (kWh/year)	69,885,484	69,885,484
Total investment (EUR thousand)	147,744	150,527

Source: Authors' representation

The complete assumptions, sizing, cost breakdown and results are show in Table 15 in the Appendix.

Using the cost assumptions as described in Section 3.5 for AEL technology, the resulting specific LCoH is EUR 14.37/kg in flexible operation and EUR 15.28/kg with baseload operation sizing. However, when considering the equivalent value of the surplus PV electricity which could be sold back to the grid, as well as revenue from oxygen sales, the resulting effective LCoH is EUR 10.64/kg with flexible and EUR 8.12/kg with baseload operation sizing. The key difference is the volume of extra electricity which could be effectively sold, reducing the effective LCoH by EUR 3.96/kWh. In the baseload case, revenue from the sale of extra electricity and oxygen would cover more than 2/3 of the green H_2 production costs.

Given the target LCoH of EUR 3.09/kg to achieve price parity with conventional H_2 sources, subsidies equalling EUR 7.55/kg or the equivalent of a CAPEX grant of EUR 100 m would be required with flexible operation sizing and EUR 5.04/kg or the equivalent of a EUR 65 m CAPEX grant with baseload operation sizing would be required.

The breakdown of the LCoH for the business case is presented in the following table.

TABLE 12. BUSINESS CASE 1. H_2 FOR AMMONIA PRODUCTION LCOH BREAKDOWN

Levelised Cost of Hydrogen	Flexible Operation	Baseload Operation
	EUR/kg	EUR/kg
Levelised Cost of Hydrogen	**14.37**	**15.28**
Equivalent levelised value of benefits per kg H_2 produced		
Equivalent value of oxygen revenue per kg H_2 produced	3.20	3.20
Equivalent value of electricity revenue per kg H_2 produced	0.53	3.96
Effective LCOH (incl. electricity and oxygen sales)	10.64	8.12
Effective LCOH (inc. revenue + CO_2 avoided costs)	9.86	7.34
Target LCoH (cost comparable to market price for grey H_2)	3.09	3.09
Required Subsidies		
Effective green H_2 LCoH	10.64	8.12
Target LCoH (cost comparable to market price for grey H_2)	3.09	3.09
Price gap between effective green LCoH and target LCoH [EUR/kg]	7.55	5.04
Subsidy required to achieve target (investment subsidy in EUR thousand)	100,058	65,011

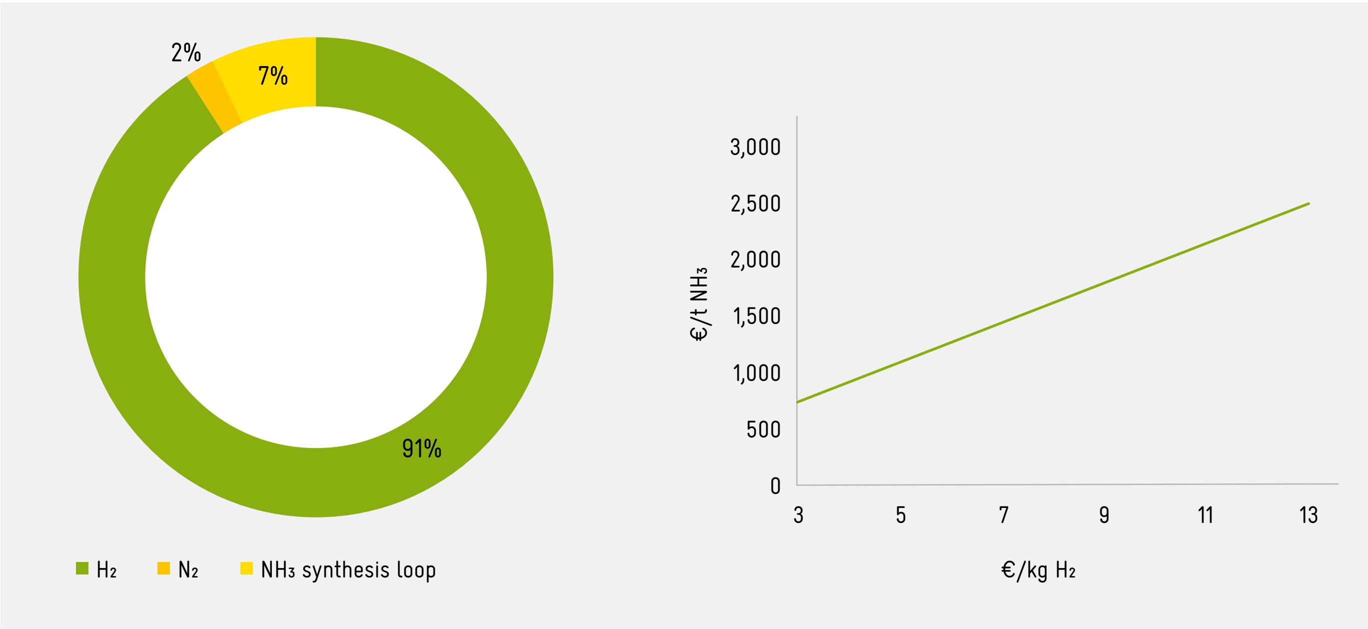
Source: Authors' representation

The replacement of conventional H_2 with green H_2 would result in a reduction of 13,000 tons/p.a. in CO_2 emissions, which has a cost of carbon of over EUR 27.7 m (assuming High-Level Commission on Carbon Prices prices) over the 25-year lifetime of the plant.

The next step in the process is to convert the green H_2 into NH_3.

Given the small size of the ammonia plant, the CAPEX is estimated to be EUR ~14.2 m (around EUR 210/ton annual capacity). Applying the previously calculated LCoH of EUR 15.28/kg H_2 and the local cost of electricity of EUR 0.05/kWh for the ASU, the resulting levelised cost of ammonia (LCoA) would be EUR 2,967/ton and would range from EUR 1,153 to 3,094/ton, based on the different effective LCoH presented.

FIGURE 18. IMPACT OF THE H_2 PRICE ON THE LCOA



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

3.2 Case 2. Green hydrogen used in food production

A food sector company located in the Rift Valley region of Kenya produces margarine and uses H_2 for the hydrogenation of its products to increase the melting point, as a preservative and to harden the texture. Its plant can process 10,000 tons of oil per year and its process is set up to process 5 tons of oil per batch, which requires 6 kg H_2 per ton, in total 60 tpa H_2. As production is carried out in a batch process, on-site storage of H_2 is in place, baseline or flexible H_2 production could be used.

Given the solar resource in the Rift Valley region, to produce 60 tpa of H_2 in flexible mode, a 2.6 MW PV plant and a 2 MW electrolyser would be required. As the PV would produce around 4.29 GWh electricity per year and the electrolyser system uses only 3.22 GWh, the remaining 1.07 GWh per year could be sold to the grid or used to offset electricity consumption in other parts of the production facility.

In addition, 480 tons of oxygen per year would be produced as a by-product of the hydrogen production, which could be sold to industrial users (assumed price EUR 0.40/kg). If baseline operation sizing was used, then to ensure consistent minimum production throughout the day the PV plant would need to be oversized at 6.38 MW and the electrolyser system size could be reduced to 1.02 MW. This would result in nearly 45% more electricity production for almost the same initial investment cost and the resulting “extra” electricity could be sold, generating an additional revenue stream, or used to offset electricity consumption in other parts of the production facility.

TABLE 13. BUSINESS CASE 2. H_2 FOR FOOD PRODUCTION SYSTEM SIZING

System Sizing	Flexible Operation	Baseload Operation
Installed PV power (kWp)	2,596	6,377
Design power electrolysis (kW)	1,951	1,016
Annual net electricity generation PV (kWh/year)	4,291,048	10,541,100
Annual net electricity consumption EL (kWh/year)	3,225,484	3,225,484
Total investment (EUR thousand)	6,332	7,288

Source: Authors’ representation

Using the cost assumptions as described in Section 3.5 AEL technology, the resulting specific LCoH is EUR 13.4/kg in flexible operation and EUR 15.28/kg with baseload operation sizing. However, when considering the equivalent value of the surplus PV electricity which could be sold back to the grid, as well as revenue from oxygen sales, the resulting effective LCoH is EUR 9.65/kg with flexible and EUR 8.12/kg with baseload operation sizing. The baseload operations investment costs require an upfront investment of EUR 7.29 m, which is 15% higher than for flexible operations when assuming the same volume of hydrogen produced. The difference in final value is due to the sale of the extra electricity, which in the baseload case contributes an equivalent value of EUR 3.96/kg of H_2 produced.

Given the target LCoH of EUR 3.09/kg to achieve price parity with conventional H_2 sources, subsidies equalling EUR 6.56/kg or the equivalent of a CAPEX grant of kEUR 3,997 would be required with flexible operation sizing and EUR 5.04/kg or the equivalent of a kEUR 1,990 CAPEX grant with baseload operation sizing would be required.

The breakdown of the LCoH for the business case is presented in the following table.

TABLE 14. BUSINESS CASE 2. H_2 FOR FOOD PRODUCTION LCOH BREAKDOWN

Levelised Cost of Hydrogen	Flexible Operation	Baseload Operation
	EUR/kg	EUR/kg
Levelised Cost of Hydrogen	**13.38**	**15.28**
Equivalent levelised value of benefits per kg H_2 produced		
Equivalent value of oxygen revenue per kg H_2 produced	3.20	3.20
Equivalent value of electricity revenue per kg H_2 produced	0.53	3.96
Effective LCoH (incl. electricity and oxygen sales)	9.65	8.12
Effective LCoH (inc. revenue + CO_2 avoided costs)	8.86	7.34
Target LCoH (cost comparable to market price for grey H_2)	3.09	3.09
Required Subsidies		
Effective green H_2 LCoH	9.65	8.12
Target LCoH (cost comparable to market price for grey H_2)	3.09	3.09
Price gap between effective green LCoH and target LCoH [EUR/kg]	6.56	5.04
Subsidy required to achieve target (investment subsidy in EUR thousand)	3,997	1,990

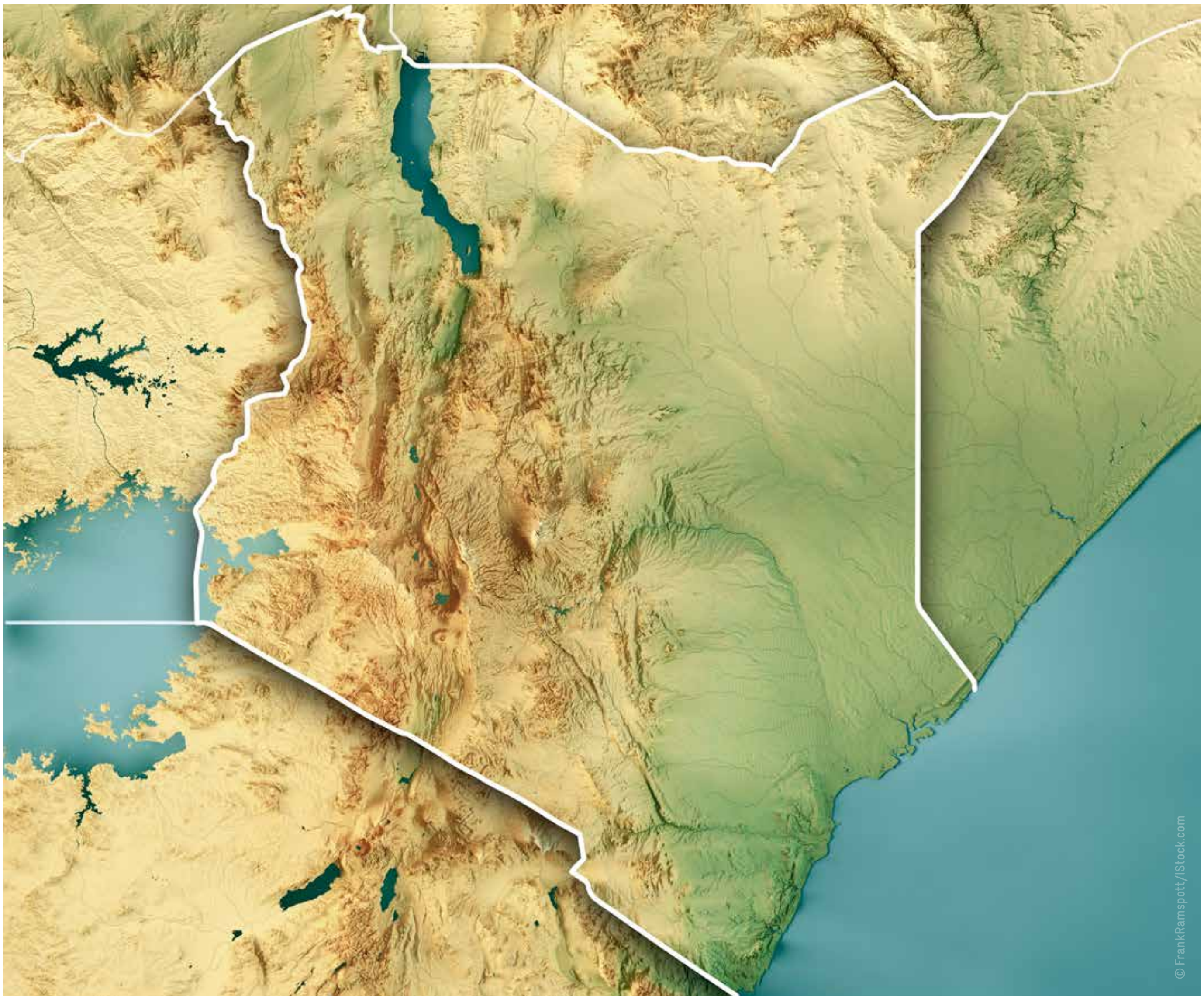
Source: Authors’ representation

The replacement of conventional H_2 with green H_2 would result in a reduction of 480 tpa CO_2 emissions, which has a cost of carbon of more than EUR 1.28 m over the 25-year lifetime of the plant.

3.3 Business case conclusions

As can be seen in the illustrative business cases, the production of green hydrogen solely by means of solar energy will require significant financial incentives over the short, medium, and long term to become cost-competitive with conventional H_2 sources. This is due to the required system "oversizing" needed to enable the constant production of H_2, as well as a lack of economies of scale due to the small production sizes compared to large, centralised production. Alternative sources of green energy, for example, the country's abundant geothermal power resources, could be harnessed to reduce the required system size and increase plant utilisation enabling 24/7 production, thus significantly lowering the overall LCoH.

The business cases further demonstrate the significant impact on the overall financial feasibility of system sizing due to operational methods, tapping into additional revenue streams and financial support structures. Although oversizing the PV system increases the overall initial investment cost, in most cases the resulting revenue from the sale of "extra" green energy more than offsets this cost and serves to subsidise the cost of H_2 production. Furthermore, financial incentives such as grants for the PV or electrolyser system could help to enable the small-scale decentralised production of green H_2 to become financially viable in the medium term.



4 THE WAY FORWARD

4. The way forward

4.1 Challenges and considerations for hydrogen implementation

Considerations for the implementation renewable energy and electrolysis facilities for hydrogen production at existing industrial facilities include:

- **Investment costs.** High investment costs leading to production costs that are higher than market costs and a lack of sufficient accessible financing.
- **Regulatory framework and approval process.** As the decentralised production of green hydrogen is relatively new, the regulatory, environmental requirements and permitting regulations are non-existent or unclear. This adds significant uncertainty and additional time and overheads to the project development process.
- **Operation staff.** Trained staff available for operations & maintenance activities.
- **Supply chain shortages.** In recent years there have been a number of factors (COVID, Ukraine, etc.) impacting supply chain components, parts and materials leading to long lead times for delivery of equipment.
- **Area requirements.** Availability of sufficient space for installation of an electrolysis plant, hydrogen storage and balance-of-plant equipment as well as the PV plant. The average space requirement for 1 MWp solar PV generating capacity requires at least 5 acres (Land Use & Solar Development, n.d.).
- **Logistical issues.** Potential issues with carrying out construction while the existing operations continue, as well as potential impacts to production and what types of tie-ins are necessary.
- **Design and engineering of plant.** Which codes and standards on the industrial site are valid and must be complied with, particularly with regard to the storage of harmful gases.
- **Power supply.** Is a reliable power supply as well as back-up power supply secured? There will be increased metering requirements to demonstrate the use of green electricity for green H_2 production.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- **Water supply.** Availability of water in the required quality and quantity (tap water or demineralised water). Hydrogen production requires significant quantities of water at a time when water is becoming increasingly scarce across Africa. It is crucial to build a green hydrogen industry in a way that it will not negatively affect water security and water-heavy industries. Water desalination is one of the proposed solutions that can reduce the hydrogen water footprint.
- **Safety aspects.** Integration of hydrogen production and the storage facility into the existing safety concept of the existing industrial plant site.
- **Control and operation.** Integration of hydrogen production and the storage facility into existing control systems.
- **Supply considerations.** Is a constant hydrogen supply necessary for operations and is this possible given local renewable resources?
- **Storage facilities.** Adequate hydrogen and electricity storage facilities are required if production relies on VRE to ensure uninterrupted production.

4.2 Opportunities and supporting frameworks for hydrogen implementation

The production of green hydrogen offers numerous opportunities which are in line with the country's climate and decarbonisation policies and their targets, including:

- The NCCAP is Kenya's primary policy document on climate change. It aims to guide the country's efforts to mitigate and adapt to climate change and promote low-carbon, climate-resilient development.

- The National Energy Policy aims to increase the share of renewable energy in Kenya's electricity mix to 100% by 2030. It also seeks to promote investment in renewable energy projects and to provide access to modern energy services to all Kenyans.

- The Climate Change Fund (CCF) was established in 2018 to finance climate change mitigation and adaptation projects in Kenya. Its objectives include providing funding for climate change projects, promoting private sector investment in climate change and supporting Research & Development & Innovation (R&D&I) in climate change.

- The LEDS is a long-term strategy that aims to guide Kenya's transition to a low-carbon economy. It sets out a vision for sustainable development and outlines policies and measures for reducing greenhouse gas emissions across all sectors of the economy.

The development of the green hydrogen sector will:

- reduce the country's GHG emissions and support the country's clean energy transmission policies, through the decarbonisation of hard-to-abate industrial sectors;

- decarbonise the agricultural sector through more sustainable production of fertilisers using green ammonia;

- reduce the country's dependency on hydrogen derivative imports such as ammonia and methanol and could be a starting point for developing local production capacities for industry;

- accelerate investment and speed up the technological development of the country. In addition, new skilled jobs will be created providing new opportunities to its population.

4.3 Local Kenyan financing instruments

Kenya does not yet have green hydrogen/PtX-specific funding or incentive mechanisms. However, the Green Fiscal Incentives Policy Framework is currently under development, which will consolidate and incorporate all major climate agendas such as the National and County Environment Policy, Sustainable Development Goals (SDGs), nationally determined contributions (NDC) goals, Kenya Vision 2030 and the national adaptation plan. The framework will provide guidelines on enhancing the private financing of climate actions, spur green innovation and technology development, improve green fiscal consolidation and drive private investments to adopt cleaner production mechanisms. The policy aims to improve government taxation and spending on climate activities by introducing environmental taxation and economic incentives such as carbon trading mechanisms and carbon tax for the carbon-intensive sector. It is expected that such a policy support tool will be low-carbon technology neutral and equally applicable to the green hydrogen economy.

4.4 Green hydrogen financing opportunities for German companies

There are four categories of financing opportunities for German companies active in green hydrogen technologies:

EU-level funding opportunities

The Clean Hydrogen Partnership (public-private partnership) aims to provide research and innovation funding for hydrogen projects for European companies (Hydrogen Europe, 2023). The funding comes in the form of grants and European Union (EU) co-funding for green hydrogen production, storage, distribution, transportation, heat and power application, hydrogen valley development, etc.

Another example is the European Union Emissions Trading System (ETS) Innovation Fund (European Union, 2023) for H_2 demonstration projects, where money raised via the EU ETS is reinvested into the Innovation Fund (public-private partnership). Under grant agreements, the fund can be used for the demonstration of innovative low-carbon technologies including green hydrogen. For example, one of the hydrogen projects that received funding from the ETS Innovation Fund is the fossil-free steel production "HYBRIT" project in Sweden.

National public funding for hydrogen projects specific to the EU Member State

Examples of national public funding include the German H2Global mechanism (H2 Global Stiftung, 2022). H2Global is an auction-based financing mechanism for green hydrogen which will conclude long-term purchase contracts on the supply side and short-term resale contracts on the demand side, ensuring planning and investment security for green H_2 investments, given the current lack of fully functioning green H_2 markets. The concept provides for the compensation of the difference between the purchase price (production plus transport costs) and the sales price (currently the market price for fossil hydrogen) for green H_2 and H_2-based derivatives. The first tender was launched in November 2022 as an auction for green ammonia, e-methanol and sustainable aviation fuel from international producers (outside EU and European Free Trade Association (EFTA) countries). The concept is developed with funding from the German Federal Ministry for Economic Affairs and Climate Action.

In addition, in 2022 the Federal Government launched the "Hydrogen Pilot Office" website, which provides combined information for hydrogen funding opportunities at national, EU and international level. H2Uppp supports German SMEs in identifying, preparing and implementing pilot projects for the production and use of green hydrogen in developing and emerging countries (BMWK, 2023). Guidance on sources of funding can be found on the BMWK website "Funding advice – Hydrogen Guidance Service" One-Stop-Shop - Wasserstoff - Funding advice (bmwk.de).

National and European banks

European and national banks such as the European Investment Bank (EIB) and Kreditanstalt für Wiederaufbau (KFW) leverage private capital investments in green hydrogen projects. A wide variety of financing instruments – including debt and equity finance, as well as investment guarantees – are available in addition to previously mentioned EU support programmes.

For instance, the EIB will provide financing advisory support as well as dedicated EIB financing products (European Investment Bank, 2021) for green hydrogen projects introduced through Hydrogen Europe – the association representing European industry, research and national and regional associations in the hydrogen and fuel cell sectors.

Private finance such as venture capital funds

Private finance such as venture capital funds (e.g. Breakthrough Energy founded by Bill Gates) and private banks are also showing interests in investing in the hydrogen sector. With over $1 billion raised in committed capital, Breakthrough Energy, through its Energy Catalyst platform, funds and invests in project companies utilising emerging climate technologies including clean hydrogen, storage, sustainable aviation fuel, etc. (Breakthrough Energy, 2022). A special programme in Europe has recently been established (Breakthrough Energy Europe) to support research and innovation in clean technology, including green hydrogen (Breakthrough Energy, 2022).

However, hydrogen projects solely based on private financing are yet to gain momentum given that there are no fully functioning markets yet for offtakers or pricing green hydrogen products.

4.5 Where to go for more information

The following resources are available to learn more about investing in H_2 in Kenya:

- **Kenya Investment Authority (KenInvest).**
  KenInvest is the government agency responsible for promoting and facilitating investment in Kenya.

- **Export Processing Zones Authority (EPZA).**
  EPZA is a State Corporation under the Ministry of Investments, Trade and Industry that promotes and facilitates export-oriented investment in Kenya. It offers a range of incentives and services to investors who locate their businesses in designated export-processing zones, including tax breaks, streamlined procedures and infrastructure support.

- **Kenya Export Promotion and Branding Agency (KEPROBA).**
  KEPROBA is a government agency that promotes and supports Kenyan exports. It works to identify and develop export markets for Kenyan products and services. In addition, the agency provides information and assistance to exporters on trade regulations and procedures.

- **Kenya Renewable Energy Association (KEREA).**
  KEREA is an industry association that represents renewable energy developers, manufacturers and service providers in Kenya.

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Appendix

Hydrogen-related standards and norms in Kenya

The main applicable standard is KS ISO 14687:1999 – Hydrogen fuel – Product specification. This standard outlines specifications for the quality characteristics of hydrogen fuel in order to assure uniformity of the hydrogen product as produced and distributed for utilisation in vehicular, appliance or other fuelling applications. This standard was introduced in 1999 and confirmed in 2020 but was gazetted and published under the Kenya Gazette Notice No. 3613 of 30/05/2003.

Other applicable standards are:

- KS 2340-1:2011 Hydrogen – Specification – Part 1: Industrial hydrogen
- KS 2340-2:2011 Hydrogen – Specification – Part 2: High purity hydrogen/Gases.

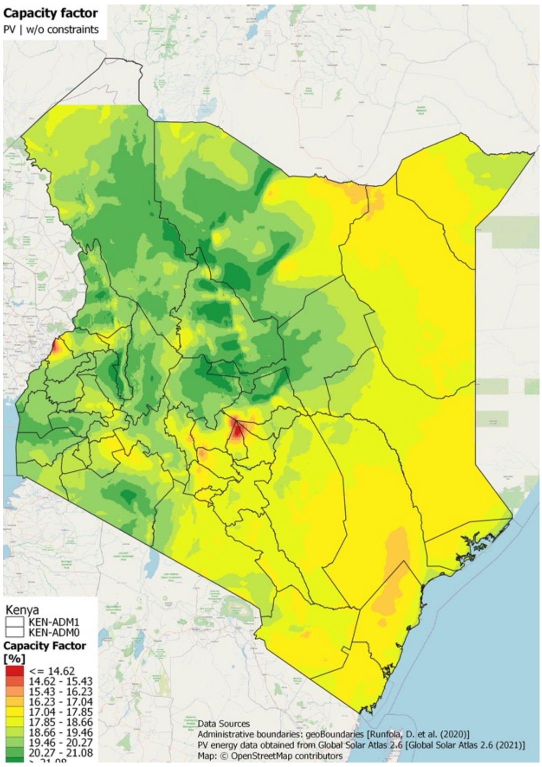
Some of the currently applied international standards are:

- ISO 14687:2019 – Hydrogen fuel quality – Product specification
- ISO/TR 15916:2015 – Basic considerations for the safety of hydrogen systems
- ISO 19880:2020 – Gaseous hydrogen – Fuelling stations
- ISO 19881:2018 – Gaseous hydrogen – Land vehicle fuel containers
- ISO 22734:2019 – Hydrogen generators using water electrolysis – Industrial, commercial, and residential applications
- ISO/TS 19883:2017 – Safety of pressure swing adsorption systems for hydrogen separation and purification.

The Kenyan standards will need to be reviewed, updated and new ones introduced to meet international standards in line with expected growing needs in production, transportation, handling, dispensing, safety and use of green hydrogen as an energy source (Ministry of Energy, Kenya, 2021).

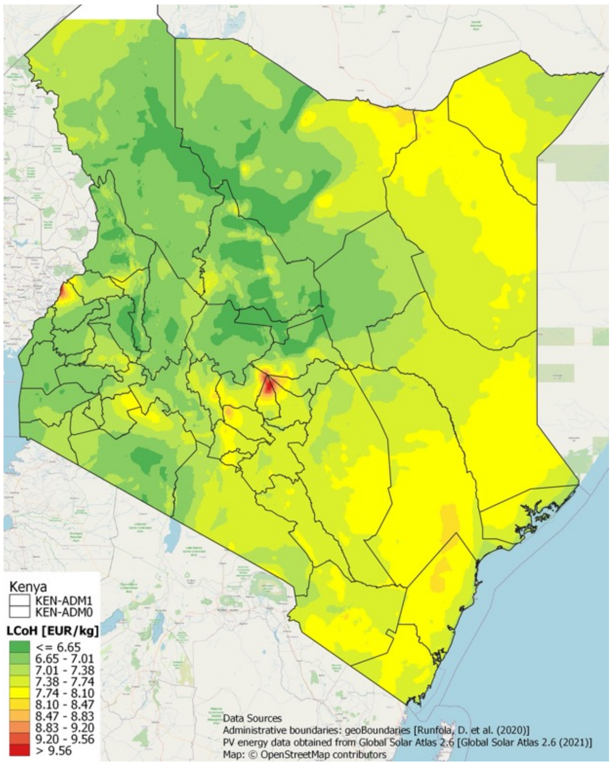
LCoH GIS maps and cost assumptions

FIGURE 19. SOLAR CAPACITY FACTOR IN KENYA



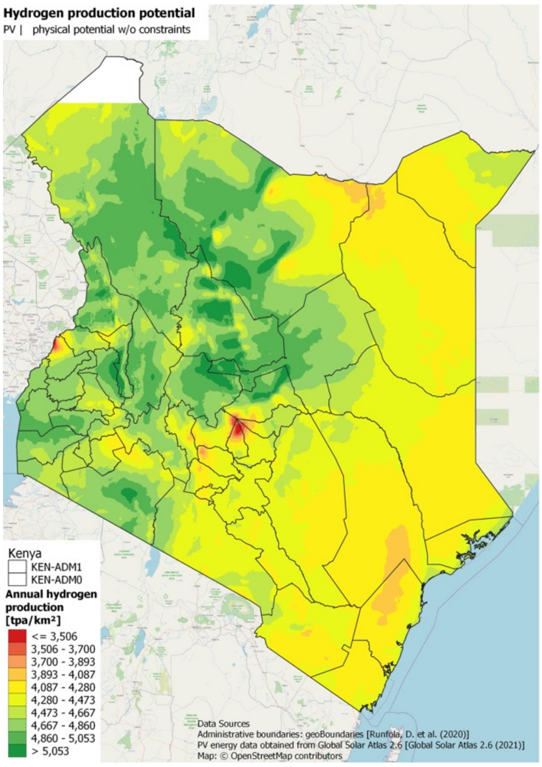
Source: Authors' own illustration, ENGIE Impact GmbH (2023)

FIGURE 20. LEVELISED COST OF HYDROGEN (LCOH) WITHOUT CONSTRAINTS



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

FIGURE 21. HYDROGEN PRODUCTION POTENTIAL WITHOUT CONSTRAINTS



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

TABLE 15. GIS MAP OF LCOH ASSUMPTIONS

Levelised Cost of Hydrogen Assumptions (GIS maps)		
Water price	4	EUR/m³
Electrolysis efficiency	62	%
CAPEX PV	713	EUR/kWi
CAPEX Electrolysis	1,300	EUR/kW
fixOPEX PV	20	EUR/kW/a
fixOPEX Electrolysis	15	EUR/kW/a
varOPEX PV	0	EUR/kWh/a
varOPEX Electrolysis	0	EUR/kg/a

TABLE 16. SUMMARY OF PV AND GREEN HYDROGEN PRODUCTION POTENTIAL BY REGION

Region	PV capacity factor PV [%]	Theoretic green hydrogen production potential		LCoH
		Area-specific potential [tpa/km²]	Total potential [tpa]	[EUR/kg]
Laikipia	20.34%	4,887	34,211,485	6.75
Uasin Gishu	20.33%	4,891	7,487,619	6.75
Samburu	20.23%	4,865	62,654,639	6.78
Siaya	20.17%	4,878	3,561,199	6.76
Kisumu	20.11%	4,846	3,300,121	6.8
West Pokot	20.06%	4,833	24,130,406	6.82
Baringo	20.05%	4,811	36,069,032	6.86
Homa Bay	20.02%	4,827	4,711,118	6.83
Turkana	19.92%	4,787	190,110,147	6.88
Busia	19.91%	4,822	1,142,889	6.84
Elgeyo-Marakwet	19.89%	4,828	5,479,254	6.84
Kakamega	19.83%	4,767	1,024,968	6.91
Isiolo	19.79%	4,761	58,874,115	6.93
Vihiga	19.69%	4,734	113,616	6.96
Narok	19.64%	4,755	23,667,448	6.94
Migori	19.53%	4,752	955,151	6.94
Marsabit	19.51%	4,608	122,387,095	7.18
Meru	19.48%	4,858	13,807,851	6.8
Nakuru	19.36%	4,680	15,129,192	7.05
Kericho	19.13%	4,597	1,829,489	7.17
Kisii	19.13%	4,568	1,393,137	7.21
Nandi	19.13%	4,648	2,900,349	7.09
Trans Nzoia	19.13%	4,621	4,833,528	7.14
Nyamira	19.08%	4,578	906,452	7.2
Bungoma	18.90%	4,356	2,278,385	7.61
Nyandarua	18.69%	4,555	4,076,453	7.24
Bomet	18.62%	4,400	140,808	7.5
Kajiado	18.61%	4,468	67,577,641	7.38
Tharaka	18.58%	4,467	589,707	7.4
Mombasa	18.34%	4,366	401,690	7.53
Machakos	18.28%	4,385	3,091,679	7.51
Nyeri	18.19%	4,575	4,264,048	7.22
Makueni	18.11%	4,344	4,665,285	7.58
Kiambu	18.10%	4,408	2,256,660	7.48
Lamu	18.09%	4,332	19,806,196	7.61
Kitui	18.07%	4,288	27,198,148	7.68
Embu	18.02%	4,303	580,915	7.67
Mandera	18.00%	4,308	86,681,727	7.64
Garissa	17.94%	4,309	131,636,148	7.65
Taita Taveta	17.92%	4,284	9,057,115	7.68

Nairobi	17.81%	4,293	1,193,470	7.67
Murang'a	17.80%	4,303	1,820,041	7.66
Wajir	17.79%	4,261	183,895,936	7.73
Kwale	17.77%	4,278	14,224,162	7.68
Tana River	17.72%	4,239	87,741,051	7.77
Kilifi	17.49%	4,181	23,620,539	7.87

Potential business case questionnaire

TABLE 17. CASE STUDIES QUESTIONNAIRE

	Question
1	Does the Company have decarbonisation goals/objectives? Are these major factors in your current investment planning?
2	Current use of hydrogen/ammonia (processes used, volume, source)
3	How do you currently transport/store your hydrogen?
4	Have you installed, or do you plan to install, PV at your facility? If not, why not?
5	Do you face challenges in the supply chain (reliable grid electricity, sourcing feedstock since COVID and Ukraine, etc.)?
6	Have you considered local green H_2 production? What aspects are you in favour of? What against?
7	Opportunities for improvement. What regulatory/policy changes would make it easier for you to do business? What types of incentives or financial support for modernisation/decarbonisation do you wish were available?

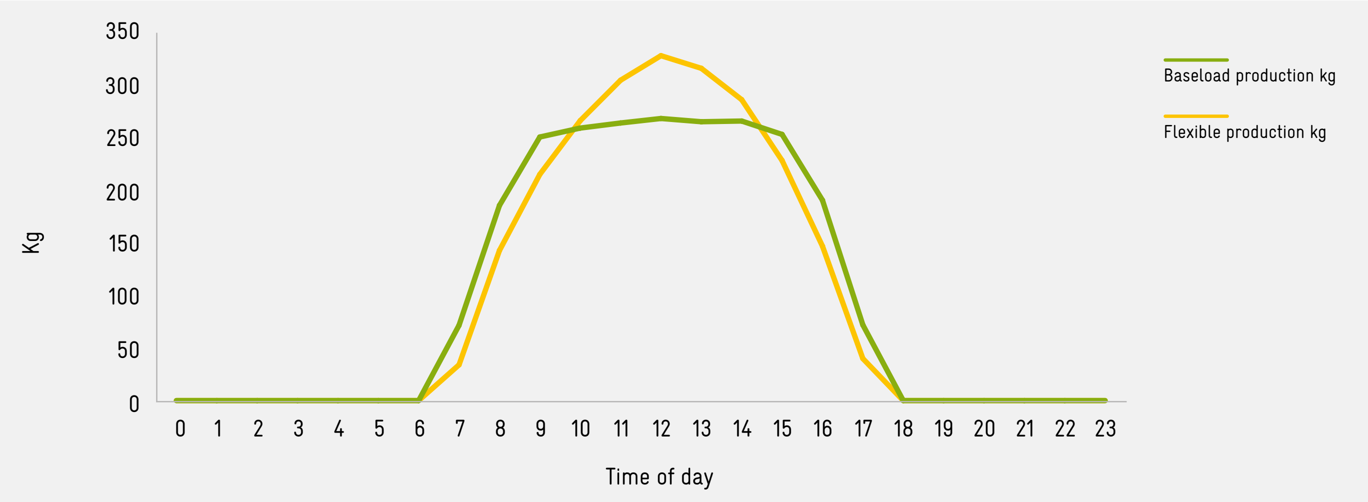
Baseload vs flexible operation explanation

It is necessary to keep in mind that oversizing of both PV and EL for a baseload H_2 supply is always required when effecting hydrogen production from PV. For example:

- Consider a H_2 demand of 800 tpa, with a baseload hourly demand of approx. 91 kg/h
- This requires, at minimum, an electrolyser of approx. 5 MW if the electrolyser were to run 24/7/365 at full load
- Taking into account an average capacity factor of PV systems of 20%, a PV system of 5x the electrolyser capacity is required, at minimum, to supply enough electricity over the course of the year (without matching hourly demand)
- Taking into account the day/night characteristics of sun light and no electricity storage, the electrolyser needs to be oversized by a factor of approx. 2 (charging H_2 storage during the day)
- In this example, the electrolyser capacity would be at least ~10 MW and the PV capacity would be at least 25 MW.

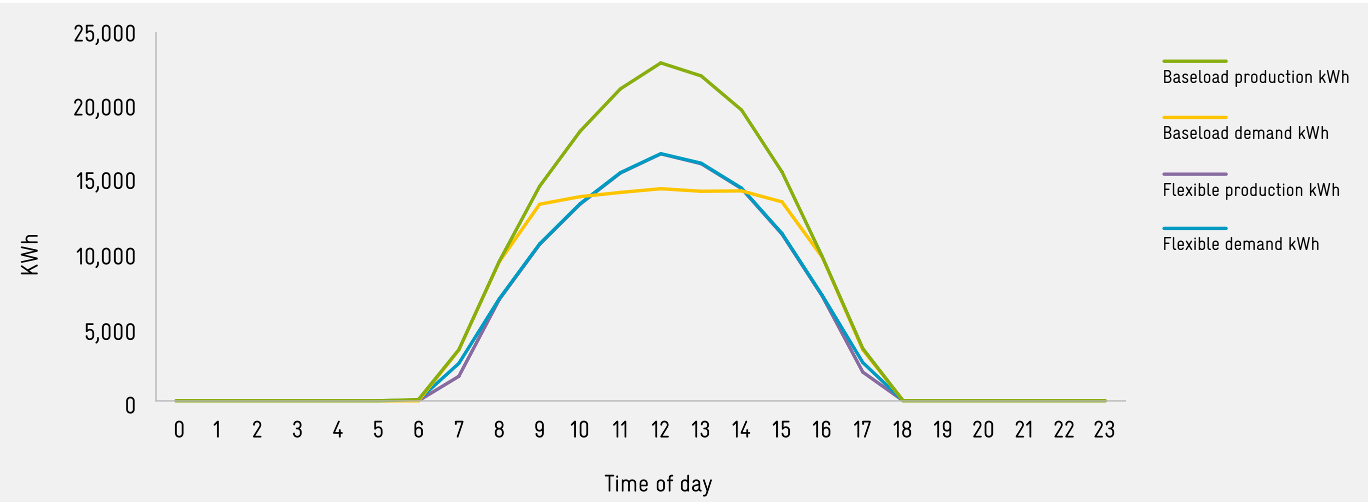
Since, from the optimisation point of view, the installation of a PV system is less expensive than the installation of an electrolysis system, the PV system is more strongly oversized than the electrolyser. The following two figures show the same annual volume of H_2 production, in flexible and baseload mode. The first figure shows the production of H_2 in flexible mode. In this case, the electrolyser needs to be oversized to be able to take full advantage of the solar peak. Whereas the green line shows production under baseload where more H_2 is produced during off-peak times, filling the H_2 storage for use when needed. However, in order to be able to produce this extra H_2 outside of the solar peak, the PV plant must be scaled up to provide the power. This can be seen in the second figure where the green and yellow lines show the electrical demand of the electrolysers in baseload and the energy production of the PV field. To provide the extra energy during the off-peak period, the solar field must be oversized; this also results in significant "extra" electricity (the difference between the green and yellow lines) during peak solar production.

FIGURE 22. FLEXIBLE VS BASELOAD H_2 PRODUCTION



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

FIGURE 23. FLEXIBLE VS BASELOAD ELECTRICITY PRODUCTION AND CONSUMPTION



Source: Authors' own illustration, ENGIE Impact GmbH (2023)

Business case financial calculation methodology

The business cases presented are illustrative of the conversion to green hydrogen for current conventional hydrogen consumers. As the business cases focus on the grey-to-green H_2 conversion, the indicative financial assessment is based on the levelised cost of hydrogen (LCoH) and the "effective" LCoH. The LCoH represents the cost to produce 1 unit (1 kg) of hydrogen, taking into account the time value of money in the form of the applied discount rate. It is calculated by dividing the total discounted lifetime system costs by the lifetime discounted volume of hydrogen production.

The first step in calculating the LCoH for the selected business is the choice of investment location, electrolyser technology and required hydrogen production volumes. The CAPEX and OPEX assumptions for the different electrolyser technologies are described in Section 3.5. One of the key aspects of the model is the choice of electrolyser operating mode: baseload or flexible operation mode. Key calculation assumptions for the business cases are shown in Table 18.

TABLE 18. KENYA LCOH BUSINESS CASE ASSUMPTIONS

Business Case Assumptions		
Prices		
Tap water price	EUR/m³	1.00
Electricity tariff (sell)	EUR/kWh	0.05
Oxygen tariff (sell)	EUR/kg	0.40
Taxes		
Import tax rate on PV	%	-
Import tax rate on electrolyser system	%	0.10
Operation		
Oxygen production volume per 1 kg of H_2	kg	8.0
Annual inflation rate (Local)	%	6.1
Water tariff escalation rate	%	2.0
Electricity tariff escalation rate	%	2.0
Oxygen escalation rate	%	0.0
Hydrogen storage	hrs	72
Financing		
Depreciation method		Straight-line depreciation
Operation period	years	25
Discount rate	%	8.0
Debt/equity ratio	%	60.0
Repayment period	years	10
Up-front fee	% of debt capital	1.0
Commitment fee	% of undrawn debt	1.5
Applied interest rate	%	9.0

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