MINISTRY OF ENERGY

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DEUTSCHE ZUSAMMENARBEIT

BASELINE STUDY ON THE POTENTIAL FOR POWER-TO-X / GREEN HYDROGEN IN KENYA

Ministry of Energy Kenya
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

January 2022

Complete Study Report
PtX Opportunities for Kenya,
Action Plan Outline to Support PtX Deployment in Kenya
Kenyan Hydrogen Investment Perspectives

Implemented by
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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Project number: P.740407.1101

Project leader Karsten Schmitt

Country Kenya

Project title: **Baseline Study on the Potential for Power-to-X / Green Hydrogen in Kenya**

Client Ministry of Energy, Kenya, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Prepared for: Green Hydrogen Working Group (GHWG)

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2	16. Feb 2022	Comments	See above		Brandi Gunn

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ABBREVIATIONS AND ACRONYMS

AFD	Agence Française de Développement
BMZ	German Federal Ministry for Economic Cooperation and Development
CAPEX	Capital Expenditure
COD	Commercial Operation Date
EAC	East African Community
EAPMP	East African Power Master Plan Study
EAPP	East African Power Pool
EE	Energy Efficiency
EU	European Union
EUR	Euro
FiT	Feed in Tariff
GDC	Geothermal Development Corporation
GDC	German Development Cooperation
GDP	Gross Domestic Product
GH2	Green Hydrogen, one of the gases that may be produced with RE under PtX
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für International Zusammmenarbeit GmbH
GoK	Government of Kenya
GW	Gigawatt
GWh	Giga Watt-hour
HV	High Voltage
HVDC	High Voltage Direct Current
IMF	International Monetary Fund
INDC	Intended Nationally Determined Contributions
JICA	Japan International Cooperation Agency
JKIA	Jomo Kenyatta International Airport
KAM	Kenya Association of Manufacturers
KenGen	Kenya Electricity Generating Company
KENINVEST	Kenya Investment Authority
KeNRA	Kenya National Resources Alliance
KEPSA	Kenya Private Sector Alliance
KES	Kenyan Shilling
KETRACO	Kenya Transmission Company
KfW	KfW Development Bank German development bank; was: Kreditanstalt für Wiederaufbau)
km	kilometre
KNBS	Kenya National Bureau of Statistics
KPC	Kenya Pipeline Company Limited
KPLC	Kenya Power and Lighting Company
KPRL	Kenya Petroleum Refineries Limited
KRC	Kenya Railways Corporation
KTDA	Kenya Tea Development Agency
kV	kilo Volt
KW	Kilowatt
kWh	kilowatt-hour
LAPSSET	Lamu Port, Southern Sudan and Ethiopia Transport
LCOH	Levelized Costs of Hydrogen
LCPDP	Least Cost Power Development Plan
LIPS-OP/XP	Lahmeyer International Power System - Operation Planning / Expansion Planning
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LTWP	Lake Turkana Wind Park
m	metre
MoE	Ministry of Energy
MOEP	Ministry of Energy and Petroleum (predecessor MoE)
MOIED	Ministry of Industrialization and Enterprise Development
MORDA	Ministry of Regional Development Authorities
MV	Medium Voltage
MW	Mega Watt (10^6 Watts)
MWh	Megawatt Hours
NCC	National Control Center
NDC	Nationally Determined Contributions
NG	Natural Gas
NPV	Net Present Value
O&M	Operation & Maintenance
OHL	Overhead Line
OPEX	Operational Expenditure
P	Active Power
PESTEL	Political, Economic, Social, Technical, Environmental and Legal (criteria)
PGTMP	Power Generation and Transmission Master Plan
PPA	Power Purchase Agreement
PtX	Power-to-X
PV	Photovoltaic
Q	Reactive Power
RD&I	Research Development and Innovation
RE	Renewable Energy
RES	Renewable Energy Sources
SCADA	Supervisory Control and Data Acquisition
SME	Small and Medium Sized Enterprises
TOR	Terms of Reference
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
US	United States of America
USD	United States Dollar
vRE	Variable Renewable Energy
WACC	Weighted average cost of capital
WB	World Bank

Ministry of Energy, Kenya, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH Complete Study Report

1 EXECUTIVE SUMMARY

This report provides the results of the "Baseline Study on the Potential for Power-to-X / Green Hydrogen in Kenya" including PtX opportunities, Action Plan Outline and Investment Perspective.

Hydrogen offers a wide range of opportunities, which were analysed in this study.

The use of hydrogen can be split into two fields:

- As **a commodity for mostly chemical and industrial scale uses**, e.g. fertilizer production. As such it has been well established worldwide for over 100 years for a wide range of uses. Until now, it is almost exclusively supplied through carbon intensive production based on fossil fuels, mainly natural gas.
- As an **energy source**. Despite its high energy density (nearly three times of natural gas) and technology availability for more than 150 years, hydrogen utilisation as an energy source has been limited to niche uses. This is because hydrogen is not a primary energy source (as fossil fuels or renewable energies) but only an energy carrier. It has to be produced with much higher energy input.

This study has looked at both potential uses for green H2: commodity for processes and energy source, considering the use specific opportunities and challenges within Kenya.

Kenya has a diverse range of opportunities for specific industrial pathways to ramp up hydrogen production and use in the country.

The study has identified the following industrial pathways to further pursue the use of green hydrogen:

1 Hydrogen as a **commodity for the production of the nitrogen content of fertilizers**, via ammonia. The domestic production of fertilizers from local resources would replace imports and by this shift value chains to Kenya and reduce supply risks. With respective savings of e.g. transport costs and through expected surplus of RE supply it may be already cost competitive in the near future. Its probable size is small from global perspective (increasing specific costs) and large from local market perspective (with strong dependence on already mature national market). Therefore, such a project needs a secure investment environment.

2 Hydrogen and its derivatives such as ammonia or methanol as a **higher priced commodity for existing and new regional industrial processes,** replacing commodity imports and enabling new industrial production processes**.** With initially small volumes this ideally is combined with the first pathway.

3 Hydrogen as an **energy carrier for selected transport (mobility) options**: (1) converting logistics equipment at defined areas such as Mombasa port to hydrogen as fuel; (2) a Nairobi transport case where – also at a defined area with clear routes – new utility or public transport vehicles fuelled with on-site generated hydrogen act as a show case for hydrogen in the sector, though with strong need for subsidies. Economies of scale and innovations may allow scaling up to other transport uses and cities.

4 Hydrogen as **a commodity and energy carrier** for larger scale uses in new technologies with an industrial shift e.g. for green domestic steel production for local and regional demand, a novum as both the technology (non-coke based) and the location (not in emerging or industrialized countries) would be new and entail certain risks.

5 Hydrogen or methanol / ammonia **as an energy carrier for off-grid supply** of isolated grids (increasing availability compared to PV battery powered grids) or single consumers such as Stations in the mobile phone network.

Key results of the five pathways with regard to their technical, economic and climate change mitigation potential are summarized below.

Table 1-1: Recommended industrial pathways

Pathway	Time frame	Technical potential (2025/30 electrolyser)	Commercial potential and trend	Comparative advantages	Limits / challenges	Climate change effect
#1 Fertilizer (H2 as a commodity via ammonia)	Medium term (start 2025-30 onwards)	300-400/400-500 MW (~1,200/1,400 MW - region)	(50) - 100 MW Cost decrease expected, but cost shares of RE and non-green H2 remain main factors	Competitive if external costs factored in (e.g. transport and foreign exchange risks)	Established market (risk), suitable size (scale, capex), water avail.	Big but abroad
#2 H2 / derivatives higher priced commodity for existing / new processes (ammonia, methanol etc.)	Short to medium term (now with pilot - 2025 onwards)	10 - 20 MW (depends on methanol techn. feasibility) + growth potential	1 – 10 MW (depends on methanol economic feasibility) Decreasing cost with volume (=market growth)	Competitive, kick-start H2 development (combine with #1, #3, potential for clean cooking)	Small market with established supply chains / standards	Small, abroad (methanol in Kenya)
#3 Transport / mobility: (1) Logistics Port Mombasa (2) Public transportation / utility Nairobi (3) large scale	Short to medium term (now with pilot - 2025 onwards) (3) 2030-2040	(1) 5–10 / > 10 MW (2) X00 MW (uncertain) (3) X000 MW, (uncertain)	Initial 5 – 10 MW, depends on funding, R&D; CAPEX to decrease but not competitive without e.g. CO_2 price	(1& 2) Confined area, kick-start H2 development/ knowhow PR /showcase	(1) Limited demand (2, 3) Technical alternatives (potential lower costs)	(1) Small, (2) Medium (3) Big
#4 H2 as energy/ commodity for large scale use e.g. steel	Medium to long term (2030-40, but start preparation now)	1,500 – 2,000 MW (3,000 – 4,000 MW region) 3 -7 m t steel / year	Depends on funding, e.g. 50 – 500 MW; huge potential with on-going large scale technological development	Market / knowhow, Technological progress	Technology, scale / size, water, costs	Big, abroad
#5 H2 energy carrier for off-grid supply	Short to medium term (now with pilot)	Aggregated 20-40 MW (e.g. part of 1000 – 2000 Base Stations)	Depends on funding, uncertain whether niche or mass market	Niche / alternative to diesel and PV-battery	Knowhow / service, costs	Small, Kenya

Other uses of hydrogen appear currently less suitable for Kenya but may rank higher and more probable in the far future – such as high-volume transport (fuels), process heat or export of energy – if enabled by further development in the country and technical innovations. Monitoring of these developments and continuous update of this analysis will help to identify and develop further industrial pathways.

Kenya's nearly 100% RE based power system may allow for large scale green hydrogen production at reasonable costs without affecting existing consumers.

For the supply of RE for the production of hydrogen, the analysis showed that sufficient RE sources are available in the country for large scale production of green Hydrogen without harming the availability and price for the demand of the current electricity consumers. Considering this as a precondition (as a specific additionality criterium, i.e. green hydrogen is only produced from additional RE capacities or excess energy), the costs for RE based electricity could be in a range of USDc 2 to 5 per kWh depending on (as technology is expected to become more efficient) what extent excess energy is compensated. This may allow for green hydrogen production costs of USD/kg 2 to 4 (compared to an international range of USD/kg 1.5 – 4) and costs for ammonia in the order from USD/t 500 to 900[1] (compared to an international range of USD/t 400 – 600). Depending on the production site these costs have to be escalated by estimated 5% to 9% to account for transmission of the electricity.

Beyond that, the only considerable infrastructure to support the development of hydrogen in Kenya is the established transport (port, railway, road) combined with infrastructure and expertise for the trade (mainly import) of commodities. Kenya lacks any other infrastructure or industries, which may in other countries facilitate the ramp up of hydrogen production, such as petroleum and gas and heavy chemical industry.

Kenya offers various suitable areas to produce hydrogen close to future demand.

Kenya offers many suitable areas for the production of hydrogen:

- **Mombasa and surrounding area** (Coast) due to the vicinity to existing infrastructure (transport, such as port, railway, road; handling / storage areas and companies for commodities including sites for chemical processes) and the availability of water through desalination. Mombasa offers advantages despite the reliance on electricity from Central and Western parts of the country.
- **Wider Olkaria area** (Rift Valley) due to vicinity to power generation sources and important power network nodes (Olkaria/Suswa) with potential for direct supply and availability of infrastructure (transport, few identified industrial parks and companies (e.g. energy) and in vicinity to Nairobi).
- **Wider Nairobi area** (Central) due to vicinity of generation sources and important power network nodes (Suswa, Nairobi) and availability of infrastructure (transport, available industrial parks with handling and storage areas and companies for commodities and industrial processes including sites for chemical processes as well as service companies and R&D).

Other sites such as in Western or Northern Kenya (e.g. Lamu/LAPSSET, Kisumu) do offer some advantages and potential, e.g. for regional development but show particular disadvantages e.g. in terms of infrastructure.

Though volumes of necessary water seem manageable in comparison to other technical challenges, special attention should be paid to each project so that local community and nature is not adversely affected by an

[1] See references in Table 4-2

additional large scale and continuous consumer. This may include water management plans and plants for storage or desalination or even surplus supply for the neighbouring community.

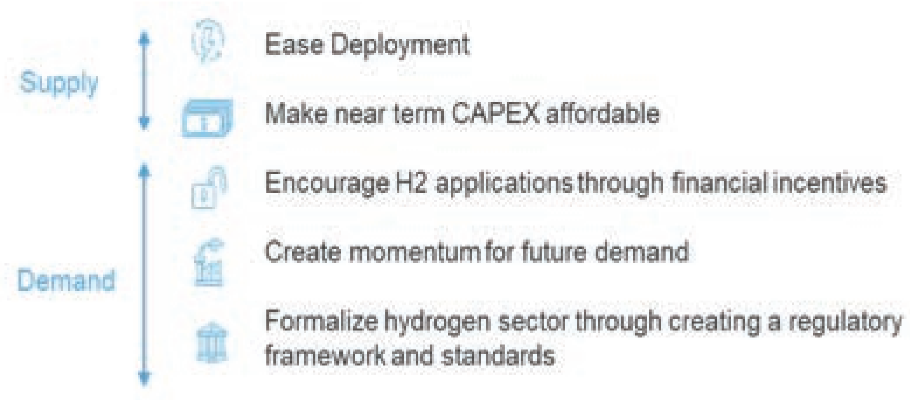
There are certain enablers or hurdles for the development of green hydrogen

Kenya aims to become a leader in the hydrogen economy in Africa by using off-peak renewable energy to produce green hydrogen which can be used to help decarbonize Kenya's economy.

The study identified various frame conditions which facilitate the green hydrogen production. A continuously expanding power system even beyond (historic) organic demand growth – including network and a diverse mix of RE capacity – will allow both the large-scale use of RE for green hydrogen and not affecting other consumers by this expansion.

New green H2 products (uses) may not be able to be sustained in an open market environment with international competition and established trade streams where interests and income of established market stakeholders will be adversely affected by these new entrants. The low(er) carbon footprint will not be of commercial help for the products unless a market develops where a premium is paid for the low carbon alternative. Therefore, the financial feasibility may require financial and market incentives at least in the short term for ramping up the production. Policy and regulatory enablers should ease deployment of RES and electroysers, make near-term capex affordable, encourage H2 applications, create momentum for future demand.

Key enablers relate to **sourcing green electricity** (green electricity source with a long term secured tariff (range), *this strongly relates to continuous and reliable expansion of RE capacity for h2 and beyond*)**, water** (rights as well as sustainable supply), **demand for hydrogen and its products** (lack of clear targets and strategies at the sector level), **frameworks for applications and infrastructure** (missing hydrogen transport, storage and application regulation for use of existing infrastructure and potentially new infrastructure) and **electrolyser scale up** (high initial costs) among others.



Kenya has a very good track record in attracting global climate finance flows into the country especially for low carbon mitigation sector. Investment in green hydrogen economy cannot be set apart from the climate finance sector. In order to attract and mobilize climate funds especially on green hydrogen, utmost importance shall be given to establish an overall economy support framework including policy, regulatory supports and fiscal incentives. The following actions would help meet this objective:

- Ease Deployment by creating a Green Hydrogen "One-Stop-Shop" assisting with all aspects of project implementation and approvals for green hydrogen investments as well as having a single coordination office for all required government agencies for approvals.

- Make near term CAPEX more affordable and encourage H2 applications through incentives such as direct funding, tax incentives, investment subsidies and innovative (leasing) financing products.
- Create momentum for future demand through policy incentives for manufactures for cleaner production and transport, carbon tax, sector integration planning which includes green hydrogen and capacity development for industry leaders to demonstrate the opportunities green hydrogen provides.
- Establish standards and requirements to make transparent technology specifications and guarantee safety of hydrogen production, transport and of applications.

A well-structured approach is a clear enabler for a successful and efficient development of a green hydrogen market.

With the identified preferential frame conditions for green H2 in Kenya amid the very high technical and economic uncertainty of green H2, the following can be summarized with regard to actions towards a green H2 strategy, road map and implementation:

Kenya neither needs to "rush" into green H2 - with the risk for too early and unsustainable commitments or lock-in decisions - nor to wait - as plenty of preparatory and no-regret work and projects can be started immediately:

- A strategy and plan leading to a reliable and comprehensive policy and regulatory framework including governance and monitoring of the topic is a prerequisite. It should be flexible enough to adopt to the uncertainty and maturing market and learn from first pilot projects
- In parallel, pilot projects and research projects of different sizes (from laboratory size to actual production for the market) should be kicked off immediately. They will proof different concepts of green H2 to be viable in Kenya. They will be the potential starting points for green H2 hubs within the country to allow for the long-term ramp up and integration of the green H2 market. There are various no regret projects to be kicked-of immediately which may also help to inform strategy and policy making process.
- Further, immediate start of building up expertise in the country (RD&I and education) will be no-regret actions as they could and should benefit from the above mentioned pilots and proof of concepts and build on existing structures (public/academic and private) as Kenya to some extent is already a hub for selected technologies and industrial processes.

With Kenya's geographical position both the domestic as well as the regional market offer attractive offsetting potential for green H2 in the medium and long-term. Whether Kenya will be able to compete on a worldwide market with the potential future green H2 hubs cannot be said today. The development of a stable local and regional market is a strong enabler for this.

The Action Plan displays these actions on a timeline.

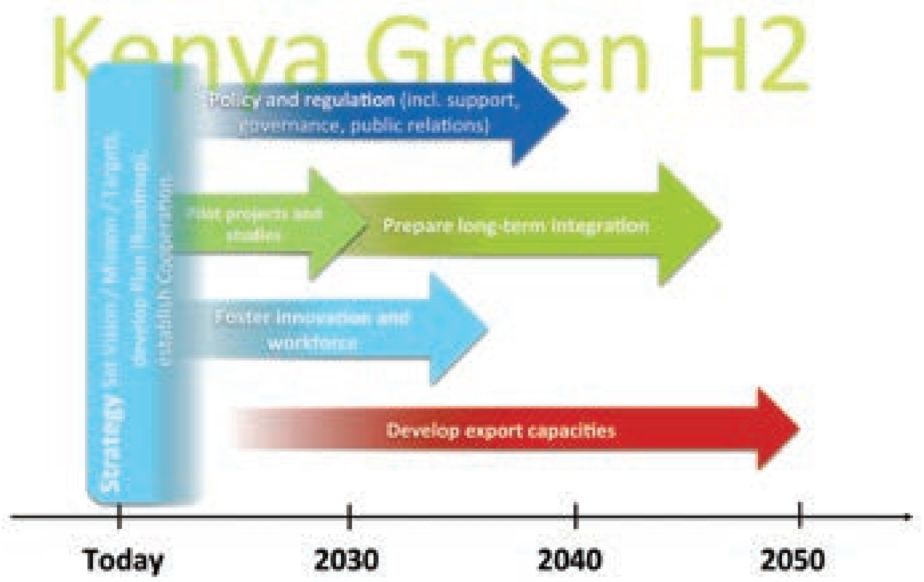


Figure 1-1: Proposed series of actions for a green H2 economy in Kenya

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2 INTRODUCTION

This section provides a general introduction to the report and underlying study project. Detailed technical introductions are provided in each of the main chapters.

2.1 Background, objectives, and scope of the project

In 2021, following a request from the Ministry of Energy (MoE) and on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ), the German Development Cooperation (GDC) contracted Tractebel Engineering GmbH (together with EED Advisory Ltd. and Gamma Systems Ltd.), also referred to as “the Consultant,” to provide consultancy services for “Baseline Study on the Potential for Power-to-X / Green Hydrogen in Kenya” in support of the Government of Kenya.

2.1.1 Project background

Important aspects in respect to the potential for green hydrogen (green H2) for Kenya are:

- Costs for RE based power generation, mainly wind and PV due to decrease of capital costs but also geothermal, have fallen in recent years, a trend which is expected to continue in the future.
- For countries with vast RE resources like Kenya this strengthens their position with this domestic supply option becoming less costly. The Kenyan power system is already largely RE based (above 90% of generated electricity) due to the dependable geothermal resources combined with hydro and wind.
- On the demand side green H2 has appeared in recent time as a new option to utilize RE based electricity. This prominent discussion is due to the need for fossil fuel alternatives to decarbonize sectors which hardly can use RE electricity directly (e.g. fertilizer or steel production and parts of the transport sector).
- The usage of green H2 in these sectors enables the reduction of CO_2 emissions. In particular costs are an important issue as presently green H2 cannot compete with so called grey hydrogen, derived from fossil fuels, which is currently applied in these industrial sectors.
- Although green H2 will be largely based on established technologies, research as well as scale of new installations have accelerated at a quick path. This provides the opportunity for cost decreases through learning curves, innovation and economies of scale and with the option to be installed worldwide.
- Across the world countries have committed themselves to emission reduction targets and green H2 is expected to play a key role in the strategies to proceed. Since many countries may not be able to produce green H2 on their own at a reasonable price, a worldwide market may develop with an emerging demand for green hydrogen and derived products coupled with the emerging of the supply side.
- Kenya may be in a good position to benefit from these developments with its RE resources and its strategical location within the Eastern African region and with coastal access; combined with domestic consumption of energy and commodities such as fertilizer which could be converted from a fossil to a hydrogen basis having in mind also additional benefits such as local value chains and job creation.

2.1.2 Project objectives

Against this background the project objectives and outcomes as per TOR are the following:

The overall objective of the study is to identify the technical and commercial potential of Power to-X technologies (most notably green hydrogen) and related industries and/or value chains in Kenya, and to present a first draft for a road map to establish a viable and sustainable PtX industry in Kenya over the next decades (by 2030, 2040 and 2050), including an initial assessment of comparative advantages, economic (net) benefits and practical feasibility (and clear indications of the limits and error margins such an early stage analysis may have).

2.1.3 Project scope

The project working steps to arrive at that objective are

- Work Package 1 Preparation and data / assumptions
- Work Package 2: Detailed assessment of PtX opportunities for Kenya
- Work Package 3: Outlining an action plan
- Work Package 4 Investment Perspectives

2.2 Objectives of the report, scope, and data sources

The overall objective of this report is to provide the following:

- The results for the potential of green hydrogen in Kenya as well as outlook on the action plan (part of Work Package 3 report) towards a road map and strategy for green hydrogen.
- An overview of the project approach and main assumptions leading to the above.

If not stated otherwise,

- All years relate to **calendar years** (data based on financial / fiscal years transferred to calendar years).
- **Study horizon is 2050** with a focus on the LCPDP period (up to 2040) and a granularity with key years 2025, 2030, 2040, and 2050.
- **Base year** (also for prices) is 2020 (extended to previous years if Covid19 impact identified).
- **Sources** of data and information are the Green Hydrogen Working Group.

2.3 Structure of the report

This report consists of the following main parts:

1 **Executive summary**, summarizing the main findings of all project tasks;
2 **Introduction** (this chapter);
3 **Methodology**, detailing the overall approach and assumptions;

4 **Green hydrogen basics and global framework**, providing an overview on the international techno-economic status, policy as well as standards and norms with regard to green hydrogen;
5 **Energy landscape Kenya**, providing the energy frame conditions for the potential future production of green hydrogen based on renewable energy and the potential future consumption of green hydrogen;
6 **PtX Opportunities**, providing the assessment results on sectors and sites for potential future supply and demand for green hydrogen;
7 **Possible Technological and Industrial Pathways for Green Hydrogen in Kenya**;
8 **Investment Perspectives** providing and overview of the investment environment for Green Hydrogen and derivative products in Kenya from the project developer point of view consisting of potential partners and funding sources, current investment roadblocks and recommended mitigation measures.
9 **Action Plan towards a Green Hydrogen Road Map**; consisting of
10 Annexes with detailed descriptions and supporting information

3 METHODOLOGY AND ASSUMPTIONS

This section details the overall approach and assumptions adopted to achieve the reported study results. It is based on the Methodological Note submitted in July 2021 and has been amended by assumptions developed since then.

3.1 Overview approach and premises

The methodology brings together in a step by step and iterative way;

1. The supply of green H2 which is determined by RE sources at costs as low as possible and availability as high as possible (both reasonably justified on a time scale and considering Kenya situation)
2. With potential demand for green H2 also on a time scale

The below figure visualizes this overall approach split into supply and demand as well as the methods / tools applied to derive the results (industrial pathways / candidates short list, action plan, pilot / focus sites).

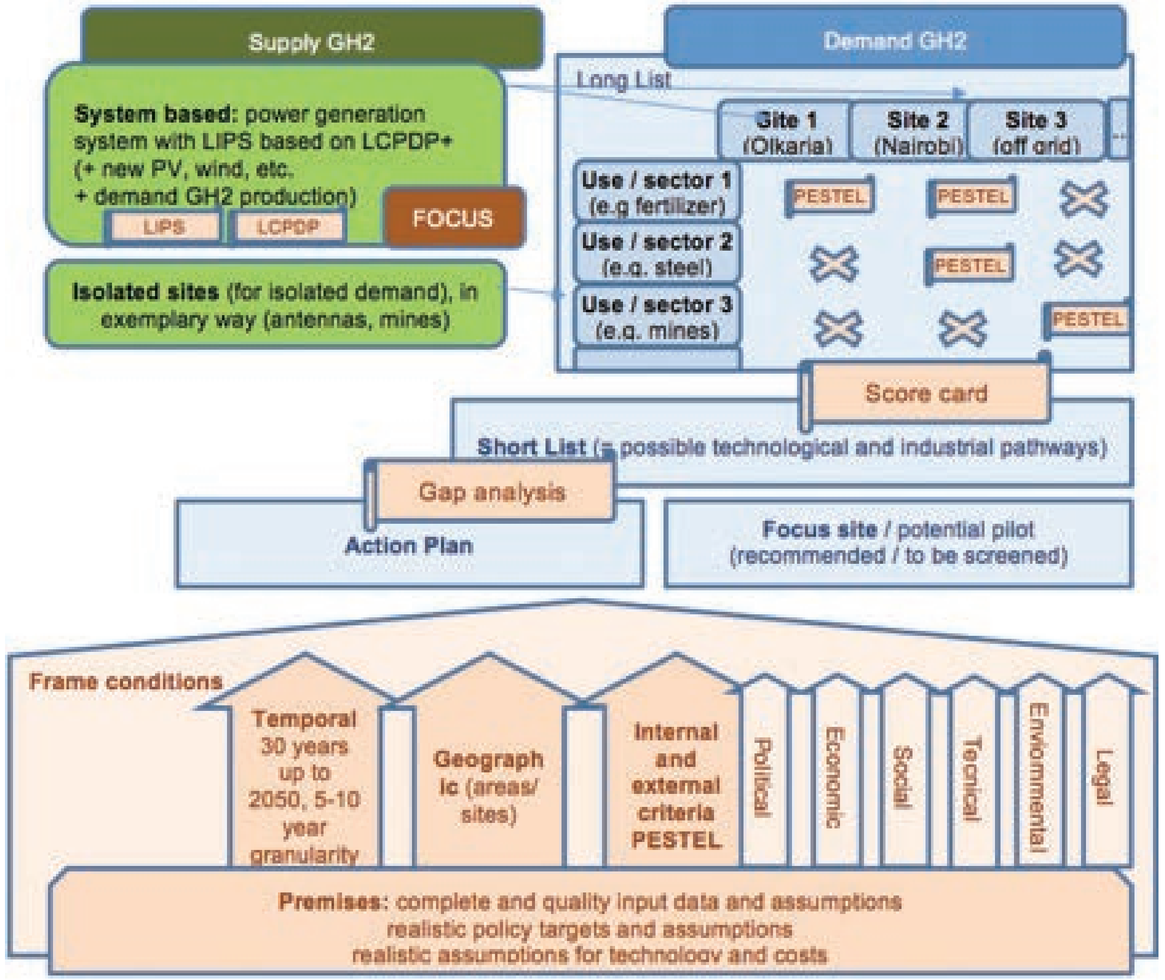


Figure 3-1: Approach - schematic overview

Supply and demand side are again differentiated

1 Supply green H2:
   a System based considering the opportunity of overall Kenyan power system as it is already largely RE based. This will be the focus of the study with regard to supply.
   b Isolated sites (for isolated demand) in a descriptive / exemplary way (e.g. for antennas)
2 Potential demand green H2, to be displayed in a matrix style (candidate matrix = long list, see below)
   a Use candidates: by different possible uses / sectors for green H2, e.g. fertilizer, mobility, and
   b Site candidate: at different sites (this is of course linked to site specific uses and power system, e.g. through estimating transmission costs).

The following parameters and differentiations are considered

- Period: **study horizon is 2050** with a focus on the LCPDP period (up to 2040) and a granularity with key years 2025, 2030, 2040, and 2050.
- **Considering geographic / distribution effects**, i.e. distribution of uses and supply of green H2.
- **Qualitative** and **quantitative** (where possible) assessments, both combined through ratings and weighting into a joint evaluation scheme ("score card")
- **Covering all relevant evaluation aspects** (as per TOR, e.g. impact on environment and society), internal as well as external effects and impacts, structured by established PESTEL approach: **P**olitical, **E**conomic, **S**ocial, **T**echnical, **E**nvironmental, and **L**egal so-called forces (=criteria)
- **Weighting and rating of criteria differentiating**
  - Weighting of each of overall 5 PESTEL forces
  - Weighting of sub-criteria (default: neutral, i.e. same weighing of each sub-criteria; with possibility to increase importance upwards and downwards, if justified)
  - Evaluation of each sub-criterion for each use / site candidate with a scale of -2 to +2 (as established for candidate ranking for Power Generation and Transmission Master Plan 2016:);
- **Narrowing down options (candidates)** from all (theoretically) possible to most preferable / promising
  - Long list (2-dimensional matrix style of use and site / supply candidates)
  - Applying criteria structured in PESTEL
  - Short list of preferable / most promising candidates
  - Description for long list candidates, again structured along PESTEL
  - Identify focus site / pilot project to be recommended / pre-screened.
- **Applying selected scenarios** (scenario analysis) were useful/suitable to cover uncertainties (e.g. for most relevant most probable and conservative technology and cost developments). This also includes sensitivity checks, e.g. the impact of different weighting assumptions)

Key premises have been identified, on which the approach is based. Suitable and solid results can only be achieved within the given time frame, if certain conditions are met. The following list highlights the most critical ones based on experience from similar assignments and work in Kenya:

- The quality of results directly depends on **quality and completeness of input data** and assumptions. An in-depth data and assumptions discussion was conducted during the regular meetings with the GHWG technical team as well as numerous data were provided and assumptions agreed. Further the consultant could contribute a wide range of information from previous assignments. However, some data gaps remain and had been bridged with assumptions.
- It is acknowledged that visions are an important part of policy making. However, for a useful action plan towards a road map the focus has to be set on **realistic targets / assumptions** with regard to government plans. Hence, realistic assumptions have to be applied e.g. in terms of demand for energy and implementation schedules of new projects which have often proved to be too optimistic compared to actual development which is impacted from external factors beyond the control of policy makers. Therefore, policies and plans were not just taken as fixed but distinguished whether they follow a rather normative scenario or whether they are in line with past developments and actual frame conditions.
- **Realistic assumptions for technology and costs** can only be based on actual available technologies as well as predictions of developments in line with trends (e.g. learning costs, effects of economies of scale). This means only off-the shelf available technologies (or technologies where current testing/piloting are showing very likely technical feasibility) are considered with rather conservative cost developments. However, (break-through) innovations which may happen but cannot be foreseen will be covered by descriptive R&D evaluations and actions.

The above described methodology will allow to meet the following planning objectives

- A first analysis of the system and its environment,
- Provide transparency and learning among involved stakeholders,
- In particular, make transparent the discussion of different (maybe contradicting) objectives of stakeholders, e.g. least cost versus environment; as a basis to establish planning consistency,
- Structure / hierarchy of objectives and criteria,
- Identification of barriers, gaps and knock-out criteria but also quick wins and no-regret solutions.

3.2 Approach for green H2 supply and costs by RE supply analysis

As described above, one part of the methodology and study is the analysis of the supply side of power for green H2 production which is determined by RE sources at costs as low as possible and availability as high as possible (both reasonably justified on a time scale and considering Kenya situation).

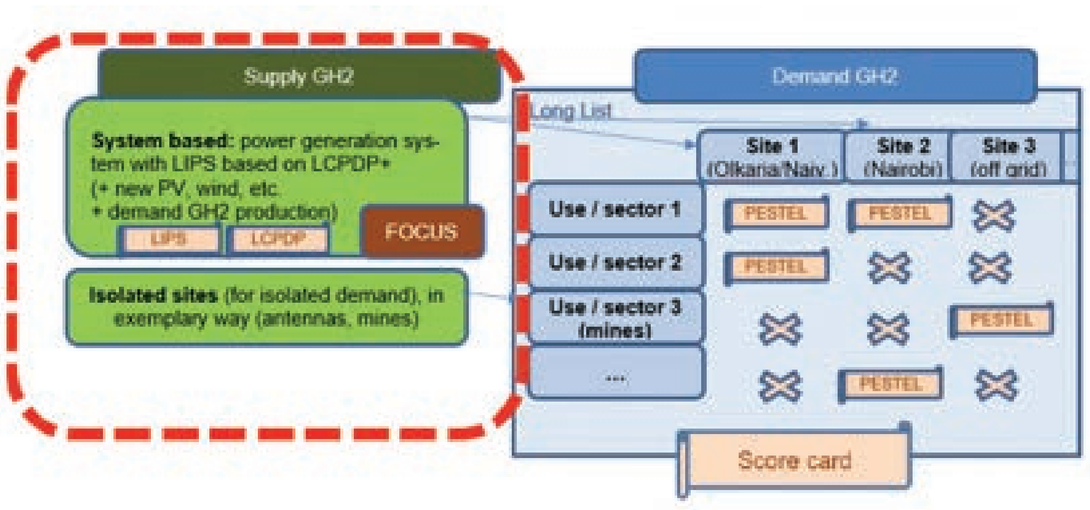


Figure 3-2: Green H2 supply as part of overall approach

Supply is differentiated into:

1 System based considering the opportunity of overall Kenyan power system as it is already largely RE based. This will be the focus of the study with regard to supply.

2 Isolated sites (for isolated demand) in a descriptive / exemplary way (e.g. for antennas)

The latter is very site specific and assumptions for technology and cost as well as detailed analysis have to be developed when sites are identified.

The focus part of green H2 supply, the first of the above is detailed as follows:

Objectives of the analysis:

- What are the projected average power (RE) costs for key years (2025, 2030, 2035, 2040, 2050) for a generic large scale PtX demand profile in Kenya considering power system opportunities and assumptions
- Reassess / confirm assumptions where Kenya was screened as low RE costs (wind/PV hybrid-based electrolyser without transport etc.) for green H2.

For this, **the following analysis steps were conducted and assumptions applied:**

- The analysis follows **a with and without comparison**, i.e. between the reference scenario for power generation system expansion (without any large scale green H2 / PtX production capacity on the demand side) and a green H2 / PtX scenario where indicative possible large scale green H2 / PtX production capacity expansion is added on top of the base scenario demand and has to be met with additional RE production. The balance provides information on the development of average RE supply costs for PtX / green H2 expansion in Kenya as well as further indications on advantages and disadvantages as well as likely necessary steps for green H2 / PtX expansion within the Kenyan power system.
- Input data assessment and assumption development for generation expansion, including RE supply:
  - **Use of official data, assumptions and models** where available and suitable for this study (this is mainly the Least Cost Power Development Plan (LCPDP) 2020-2040, version January 2021 and revised medium-term LCPDP 2021-2030, version April 2021; with focus on Reference Scenario and Optimized Case expansion plan).
  - **Adaption and widening of set of expansion planning assumptions** by the consultant for the practical purpose of this analysis: to apply the most probable generation capacity expansion path as a starting point for large scale H2 production expansion and to consider new potential supply options to serve this additional demand. This means considerably ramping up RE supply options through generic wind and PV projects as well as hydropower imports (on top of defined geothermal and PV and wind candidates). These are in part necessary large-scale supply options which may not have been needed for the normal (without H2) demand growth. These adaptions are based on discussions with sector planning officials also from other projects as well as further modifications by the consultant. The main adaptions are
    - Various commissioning years updates according to actual project development.[2]
    - The HVDC interconnector is considered with 400 MW baseload import with an availability of at least 85% as contractually agreed.[3]
    - Lamu coal power plant is not considered neither as committed nor as candidate plant.[4]
    - All available candidate geothermal plants
    - No Battery Energy Storage System (BESS) as this is in part a competing technology to the production of hydrogen, both benefiting from surplus electricity in the night. The optimal solution (i.e. how much BESS and how much H2 production is optimal) has to be found with a separate comparative study.
    - Assumptions on (additional) potential power imports as discussed with the GHWG technical team. These are assumptions which are considered - in general - technically possible (to be transmitted via existing and planned lines and based on generation capacity under construction or already available) and for costs in possible ranges.[5]
    - Wind and PV plants: all projects which are planned but have not been picked neither in the LCPDP. Additional generic wind and PV plants with adapted cost degression according to latest IRENA's forecasted learning curves and reduction of PV capex according to actual projects in Kenya.[6]

In the following table the most relevant supply assumptions are provided.

2 Kipeto Wind Phase 1 (50 MW) and Selenkei PV (40 MW) already commissioned, Olkaria 1 Unit 6 (83 MW and Eldosol Cedate PV (40 MW) operational 2022, HVDC interconnector with Ethiopia, Olkaria I Uprating (20 MW) and Olkaria IV Uprating (20 MW) expected to be operational for 2023, Olkaria 1 Unit 1 Rehab (17 MW) and Menengai 1 Phase 1 Stage 1 (103 MW) operational 2024).

3 Agreement between the Governments of Kenya and Ethiopia in 2012 and documented in Power Purchase Agreement (PPA). For comparison: In the LCPDP 2020-2040 scenarios it was assumed with 200 MW, in the revised LCPDP 2021-2030 it was 200 MW baseload import plus 200 MW variable import. The Consultant acknowledges, that a Task Force has been commissioned by the GoK to review all PPAs, including the one with Ethiopia. However, it is deemed very unlikely that the PPA with an agreed take-or-pay baseload delivery will be renegotiated for the better for Kenya. For conservatism reasons thus, the PPA is considered as it has been closed in 2012.

4 There is a signed PPA for Lamu, but the likelihood that it is built is very small for various reasons (The project has been delayed multiple times including court cases. As shown in the Long-Term Generation Plan conducted by Lahmeyer International in 2016, there is no need for such a large plant within the Kenyan electricity system. Based on this analysis, the coal power plant would have only very low utilisation, which would make it a stranded asset. Furthermore, the probability for financing of such a coal power plant is decreasing, make the realisation of such plant impossible).

5 Hydropower import candidate Ethiopia 1: 500 MW base load (availability of at least 85%), 2025 onwards for 50 USD/MWh (hydropower cost with a sufficient margin as the interconnector is already available), and Hydropower import candidate Ethiopia 2: 300 to 600 MW fully flexible, 2030/2035 onwards for 80 USD/MWh (this may also come in part from other neighbouring countries with surplus hydropower capacity, hydropower cost with a sufficient margin for flexible provision and interconnector already available or under construction).

6 Additional 800 MW Turkana generic, 400 MW Kipeto generic, 200 MW Ngong generic; additional 550 MW generic PV; PV capex 2021 at 1,150 USD/kW.

Table 3-1: Most relevant assumptions for the supply of electricity for the electrolysis process

Source	Expansion	Cost
Geothermal	All available expansion candidate geothermal plants (i.e. 800 MW more compared to what has been found optimal within the reference expansion path in the LCPDP 2020-2040)	As given within LCPDP 2020-2040 for each respective geothermal plant candidate
Wind	100 MW each in 2025 & 2026, 200 MW each in 2032 & 2033, 250 MW in 2034, 100 MW each in 2035 & 2036 & 2037, 600 MW in 2039 (overall expansion of 1,750 MW until 2040)	As given within LCPDP 2020-2040 (1,750 USD/kW in 2021) expected to decrease according to IRENA forecast at 3% per year until 2022, then at 2% per year thereafter
PV	Annual capacity addition of 50 MW starting from 2030 on (overall expansion of 550 MW until 2040)	1,110 USD/kWp (2021) expected to decrease according to IRENA forecast at 3.5% per year until 2030, then at 1% per year thereafter
Imports	500 MW base load hydropower import expansion candidate from 2025 onwards 2 x 300 MW flexible hydropower import expansion candidate from 2030 and 2035 onwards	50 USD/MWh 80 USD/MWh

- **Development of PtX / green H2 generic demand patterns and expansion**. The aim is to provide an indicative expansion path on how large scale PtX / green H2 demand may look like to derive a range on potential RE supply costs for this green H2 / PtX. It should be noted that these are not targets but possible expansion paths. It is based on the analysis of sectors / PTX opportunities and adapted in an iterative approach. It should however not be seen as the only possible or best expansion. The actual expansion strongly depends on the actual economics, technological innovations, regulatory and policy framework and the market forces including global competition. If for instance mobility is transferred to H2 much quicker the indicative demand may be rather on the lower side; if large scale industrial applications (like fertilizer production to cover the majority of the local market) will not be possible for market or technical reasons the indicative expansion path may be rather on the higher side. It is recommended to further develop such PtX / green H2 expansion paths as scenario analyses within energy / power system expansion planning and to support the strategy development, implementation and updates.
  - Base demand (any non PtX / green H2 demand) as per LCPDP base demand scenario, with 8760h load curves 2020 to 2040, with constant system load factor of 69.9%, average annual increase of demand for power and energy by between 3.5 to 3.9% in the next five years (similar to pre-COVID19 crisis growth rates) and by an average of 5.7% between 2026 and 2040. This will increase current peak demand of around 2,000 MW by 175% to 5,500 MW in 2040 and the same growth for energy from around 12,000 GWh to 34,000 GWh in 2040

  - Deriving potential PtX / green H2 demand from sector analysis / PtX opportunities:
    - Assuming large-scale demand for green H2 / PtX to start by around 2025 (2025 is set as start as 5 to 10 years steps are the granularity of this study).
    - Respective plant(s) (accumulated around 100 MW electrolyser capacity at about 70% load factor) to cover both i) large-scale demand for H2 / ammonia most likely for fertilizer production (e.g. at around 20% of nitrogen content of all domestically consumed fertilizer, around 140,000 Mt/a) and ii) replacing (high value) imports of (grey) commodities such as H2, ammonia, and methanol (which would make up about 10 to 20% of the initial total H2 production).
    - Continuously increasing demand from both sources assuming green H2 to cover nearly 100% of domestic nitrogen-based fertilizer production by 2034 (which is assumed to grow by 2% each year) and 10% of regional demand (assuming a competitive advantage due to its strategic location and a head start) as well as 5% annual increase for domestically produced green commodities (assuming a competitive advantage compared due to the locally produced nature). Due to this growth, electrolysis capacity is assumed to increase to some 500 MW in 2030 and 2,500 MW in 2040.
    - In 2030, another PtX / green H2 demand thread is assumed to add to the previous, in the range of some 50 MW electrolyser capacity, e.g. for steel direct reduction technology (but alternatively also for e.g. e-fuel (PtL) generation or other mobility depending on technological breakthrough). Seen as a pilot this capacity is expected to increase tenfold 5 years later with a commercial scale plant of considerable size (e.g. equal to a steel production of a quarter of national demand or equivalent of e-fuel / PtL production or other mobility). After 2035, this technology is scaled by 10% annual growth to reach a total of 2,500 MW electrolysis capacity towards the end of the study.
    - The above details the need for the electrolysis. For economic reasons the electrolysis should possibly run at full load and technically a continuous operation should be preferred (depending also on the actual electrolyser technology). However, the electrolysis is more flexible than other processes (e.g. ammonia synthesis) which have to run continuously for technical reason. Further, to some extent, H2 can be stored to allow for a continuous supply to successive processes. Therefore, the consumption profile of the electrolysis process has been shaped to support the electricity grid (see following figure). The electricity system of Kenya has a large share of must-run base load power generation source (e.g. geothermal, must-run imports), which leads to excess generation mainly during night time (which will increase in 2023 considerably) but to some extent also during non-peak daytime. On the other hand, the Kenyan electricity system is short in peaking capacity. Based on the anyways required H2 storage systems, the electrolysis can be operated in a flexible manner to support the grid. For this reason, the bulk of H2 is considered to be produced during night and off-peak daytime. During peak load period in the evening, no (or only a considerably lower level of) H2 is produced. This would increase the system load factor from forecasted 70% to 73% in 2025, 77% in 2030 and above 83% beyond 2035. Through H2 the surplus energy is used and also the overall system operation will benefit from a more balanced operation of a much larger system.
    - Some processes related to the H2 economy are base load such as ammonia synthesis and ancillaries. Based on the indicative PtX / green expansion they are estimated to be in the range of 10% in the beginning increasing to 14% in the long term (assuming a higher share of sophisticated processes connected to the H2 production, which could be steel production or e-fuel generation)

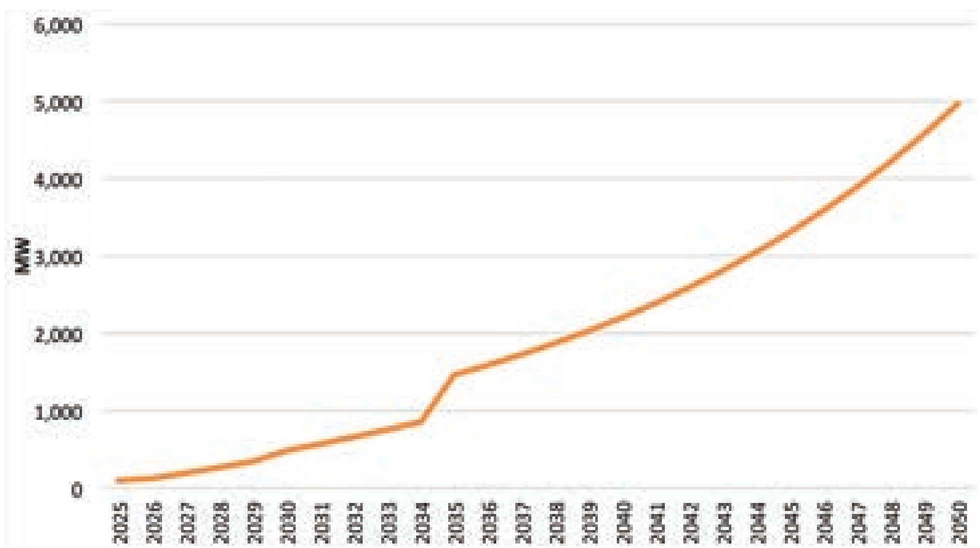


Figure 3-3: Indicative electrolyser capacity expansion assumed for power system analysis

- No network constraints (applied later in site specific analysis of use / site candidates).

- Update with LIPS-XP the reference (base) scenario with above listed updates to derive total generation system costs for 2025, 2030, 2035, 2040, and 2050 (derived from 2040).
- Determine with LIPS-XP for the other scenario (PtX / green H2) the potential least cost RE availability and overall system costs for key years 2025, 2030, 2035, 2040, 2050 (derived from 2040).
- Specify range of RE based electricity costs e.g. XY USDc/kWh for green H2-consumption (balance of reference and PtX / green H2 scenarios) as key input for large scale green H2 production.
- Adapted for use / site candidates in the PESTEL analysis considering transmission losses and possible capacity expansion needs (or wheeling charges, but less likely to be suitable/available). By this “lower hanging fruits” for green H2 production and use enabled by the existing system (i.e. capacities) will be identified.

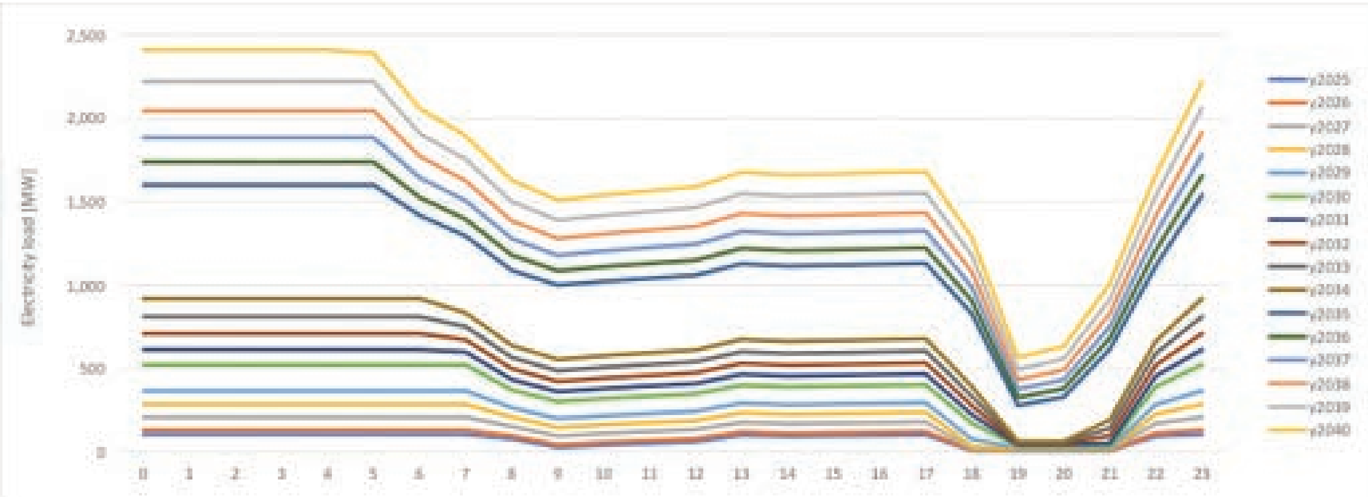


Figure 3-4: Projected development of average daily electricity demand for electrolysis

3.3 Approach for green H2 demand (PtX Opportunities / Candidates)

As described above, this second part of the methodology and study is the analysis of the demand side of green H2 the assessment on sectors and sites for potential future supply and demand for green hydrogen, the actual baseline study, covering topics such as *“qualitative and quantitative analysis of PTX associated technology and its market (domestic and export), cost, infrastructure, environmental and sustainability aspects”*, as described in the TOR.

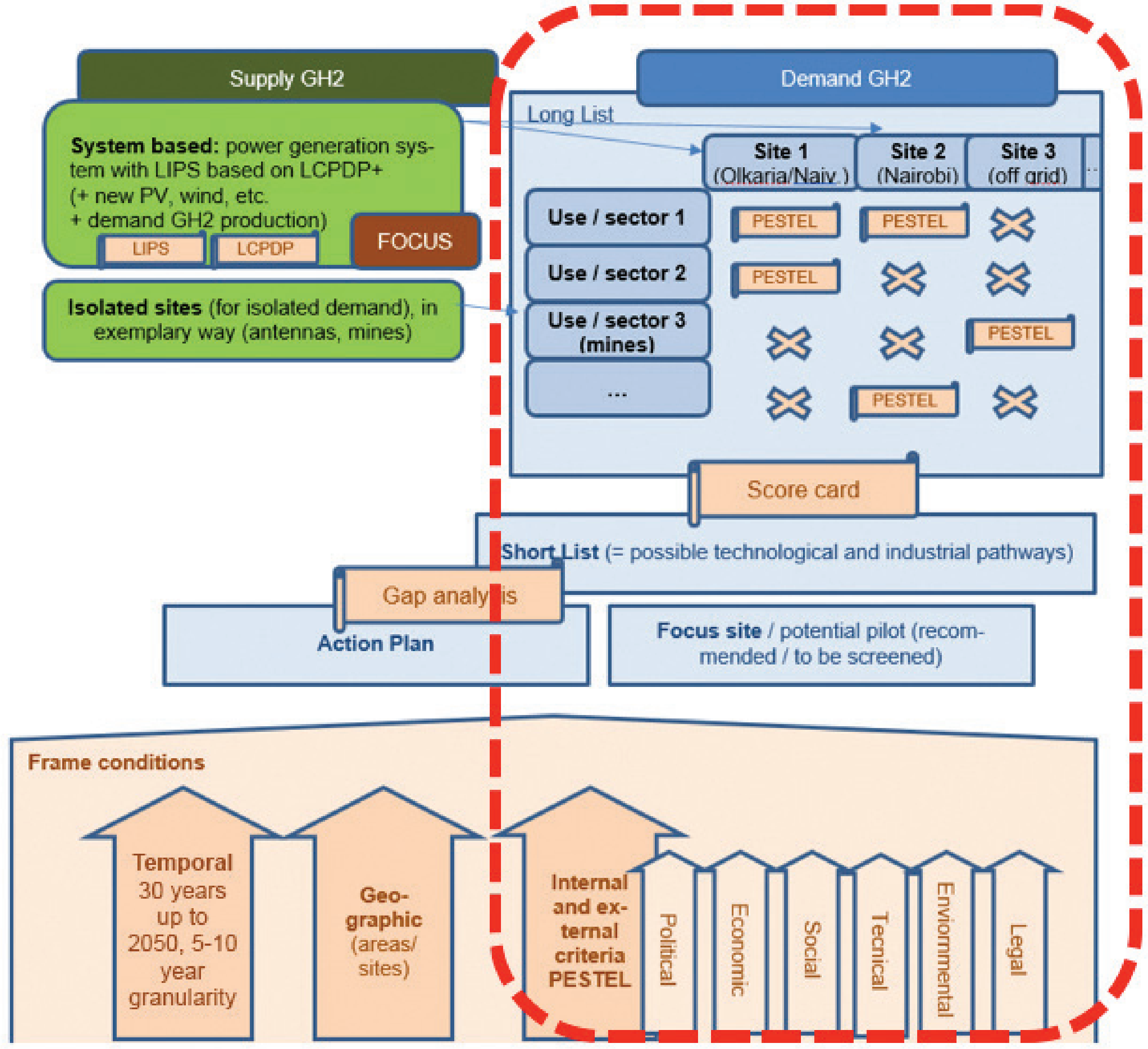


Figure 3-5: Green H2 demand as part of overall approach

Potential demand Green H2, to be displayed in a matrix style (candidate matrix = long list, see below)

1 Use candidates: by different possible uses or sectors for Green H2, e.g. fertilizer, mobility, and

2 Site candidate: at different sites (this is of course linked to site specific uses and power system, e.g. through estimating transmission costs), which is determined by RE sources at costs as low as possible and availability as high as possible (both reasonably justified on a time scale and considering Kenya situation).

3.3.1 Green H2 Candidates matrix (=long list)

Starting point is the screening of current use (sectors/production processes) of (grey) H2 and potential future use of (green) H2 (=use candidates) as well as related sites and areas in Kenya (=site candidates).

This long list will be overlapped in a matrix as not all uses will be possible or suitable at all sites. Below is a draft matrix exemplifying this approach.

	Area (site candidate)						
Subsector (use candidate)	Olkaria (Rift Valley)	Mombasa area (Coast)	Lamu area / LAPSSET (Coast)	Nairobi area (Central)	7-Forks / Thika (Central)	Western Kenya	Lake Turkana area
Agriculture - fertilizer	x	x	x	x	x	x	
Manufacture - light industry	x	x	x	x	x	x	
Manufacture - heavy industry	x	x		x			
Mining and quarrying	x	x	x			x	
Electricity	x	x	x	x	x	x	x
Transport / mobility	x	x		x			
Ports and maritime (fuel)	x	x	(x)	x			
Aviation	x	x		x			
Road transport	(x)	(x)		x			
Rail transport	(x)	x		(x)			

Figure 3-6: Green H2 Candidates matrix (=long list)

The potential export of green H2 (possibly converted to other commodities such as ammonia) is included in the use candidate of maritime fuel.

3.3.2 Multi-criteria score card based analysis structured by PESTEL approach and Levelized Costs of Hydrogen (LCOH) (to arrive at short list)

The core analysis of long list of green H2 candidates (matrix of use and site candidates) will be done combining the following tools and methods:

- PESTEL
- Levelized costs of hydrogen (LCOH) estimate to facilitate evaluation of economic forces
- Score card for evaluation and ranking

The prioritisation assessment is carried out by means of a PESTEL analysis for which qualitative and quantitative data for the assessment of the candidates will be collected and analysed. This concept has been already successfully applied in various similar studies, including the candidates assessment for the Power Generation and Transmission Master Plan for Kenya 2016. Within the green H2 study the approach will be further extended to allow an overall ranking and comparison of candidates.

The PESTEL analysis examines the candidates' environment, which covers the following so-called forces:

P - Political forces

E - Economic forces

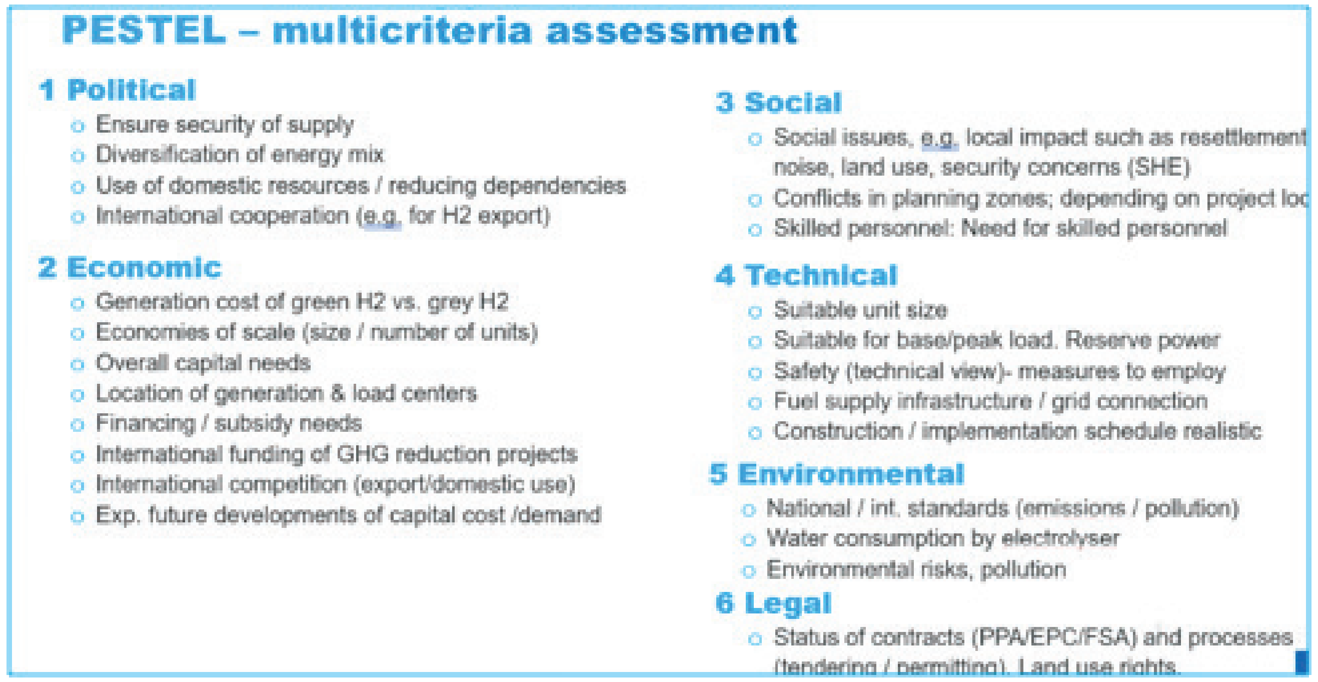
S - Social forces

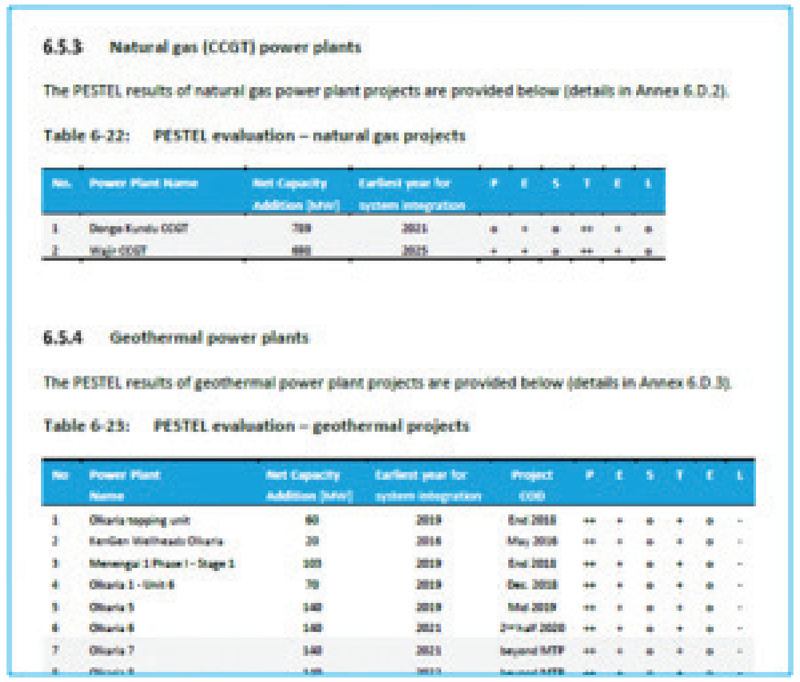
T - Technological forces

E - Environmental forces

L - Legal forces

The PESTEL framework provides a comprehensive list of influences on the possible success or failure of projects. Therefore, key drivers for evaluating the expansion candidates will be assumed according to the Consultant's experience in previous projects as well as particularities of the Kenyan power sector. The following table lists exemplary key drivers or planning criteria respectively, whose influence on the candidates could be considered in the analysis.





6.5.3 Natural gas (CCGT) power plants

The PESTEL results of natural gas power plant projects are provided below (details in Annex 6.D.2).

Table 6-22: PESTEL evaluation – natural gas projects

No.	Power Plant Name	Net Capacity Addition [MW]	Earliest year for system integration	P	E	S	T	E	L
1	Dongo Kundu CCGT	700	2021	o	+	o	++	+	o
2	Wajir CCGT	480	2025	+	+	o	++	+	o

6.5.4 Geothermal power plants

The PESTEL results of geothermal power plant projects are provided below (details in Annex 6.D.3).

Table 6-23: PESTEL evaluation – geothermal projects

No	Power Plant Name	Net Capacity Addition [MW]	Earliest year for system integration	Project COD	P	E	S	T	E	L
1	Olkaria topping unit	60	2019	End 2018	++	+	o	+	o	-
2	KenGen Wellheads Olkaria	20	2018	May 2018	++	+	o	+	o	-
3	Menengai 1 Phase I - Stage 1	103	2019	End 2018	++	+	o	+	o	-
4	Olkaria 1 - Unit 6	70	2019	Dec. 2018	++	+	o	+	o	-
5	Olkaria 5	140	2019	Mid 2019	++	+	o	+	o	-
6	Olkaria 6	140	2021	2nd half 2020	++	+	o	+	o	-
7	Olkaria 7	140	2021	beyond MTP	++	+	o	+	o	-
8	Olkaria 8	140	2022	beyond MTP	[illegible]					

Figure 3-7: Exemplary PESTEL criteria and exemplary PESTEL results from PGTMP 2016

The detailed criteria are provided in Annex A.

Levelized cost of hydrogen in Kenya are based mainly on the results of green H2 supply and costs through RE supply as detailed above, applying common methods (spreadsheet model with discounted cash flows).

The above methods are combined in a spread sheet-based score card which allows the evaluation of each and every candidate along the PESTEL criteria and a successive ranking. Below a cut out of the score card is shown.

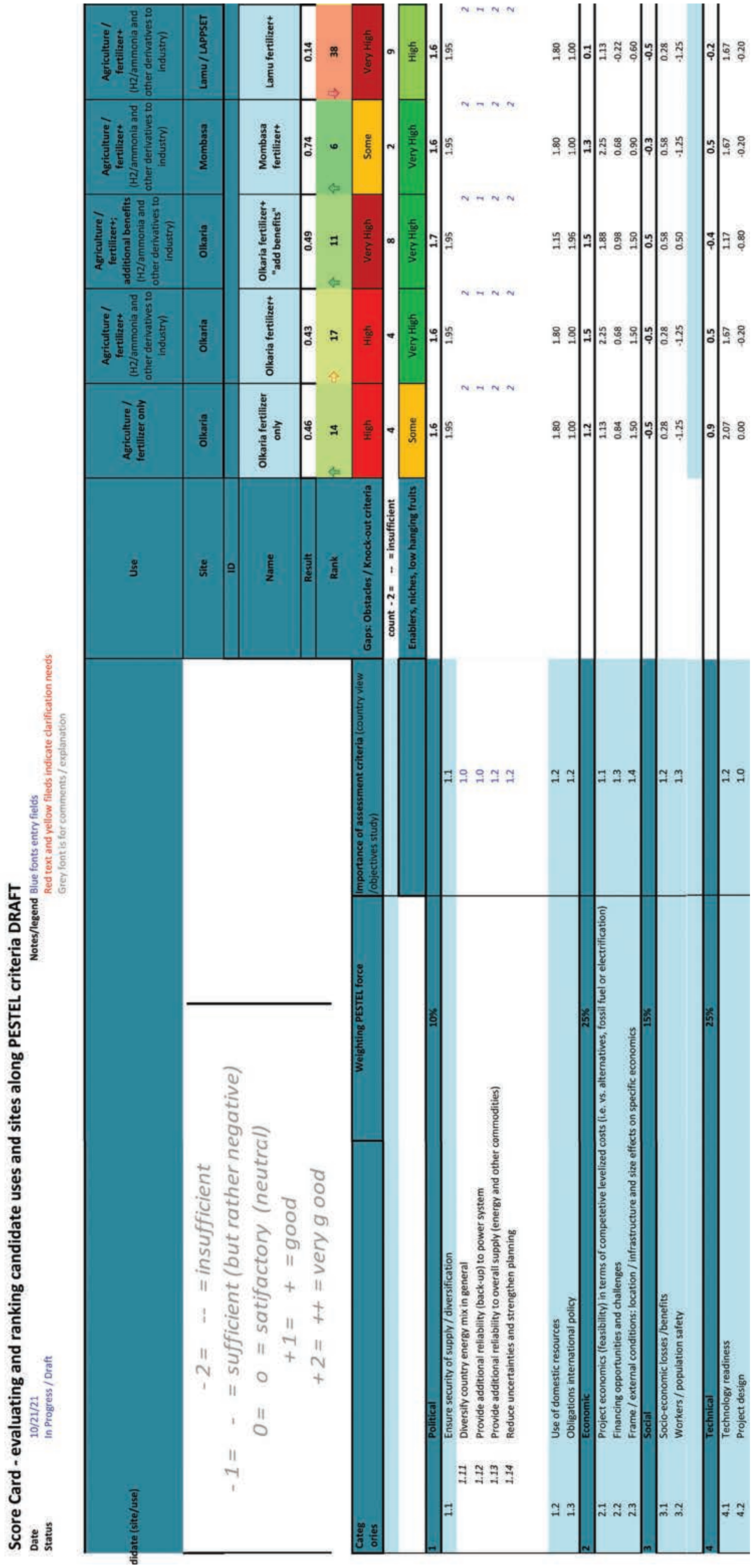


Figure 3-8: Score card with evaluation / weighting examples

In the score card three types of weighting and evaluation scores are suggested to be applied to allow for a transparent evaluation and consideration of planning objectives:

- Weighting of each of overall 5 PESTEL forces with sensitivity testing

Force	default weight	sensitivity tests, e.g	
Political	10%	17%	5%
Ecocomic	25%	17%	35%
Social	15%	17%	5%
Technical	25%	17%	35%
Environmental	15%	17%	10%
Legal	10%	17%	10%

- Weighting of sub-criteria (default: neutral, i.e. same weighing of each sub-criteria; with possibility to increase importance by up to 50% upwards and downwards, if justified)
- Evaluation of each sub-criterion for each use / site candidate with a scale of -2 to +2 (similar to scale established for candidate ranking for Power Generation and Transmission Master Plan 2016:
  - -2 = -- = insufficient;
  - -1 = - = sufficient (but rather negative),
  - 0 = o = satisfactory (neutral),
  - +1 = + = good,
  - 2 = ++ = very good);
- Were possible these categories will be supported by quantitative ranges (e.g. if it concerns costs)

This system does also allow for identification and visualization if certain candidates are beneficial but linked with a certain number of potential obstacles or knock-out criteria, i.e. supporting a gap analysis. Further supporting factors ca be evaluated, i.e. to highlight enablers, identify niches or so-called lower hanging fruits

Through ranking and detailed assessments along PESTEL criteria each use and site candidate was evaluated and ranked so that the prominent and most promising uses and sites could be identified and respective industrial paths (along uses/sectors) developed.

3.4 Deriving Possible technological and industrial pathways for Kenya and Action Plan

The short-listed candidates with the detailed PESTEL structured assessment (as described in the previous chapter) will allow for the description of industrial pathways. Together with the analysis of challenges and opportunities and a gap analysis this was the basis for the formulation of the action plan developed in Work Package 3 and provided in chapter 9.

4 GREEN HYDROGEN BASICS AND GLOBAL FRAMEWORK

This section provides a brief introduction to green hydrogen with an overview of the international techno-economic status and policy as well as a summary on safety, risks and standards/norms.

The use of hydrogen can be split into two fields:

- As **a commodity for mostly chemical and industrial scale uses**, e.g. fertilizer production. As such it has been well established worldwide for more than 100 years for a wide range of uses. Up to date, it is quasi exclusively supplied through carbon intensive production based on fossil fuels, mainly natural gas.
- As an **energy source**. Hydrogen has a high energy density (nearly three times of natural gas and petroleum products) and the technology for the energetic use of hydrogen exists for more than 150 years. However, its utilisation as an energy source has been limited to niche uses. This is because hydrogen is not a primary energy source (as fossil fuels are or uranium or renewable energies) but only an energy carrier. As such it has to be produced with much higher energy input. If this comes from renewable energies it is an option for carbon neutrality of processes, which is the main driver for hydrogen analysis in recent years, including this study.

This study has looked at both potential uses for green H2: commodity for processes and energy source, always considering the opportunities but also challenges within Kenya.

As an introduction, the key opportunities to motivate the use of green H2 in Kenya are listed as well as main challenges.

Table 4-1: Opportunities and challenges of green hydrogen

Opportunities for production and use of green H2	Challenges for production and use of green H2
■ The use of green H2 avoids GHG emissions, thus can help to achieve national NDC (National Determined Contribution) and can be exported under preferential conditions to EU (grey or partially blue H2 cannot) ■ H2 is abundant and not toxic ■ H2 is a commodity widely used in chemical production processes ■ Application of green H2 technologies can create new jobs and induce development of new domestic expertise ■ Domestic production of green H2 reduces the use of fossil energy resources and reduces import dependency ■ Green H2 is a multi-purpose energy carrier and enable flexible use and storage of intermittent renewable e.g. from solar or wind; one is the support of the balancing of power supply and demand ■ Resource for export and by this, creation of foreign exchange reserves ■ Green H2 technologies are scaling up and significant (cost) learning curves are expected	■ The costs of green H2 are currently high (due to early market status) restricting its use today to hard-to-abate sectors ■ H2 has a low density and thus low volumetric energy density under standard conditions (lower than natural gas) ■ The physical properties of H2 (molecule size, ignition energy, flammability limits) require increased attention with regard to safety and risk management ■ Large-scale storage of H2 requires pressurization or conversion to other chemical hydrogen carriers ■ Efficiency of H2 transport is lower than that of conventional fuels (oil or natural gas) due to the energy density ■ The production of green H2 requires to build up additional RE capacities or excess RE energy, which would otherwise not be required or used, i.e. the supply of other demand for electricity by RE shall not be affected (additionality criteria, definition varies/under development)

4.1 Techno-economics of green H2

This section summarizes the following assumptions for the study:[7]

- Definitions of hydrogen and its main derivatives relevant for this study;
- Technical processes and parameters (including emission factors and water needs) as well as
- Average costs with regard to current status of technologies and a brief outlook on potential cost developments (e.g. with regard to potential innovations, learning curves and respective cost decreases).

As an introduction the following graphics visualize the dominant current production and use of – mostly grey - hydrogen today as well as the carbon-intensity differentiation of hydrogen, so called “colours”.

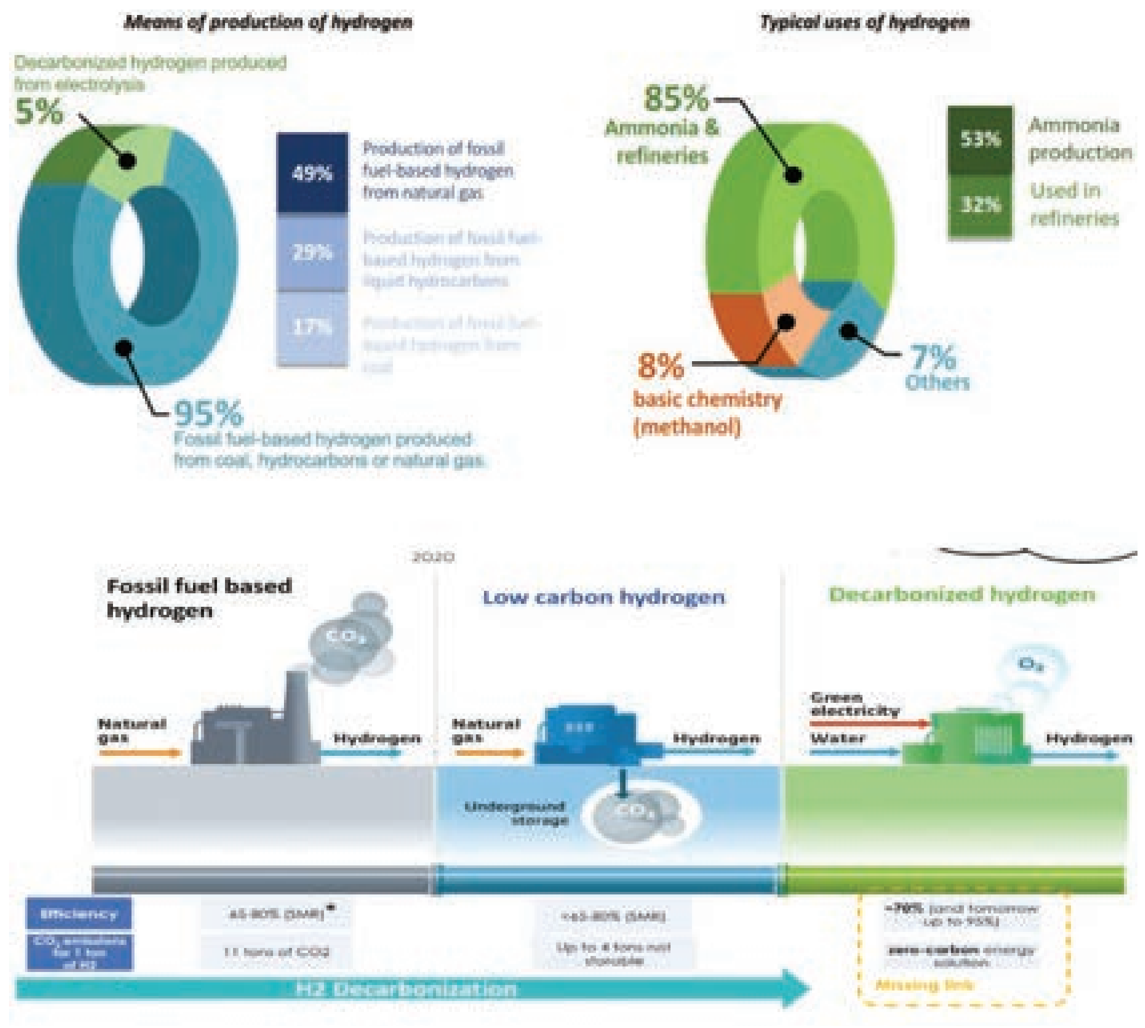


Figure 4-1: Main production and usage of hydrogen today and the “colours of hydrogen”[8]

7 Note on cost calculations and benchmarks: The estimates provided - in particular cost ranges - represent the general high uncertainty of the topic of green hydrogen highly depend on the specific sites and countries with differing conditions such as RE costs and markets (e.g. for natural gas, electricity). The figures are derived from a literature review and are meant as a general benchmark for this study. They differ from calculations of cost ranges in section 5.3, which are derived with Kenya-specific assumptions, e.g. for RE costs and water costs. Both cost ranges represent also the scope of the study (comparing a wide range of current and future uses/sectors and locations). Because a quantitative analysis is often limited by these uncertainties and ranges it is therefore embedded in the overall comparative (rather qualitative) PESTEL analysis. Cost calculations should of course be detailed in any successive studies.

8 The specified electrolysis efficiency values refer the higher heating values (HHV) of hydrogen.

Table 4-2: Basic definitions and processes around PtX and green hydrogen

Name	Definition / process	Costs today	Cost future (~2030)	CO2 emissions	Water needs
Hydrogen	**Most abundant element; commodity most important for several chemical production processes** (e.g. oil and gas refining, ammonia production) **and energy source / carrier.** Reacts with oxygen in an exothermal reaction (combustion) providing energy (heat, electricity depending on process). Lower heating value 120 MJ/kg (33.3 kWh/kg) Higher heating value 142 MJ/kg (39.4 kWh/kg) Normal density 0.089 kg/m3 (at normal temperature and pressure conditions)	Depends on production processes / “colour” (see below)	Depends on production processes / “colour” (see below)	No direct emissions when reacting with O2 i.e. in a fuel cell to generate electricity.	No. Water is a reaction production during the combustion of H2.
Conventional **(grey) hydrogen**	**Today’s supply of hydrogen**. Produced from fossil fuels (main process: natural gas through steam methane reforming (SMR) most important source: nearly 50% of worldwide H2 production and nearly all merchant H2) Efficiency 65-75% (endothermic = consumes energy)	USD/kg 1 – 2.5[9] (depending on the price of fossil fuel)	Uncertain USD/kg 2 – 4.3 (with USD 180 per t CO2) No cost reduction potential but increase if CO2 emission costs are added	Lower end 7-9 kg CO2 / kg H2 (SMR natural gas) without natural gas leakages considered Higher end 13 – 14 kg CO2 / kg H2 (SMR natural gas) with natural gas leakages considered, i.e. some 0.1 kg CO2 / MJ	4.5 kg H2O/ kg H2 and more
Green hydrogen (green H2)	**“Real” CO2 neutral hydrogen foreseen to replace grey hydrogen as well as decarbonize processes currently based on fossil fuels (e.g. steel production)** Produced by water electrolysis with electricity from renewable energy. Established technology but available in MW scale and upscaling to industrial GW scale though yet not cost competitive. Efficiency 60-70% (i.e. 47-55 kWh / kg H2; exothermic = produces low temperature heat (< 60 °C) 14-22 kWh / kg H2) Oxygen production as by-product (8 kg O2 per kg H2)	USD/kg 2.5 – 7.0 (depending on costs of renewable energy and utilization of electrolyser (partial vs. full load), e.g. USD/MWh 20 - 80)	USD/kg 1.5 – 4[10] (depending on costs of renewable energy and economies of scale / learning curve electrolyser, e.g. efficiency to 75%, stack lifetime > 90 000 h)	Per definition CO2 free (but marginal emissions from production of renewable energy power plant, i.e. 0.25 kg CO2 / kg H2 if RE cradle to grave emissions PV and wind 5 g/kWh)	14 kg H2O/ kg H2 (high when using tap water requiring more purification; lower when using demineralised water) Cost assumption for this study USD/m^3 3-4

9 Derived from: IRENA (2020), Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5ºC Climate Goal, International Renewable Energy Agency.

10 ebenda

Name	Definition / process	Costs today	Cost future (~2030)	CO2 emissions	Water needs
Blue hydrogen	Low-carbon, almost CO2 neutral alternative, but not considered desirable in terms of climate change and sustainability (fossil fuel depending, CO2 emissions, lock-in effects). Emitted CO2 from SMR is captured and stored or utilized (CCS) and not avoided. Often discussed as bridge technology to scale up industrial scale hydrogen use.	USD/kg 1.2 – 2.5[11] (depending on the price of fossil fuel)	USD/kg 1.2 – 2.5 (no / little cost reduction potential from CCS economies of scale)	CO2 emissions from process and storage leakages and CCS energy needs	See grey hydrogen
Ammonia	Ammonia (NH3) is a colourless toxic chemical compound (gaseous state under standard conditions), as commodity produced in the Haber Bosch synthesis process in liquid state (-33 °C). with N2 and H2 (~18 wt.-% H2) as educts. It is used for a wide range of industrial processes and as base chemical for other products (e.g. fertilizers). It can be used as a liquid fuel in engines or fuel cells. Lower heating value 18.9 MJ/kg (5.3 kWh/kg) Higher heating value 22.5 MJ/kg (6.3 kWh/kg) Gas density 0.76 kg/m^3 (standard conditions) Liquid density 682 kg/m^3 (-33 °C)	USD/t 200-900[12] Based on grey hydrogen (depending on cost of natural gas and factory costs) + transport USD/t 700-1,000 Based on green hydrogen (depending on cost of green H2 (~USD/ kg 4-5) and factory costs) + transport	USD/t 230-930 Based on grey hydrogen (with USD 180 per t CO2) + transport USD/t 400-600 Based on green hydrogen (depending on costs of renewable energy and economies of scale / learning curve electrolyser, e.g. efficiency to 75%) + transport	~2 kg CO2 per kg ammonia (Based on grey hydrogen from SMR) Green ammonia per definition CO2-neutral. Based on green hydrogen, if all production processes (see green H2 above)	Make-up water for steam generation (~5 m^3/ t NH3)
Methanol	Methanol (CH3OH) is a colourless liquid used as fuel or as base chemical for other products. Today's production process relies on grey H2 and CO2 from SMR as inputs. If based on green H2 the methanol synthesis would be one option for a Power-to-Liquid value chain. Lower heating value 20,1 MJ/kg (5.5 kWh/kg) Higher heating value 22,9 MJ/kg (6.4 kWh/kg) Liquid density 810 kg/m^3 (STP)	USD/t 350-400[13] Based on fossil fuels (coal, natural gas, petroleum) + transport USD/t 900-1,000 (depending on green hydrogen cost)	USD/t 380-430 Based on fossil fuels (with USD 180 per t CO2) + transport USD/t 400-500 (depending on green hydrogen cost)	~0.7-1 kg CO2 per kg methanol (Based on grey hydrogen from SMR)	
Green H2 to electricity (heat and power generation)	**"Re-electrification" process to generate electricity from hydrogen using i) fuel cells ii) gas turbines iii) gas engines.** The most common are gas turbines at utility scale and fuel cells & gas engines at medium/ small scale. Conversion efficiency is comparable to NG-fired power plants (30-60%)	USD/MWh_{el} 150 - 700 (fuel cost share only, heat is not used, depending on green H2 costs and efficiency; capex and opex may considerably increase generation costs depending on capacity factor)	USD/MWh_{el} 100 - 400 (fuel cost share only, if heat is not used, depending on green H2 costs and efficiency; capex and opex may considerably increase generation costs depending on capacity factor)	No direct emissions.	No. Provides water when reacting with oxygen
Hydrogen transport and storage	**Hydrogen can be transported and stored in steel or composite material tanks** (different scale from cylinders to storage tanks and trucks) and **pipelines and underground salt caverns** requiring different pressures with strict material requirements for high safety and reduction of losses.	Electricity consumption for compression less than 10% of energy content (depending on pressure ratio)		No direct emissions.	No.

11 Derived from: IEA (2019), The Future of Hydrogen, International Energy Agency.

12 Market price range (2010-2020): Anhydrous ammonia prices Illinois, USA (https://www.proag.com/news/2020-fertilizer-prices-remain-low/

13 Derived from: IEA (2019), The Future of Hydrogen, International Energy Agency.

Considering the above and latest research on green H2, the following general statements are commonly made and are applied within this study:

- **Green hydrogen is the only climate-neutral and sustainable form of hydrogen which can be produced at scale.** It is contested, whether alternatives are needed to scale up hydrogen use in sectors where hydrogen is currently not used. However, this discussion is not relevant for this study as there are no opportunities for these alternatives to green H2 in Kenya.
- **Green H2 costs are determined by i) cost of electricity from renewable energy** (which could be in the range of USD/MWh 15 to 200, depending on source, site and availability, e.g. PV plants may provide electricity at levelized costs of below USD/MWh 20 but only at capacity factors below 25%; higher availabilities usually come at higher costs), **ii) efficiency of the electrolyser** which is set by physical limits with rather limited technical improvements possible and **iii) the utilization factor of (capital intensive) electrolyser** (the latter is closely linked to the first, i.e. capacity factor or availability of renewable energy).
- **Green H2 costs today is three-times of grey hydrogen** (e.g. USD / kg 2.5 versus 0.7 on the lower end) while electricity base on renewable energy is already competitive with fossil fuels for many utilizations (e.g. grid electricity, battery electric vehicles). Hence, it is a general consensus that **compared to Green H2; electrification based on renewable energy is the more cost-efficient solution today and likely in the**

future. Focus of green H2 should be laid on applications where electrification is technically not possible or suitable.

- Hydrogen **transport and delivery cost** are a significant cost component in **small-scale projects**. For small-scale production volumes transport distances should be minimized and the close to the consumption point. Large-scale hydrogen transport can reduce the transport cost significantly but requires the **availability of suitable infrastructures** for transport (pipelines), processing (conversion plants) and storage (geological underground storage).
- **Oxygen as the main by-product in green H2 production could slightly improve the economics of green H2** if used in other processes (e.g. steel production – the largest consumer of oxygen - and other metals, glass production, gasification and gas-to liquid processes e.g. for municipal wastewater treatment, health care). However, this margin is negligible from today's point of view due to established industrial scale production the costs for oxygen are rather low (e.g. electricity need below 0.5 kWh for 1 kg oxygen in pressure swing adsorption, PSA).
- **Water is technically and economically less critical compared to other parameters of green H2** (e.g. RE electricity supply requirements and H2 storage / transport issues). For water as input for green H2 there are clear technical requirements and solutions with a relatively low cost share between 1% and 5% of costs of green H2. However, water availability including seasonal or climate change induced variations have to be considered (see section 5.4)
- **Land requirements for** electrolysis and H2 storage a relatively low for sizes likely relevant in Kenya, e.g. 4000 to 5000 m^3 for the 100 MW electrolyser and 3-4 hour storage (i.e. some 30 to 50 m^3 per MW electrolyser capacity depending on kind of storage (pressure) and other facility needs. Of course, this does not include the land for RE capacity which likely is situated at other sites were resources are sufficient and connected via (preferably existing) transmission lines. The land needs vary from relatively low need for geothermal plants to much higher needs for PV (e.g. in the range of 5,000 to 10,000 m^3 per MW installed capacity) and wind (10 to 15 times the need for PV), where the land may still be available for other uses (to some extend also valid for PV).
- **In summary, green H2 does have its highest economic feasibility for utilization in regional areas with low electricity costs, high capacity factors and with close proximity to potential demand sites or existing infrastructure where green H2 can be used either as a feedstock or fuel and where the direct use of electricity is not suitable or economically viable.** The difference between this use and e.g. use as transport or high heat fuel may reduce in future with scaling up green H2 production and consumption and respective effects on economies and technology / innovation but the order of feasibility will likely remain.

4.2 Potential uses of green H2

In order to identify and rank potential future uses of green H2 in Kenya, as a first step the general differentiation is done into four fields.

Table 4-3: Clustering of potential green H2 use

	Established H2 uses (grey H2 today) (established technologies / processes = "ready" for green H2)	**Potential future green H2 uses** (new technologies / processes = feasibility to be proven)
Large scale (industrial) uses (high volume = low price)	Ammonia for fertilizer production Oil refining Heavy chemistry (H2 peroxide as disinfectant, bleaching etc., ammonia, methanol chlorine)	Power generation and energy storage (grid and off-site large scale e.g. mining) Heavy industry in particular steel (iron ore processing) High-temperature process heat generation
Small scale uses (low volume = high price)	Metallurgy Glass production Electronics / semiconductors / batteries Food processing (hydrogenated fats) Aerospace / rocket fuel Chemical processing of textile, wood, pulp and paper etc. (in part with above listed chemicals, e.g. peroxide).	Mobility (trucks, forklifts, busses, trains, ships, airplanes, etc.) Synthetic fuels (including methanol) On site off-grid supply and storage

The following table lists all relevant established and future uses for H2 to be screened for this study.

It is clustered by sectors (along the sector structure and terminology of the Kenya National Bureau of Statistics, KNBS) and technologies/uses as a basis for the identification of potential technological and industrial pathways for Kenya.

It further provides a first categorization with regard to

1. Worldwide **current use of (grey) H2** and estimated size (small/medium/large);
2. Worldwide **potential future size** as well as a ranking (low/medium/high probability) in terms of **usefulness to convert to green H2** (in comparison with other use cases for green H2 as well as alternative decarbonization options, in particular electrification of processes);
3. Overall time frame on when such a conversion to green H2 will likely become relevant;
4. Relevance for **Kenya in terms of (current) importance of sectors and particular uses** (summarizing chapter 6 analysis).

Table 4-4: Potential sectors for future green H2 use (technological and industrial pathways)

#	Sector / Subsector	Kind of use of H2 (technology/process)	Use of H2 today (mainly grey)	Probability for future green H2 use and est. volume	Time frame for future green H2 use	Relevance of sector / use in Kenya	Sector size (GDP share)	Geographic focus
1	**Agriculture**							
1.1	Fertilizer production	Production of nitrogen content	Large	High / large	Medium-term	High / medium	18% agriculture (growing of crops)	Central (Nairobi, Thika); lesser: Coast (Mombasa, Athi River), Eldoret, Narok
2.1	**Manufacture - light industry**							
2.1.1	Food products (processing)	Hydrogenation (saturation fats, sugar alcohols), packaging/conservation Refrigerant (ammonia) Bleaching, antimicrobial /sterilizing (H2 peroxide)	Medium	High / medium	Medium to Long-term	High / medium	5% manufacture of food etc.	Central (Nairobi, Thika); lesser: Western (Kisumu)
2.1.2	Semiconductors / electronics and other machinery, equipment	Protection gas, carrier gas, leakage test, cooling agent (ammonia also widely used in electronics industry)	Small	High / small	Medium to Long-term	Low / medium	0.1% manufacture of electrical equipment etc.	Central (Nairobi), Coast (Mombasa)
2.1.3	Textile, wood, leather, rubber, pulp etc. (material processing)	Reagent (bleaching, cleaning and other treatments with H2 derivatives, including wastewater treatment, purification of water)	Small	High / small	Medium to Long-term	Low / not known	0.4% manufacture of textile, wood, leather etc.	Central (Nairobi, Thika), lesser: Ruiru, Eldoret
2.1.4	Glass production (flat glass)	Protection gas/protective atmosphere (with nitrogen) in float glass tin bath For high temperature (replacement of natural gas for burners) see 2.2.3	Small	High / small	Medium-term	Medium (incl. construction work) / no	Not available	Central Nairobi)
2.2	Manufacture - heavy industry							
2.2.1	Steel production	Reducing agent	Pilot project with green H2	High / large	Medium-term	Medium / no	0.6% manufacture of basic metals	Central (Nairobi): Coast (Athi River, Mombasa), lesser: Western (Homa Bay)
2.2.2	Metal processing	Protection gas, welding	Medium	High / medium	Long-term	Medium / uncertain	0.6% manufacture of basic metals	See above
2.2.3	Cement and other high temperature industrial process heat (>400°C)	Combustion for high temperature heat generation / incl. replacement of natural gas for burners	Not yet (development stage for green H2)	Medium / large	Long-term	Medium / high	0.5% manufacture of non metal products	Coast (Mombasa, Athi River), Central (Nairobi)
2.2.4.	Low-medium temperature industrial process heat	Heat and power generation in CHP plants or boilers (steam generation), waste heat from electrolyzes	Pilot (with green H2, experimental)	Low / large	Long-term	High / high	Not available	Central (Nairobi, Thika), Coast (Mombasa, Athi River)
2.2.5	Refining incl. petrochemical industry	Hydrocracking, desulphurisation	Large	High / large	Medium-term	Low / not anymore	0.01% manufacture of coke and refined petroleum products	Coast (Mombasa), Central (Nairobi)
2.2.6	Chemical products (heavy chemistry)	Base chemical for i.e. acetic acid and formaldehyde production; refrigerant for ultralow temperatures etc.	Large	High / large	Medium-term	Medium / uncertain	0.7% manufacture of chemicals and chemical products and pharmaceuticals	See above

#	Sector / Subsector	Kind of use of H2 (technology/process)	Use of H2 today (mainly grey)	Probability for future green H2 use and est. volume	Time frame for future green H2 use	Relevance of sector / use in Kenya	Sector size (GDP share)	Geographic focus
3	Mining and quarrying							
3.1	Open pit mining of metal ores and other - vehicles	Heavy duty, specialized vehicles	Pilot project with green H2 in operation (experimental)	Medium / small-medium	Medium-term	Low / medium	1% mining and quarrying	Coast (Kwale, Mombasa), Western / Rift Valley
3.2	Mining of metal ores and other – power supply	Off-grid power / energy supply (see also 4.5)	-	Medium / small	Medium to long-term	Low / high	1% mining and quarrying	See above
3.3	Fuel exports	Hydrogen as energy commodity, ammonia / methanol as energy commodity / hydrogen carrier	Low (pilots)	High / high	Medium to long-term	Low / low	0%	n/a
3.4	Mining of metal ores and other – materials	Blasting agent (ammonia nitrate), extraction of some metals from ores	Low (via ammonia)	Medium / small	Medium-term	Low / medium	1% mining and quarrying	See above
3.5	Fuel liquid, methanol as fuel	Methanol as fuel domestic (cooking), transport, power supply	Low	Medium / medium	Medium-term	Medium / low	Not available	Not available
4	Electricity							
4.1	Base load electricity supply	Electricity generation base load	Pilot (with green H2, experimental)	Low / large	Long-term	Medium / low	1.6% electricity supply	Rift Valley (Olkaria), Central (Nairobi, Thika), Western, Coast
4.2	Back-up / peaking electricity supply	Electricity generation for (seasonal) back-up / peaking	Pilot (with green H2, experimental)	Medium / small	Long-term	Medium / high	1.6% electricity supply	See above
4.3	Energy storage	Seasonal energy storage (focus electricity supply)	-	High / large	Long-term	Medium / no	1.6% electricity supply	n/a

#	Sector / Subsector	Kind of use of H2 (technology/process)	Use of H2 today (mainly grey)	Probability for future green H2 use and est. volume	Time frame for future green H2 use	Relevance of sector / use in Kenya	Sector size (GDP share)	Geographic focus
4.4	Combined (low) heat and power supply residential and commercial buildings, industry	Heat and power generation in fuel cells; Use of low heat from electrolyzes	Low (with natural gas), pilots / commercial start with green H2	Low / large	Long-term	Low / low	Not available	n/a
4.5	Off-grid supply of electricity	Electricity generation and storage (alternative to diesel and battery) direct H2 / via ammonia	Low (pilots with green H2 and ammonia)	Medium / small	Medium-term	Low / high	1.6% electricity supply	All Kenya, mainly Western, Northern, Eastern
5	Transport / mobility							
	Ports and maritime						1.2% all other transport (mainly maritime)	Coast (Mombasa, Lamu)
5.1	Logistics and material handling	Fuel for vehicles (trucks, forklifts, reach stacker)	Pilot projects of several manufacturers in operation.	High / medium	Short-medium term	High / high		
5.2.1	Maritime shipping (cargo)	Fuel for ships (incl. derivatives)	Pilots (only derivatives)	Medium / large	Long-term	High / low		
5.2.2	Special purpose ships (offshore service vessels)	Fuel for ships (incl. derivatives)	Pilots (only derivatives)	Medium / small	Medium	Low / low		
5.2.3	Inland water shipping (cargo)	Fuel for ships (incl. derivatives)	-	Medium / medium	Long-term	Low / medium		Western (Kisumu, Homa Bay)
5.2.4	Inland water shipping (passenger transport)	Fuel for ships (incl. derivatives)	-	Medium / medium	Medium	Low / medium		Western (Kisumu, Homa Bay)

#	Sector / Subsector	Kind of use of H2 (technology/process)	Use of H2 today (mainly grey)	Probability for future green H2 use and est. volume	Time frame for future green H2 use	Relevance of sector / use in Kenya	Sector size (GDP share)	Geographic focus
5.3	Aviation	Fuel for planes differentiated into regional/medium distance and long distance	Pilot (experimental) for e-Kerosene (green H2) started	Medium to high / large	Long-term	Medium / medium	1.0% aviation	Central (Nairobi), Coast (Mombasa), lesser: Western etc.
5.4	Road transport not private vehicles						10% land transport	All Kenya, mainly Central (Nairobi), Coast (Mombasa), Western
5.4.1	Public road transport	Fuel for vehicles (city & coach busses)	Low (also green H2)	High / medium	Short-medium term	High / high		
5.4.2	Heavy-duty road transport	Fuel for vehicles (trucks)	Low (also green H2)	High / large	Medium	High / high		
5.5	Rail transport						10% land transport	Central (Nairobi), Coast (Mombasa), lesser: Western
5.5.1	Public rail transport	Fuel for vehicles (railcars)	Low (also green H2)	Medium-high / medium	Short-medium	Medium / medium		
5.5.2	Industrial rail transport	Fuel for vehicles (shunter and long-haul locomotives) as H2 or green methanol	pilots	Medium / medium	Long-term	Medium / medium		
5.6	Private road transport	Fuel for vehicles (cars), as H2 or green methanol	Low (also green H2)	Low / large	Short-term	High / high	10% land transport	All Kenya, mainly Central (Nairobi), Coast (Mombasa), Western

4.3 Global frame of green H2 today

This section provides a brief overview on the political frame and discussion, lists main countries and actors as well as exemplary initiatives, having a potential direct or indirect impact on green hydrogen in Kenya. For Kenya this global frame means a strong potential for funding and transfer of knowhow but also strong competition among countries and projects, e.g. if it comes to envisaged international trade of green hydrogen; in particular with countries closer to the future large scale demand such as EU and Japan and with established industries and infrastructure.

This short summary is also the basic for screening the potential for green hydrogen from Kenya within the future global trade. Since it is a very new and vibrant development this can only be a snapshot and should be completed in a separate exercise, updated continuously including the implications for Kenya.

4.3.1 Hydrogen strategies and policy priorities examples

Building a H2 national strategy is the starting point by defining the targets, addressing concrete policies and evaluating their consistency with existing energy policies. By mid-2021, more than 40 countries had published a hydrogen strategy or are developing one, in some supporting policies already formulated. These countries include Austria, Australia, Canada, Chile, France, Germany, Italy, Morocco, the Netherlands, Norway, Portugal, Spain, along with the European Union. Around 100 large scale projects are being planned worldwide to use H2 in industrial sectors.

In several countries and on EU level the policy priorities with regard to national and regional hydrogen strategies have been defined: A number of strategies aim at supporting the market development by setting ambitious growth targets for the production of green hydrogen and its derivatives.

- Germany's strategy for hydrogen "Nationale Wasserstoffstrategie" (BMWI 2020), includes a
  - EUR 350 million-strong funding framework under the German hydrogen strategy with a duration until 2024 to support hydrogen projects outside EU to ramp up hydrogen capacity, with individual grants of up to EUR 15 million for private sector projects and up to EUR 5 million for scientific / R&D projects.
- European Commission's Hydrogen Policy "A hydrogen strategy for a climate neutral Europe" (EU 2020).
- Various Arabic petroleum / gas exporting countries such Arabic Saudi Arabia with focus on Neom or Oman.
- In addition, there are private sector initiatives such as BASF / RWE or Porsche / Siemens and strategic partnerships e.g. between IRENA and Morocco.

Though geo-strategic considerations might also play a role, it is important to note that in the EU member states the main driver for the introduction of green hydrogen policies is the decarbonization of sectors such as industry and transportation where storing, moving or delivering renewable electricity will be facilitated by the energy carrier green hydrogen and its derivatives.

In many industrialized countries **the development of the green hydrogen market will therefore be policy-driven and not only determined by the production cost** of the green hydrogen products relative to its "grey" (based on the combustion of fossil fuels) equivalents.

Policy targets for electrolysis capacity or sector specific targets, for example, those defined in countries such as France, Sweden or Germany for the usage of e-fuels in the aviation industry will create a demand for green hydrogen independent of its current production costs. Regulatory changes might also lead to changes in carbon pricing in the EU which would have a significant impact on the competitiveness of green hydrogen products.

Within the EU most stakeholders share the view that it would be very challenging for EU countries to install large amounts of additional renewable electricity generation capacity which would be necessary in order to achieve the target of becoming climate neutral within the next decades. The German government foresees **a hydrogen demand of 110 TWh by 2030**. Electrolysers with a capacity of up to 5 GW are supposed to be built in Germany until 2030, which would result in a hydrogen production of approx. 14 TWh resulting in 13% of all hydrogen to be consumed being produced by means of renewable energy. In order to increase the share of green hydrogen the German government acknowledges that it needs to build partnerships with exporting countries and has allocated 2 billion Euro to develop such partnerships.

The policy-driven demand for green hydrogen and its derivatives would contribute to enable cost reductions in the production of green hydrogen through economies of scale. Countries investing early into the production of green hydrogen will be best positioned to profit from a growing demand as they will be building up the human resources and technological experience necessary for producing green hydrogen at competitive cost level.

Regarding the African continent the examples of current hydrogen sector developments in South Africa and Namibia are outlined:

- South Africa: The government considers hydrogen a key priority to achieve South Africa's decarbonization objectives. Currently the development of a national hydrogen road map is underway. The South African government's Department of Science and Innovation (DSI) recently conducted a study together with industrial partners -t he hydrogen valley road map, published in October 2021. The intention of that study is to complement the national strategy under development: Three hubs for green H2 have been identified for South Africa based on locations with potential for a high concentration of future hydrogen demand and the possibility to produce hydrogen (available infrastructure and RE energy resources) as well as socio-economic aspects. These hubs will host pilot projects contributing to the launch of the hydrogen economy. Identified pilot projects are in the mobility (mining trucks, busses), industrial (ammonia/chemicals) and buildings (fuel cell power) sectors. In the mobility sector, mining companies are already pursuing to deploy hydrogen mining trucks.
- Namibia: The government of Namibia is strongly focusing on export possibilities for hydrogen. A call for tender was launched and in November 2021, a preferred bidder was selected by the Government of Namibia for a USD 9.4 billion green hydrogen project. Namibia received nine bids from six developers for the two sites. The project aims to produce up to 300,000 tons per year of green hydrogen and green ammonia. The first phase is expected to enter production in 2026 of 2 GW of RE electricity generation for producing green H2 and green ammonia. Further expansion by 3 GW of electrolyser capacity is planned. Two separate but adjacent sites shall be developed, where it envisions massive desalination plants. The sites would also include wind and solar farms as well as electrolysers for the production of green hydrogen and ammonia for export. High wind speeds in Namibia mean that the generation of wind power is particularly profitable; and the solar power is characterized by very high solar irradiation due to the geographic location, with capacity factors of 25 to 30%.

4.3.2 Policy instrument example – H2Global

The H2 Global concept is currently being developed as a support system. Key elements are:

- auction-based promotion of a H2 market ramp-up;
- single buyer to conclude long-term purchase contracts and short-term resale contracts on the demand side; providing planning and investment security for GH2 investments
- aim is to stimulate a long-term market demand

- subsidizing the green H2 through the compensation of the difference between green H2 cost and current H2 market price (determined by grey H2 production cost)

Several countries are **designing support mechanisms in** order to achieve the objectives set out in their hydrogen strategies. H2Global is a concept proposal for the auction-based promotion of an H2 market ramp-up of green H2 and PtX products. It was developed with funding from the German Federal Ministry for Economic Affairs and Energy (BMWi). **The concept provides for the temporary 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 H2 and H2 derivatives. By indirectly subsidizing the price of green H2 for a limited period of time, the **aim is to stimulate a long-term market demand for emission-free hydrogen in Germany** in order to provide incentives for private investment in H2 production, transport and application infrastructure in Germany and abroad. The concept addresses in particular the foreseeable rapid increase in the need for imports to cover the demand for H2 and PtX derivatives in Germany.

In order to bring supply and demand together, an intermediary (Hydrogen Intermediary Company – HINT.CO) is to be set up, which will conclude long-term purchase contracts on the supply side and short-term resale contracts on the demand side. It temporarily balances the existing difference between supply and demand price for green H2 and PtX via a support mechanism based on the Contracts for Difference (CfD) approach. **Operator consortia and investors thus receive the necessary planning and investment security** for the construction of large-volume electrolysis capacities, as they can base their business and financing model on the long-term purchase contracts at cost-reflective prices.

4.3.3 Guarantees of origin and certification of green hydrogen

The certification of the "green" hydrogen and the proof of its origin will increase the acceptance and facilitate producing and trading of the product. The standard set for the certification of green hydrogen should e.g. guarantee the reduction in emissions compared to equivalent "grey" products.

A challenge will be to harmonize existing regional certification schemes or guarantees of origin (GoOs), such as the "CertifHy" project[14] in the EU, combining initiatives from other countries and regions in order to develop a solid framework for the international trade of green hydrogen products. The standards developed for the certification and the GoOs should consider the conditions in the different countries where green hydrogen markets might develop. The availability of data, electricity grid, electricity market design, etc., in the future hydrogen exporting countries or the importing countries generally differ considerably from one another. Currently there is no international approach for the certification of green hydrogen and its derivatives, but due to the increasing importance it is expected that initiatives for the harmonization of standards will be initiated in the short-term.

4.3.4 Additionality criteria

With regard to the reduction of greenhouse gas (GHG) emissions the term additionality is used. It means that a production project that results in the reduction of GHG would not have been realised without the buyer in the market with the aim of GHG reduction.

In particular, this term is adopted in regard to a clean energy project: Additionality is achieved by a project, when it has the effect of adding new renewable energy generation or also understood, if renewable energy is used for that project that otherwise would be curtailed.

14 For further detailed information see: www.certifhy.eu

The discussion about the exact definition of conditions and requirements for the additionality criteria requested by European countries is currently ongoing.

According to IRENA (2020)[15] for the principle of additionality, at least three elements should be followed: renewable electricity production and consumption should be **(1) additional, and with a (2) temporal and (3) geographical correlation.**

Examples of such measures are distinguished by their degree of compliance with that principle of additionality:

“**Recasting the renewable energy target and quotas.** The renewable electricity capacity targets or quotas can be either increased to account for electrolyser needs or they could exclude the electricity consumed by electrolysers. This ensures that additional renewables deployment takes place.

Allow (or impose) PPAs with merchant power plants. Grid-connected electrolysers could be asked to have PPAs with additional renewable energy power plants that are not receiving any other type of support. A methodology should be in place to ensure a temporal and geographical correlation between the electricity production unit and the electrolyser production

Measures to take advantage of otherwise curtailed energy. With high shares of VRE in the power mix, VRE curtailment may increase. Policy makers can promote electrolysers’ consumption of electricity that otherwise would have been curtailed. This can be done by prioritising the development of electrolysers in areas with grid congestion due to excessive VRE production. This measure alone may not justify the electrolyser’s installation, since the number of hours of curtailment are less than that needed to achieve the greatest reduction in the per-unit cost of investment.”

The scoring in the PESTEL analysis takes into account the usage of excess RE electricity in the system for H2 production as well as new RE capacities that need to be built for a project case; the bigger the resulting additional use of RE electricity the higher the score of a case.

4.4 Safety issues, risks and international standards and norms

This section summarizes critical issues with regard to safety of large-scale production and use of (green) H2. Most derivatives of H2 also pose individual risks. For instance, ammonia is a toxic flammable substance. Methanol poses a particular risk as the lethal dose and dose for blindness is very small and appearance is similar to common alcohol, the combination a considerable disadvantage if it comes to domestic use. However, these substances are not new to Kenya. Therefore, they are not addressed in detail but mentioned if it comes to the evaluation of use / site candidates with regard to the local environment and application.

4.4.1 Key risks associated with H2

H2 is a non-toxic gas. But there are certain risks associated with its production, storage, transport and use:

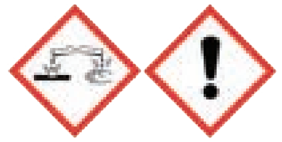
- **Diffusion:** H2 molecules are small and therefore they can easily penetrate into small gaps. As a result, leaks are more likely to occur than for other gases.

15 IRENA (2020), Green Hydrogen: A guide to policy making, International Renewable Energy Agency, Abu Dhabi

- **Flammability**: given its wide flammability range (4% -75%) and low ignition energy (0.02 mJ, lower than a static electricity discharge), the risk of H2 ignition is very high. The main consequence of a leak would therefore be a fire at the location of the leak. Due to the high risk of ignition there is a need for perfectly sealed electrical equipment in areas where hydrogen combined with oxygen-air may be present. A hydrogen flame has a relatively low radiation, which limits the risk of a domino effect by thermal radiation.
- **Explosion**: in a confined space, H2 accumulates rapidly. Ignition of a hydrogen cloud in an enclosed space or congested environment will result in an explosion. However, in an open space (for example outdoors), hydrogen will disperse quickly thanks to its high volatility and diffusivity, which reduces the risk of explosion.
- **Degradation of materials**: H2 has a negative impact on plasticity of certain materials, and a loss of ductility could be induced by hydrogen. This can lead to early loss of containment. All metals are potentially sensitive to this impact.
- **Human detection:** H2 is odourless and invisible to the human eye increasing the risk that leakages are not detected.
- **Noise**: a hydrogen leak will also generate a lot of noise when relaxing. For example, a leak of 4 mm at 200 bar produces a noise of 130 dB at about 1.5 meters.
- **Pneumatic explosion**: when a hydrogen-containing tank is heated up (e.g. by an external fire), the internal pressure of the tank increases under the effect of heat. If the internal pressure becomes greater than the burst pressure of the tank, a pneumatic explosion can occur. The sudden release of a high volume of H2 following the rupture can generate a short-lived fireball with a high potential radiation effect.
- **Asphyxiation:** although H2 is not toxic, a hydrogen-rich environment also means oxygen depletion which poses a risk for suffocation.

The following table displays the key risks of hydrogen, oxygen and the electrolyser material hydroxide.

Table 4-5: Risks of hydrogen, oxygen and the electrolyser material hydroxide

Product	Use in installation	Associated risks	
Hydrogen	Hydrogen is produced by electrolysis, compressed and stored. It is then transported by pipes or by trucks type tube trailers.	Extremely flammable and pressurized gas	
Oxygen	Oxygen is a co-product of water electrolysis. It can be recovered or released into the atmosphere.	Oxidizer and gas under pressure (according to electrolysis technology)	
Potash (potash hydroxide solution)	Potash is used in alkaline type electrolysers.	Corrosive and irritating	

4.4.2 International norms and standards

Below the main international standards are listed that relate to the design and engineering of facilities in the context of hydrogen.

Hydrogen Systems

- SAE J2600: Compressed Hydrogen Surface Vehicle Fueling Connection Device.
- SAE J2601: Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles.
- ISO/FDIS 17268: Gaseous Hydrogen land Vehicle refuelling connection Devices.
- ISO/TS 19880-1: Gaseous Hydrogen – Fuelling Stations – Part 1: General Requirements.
- FD ISO/TR 15916: Basic considerations for the safety of hydrogen systems. It identifies fundamentals questions regarding hazards and safety aspects associated with hydrogen systems.
- ISO 22734, Hydrogen Generators using Water Electrolysis Process.
- ISO 26142:2010 Hydrogen Detection Apparatus – Stationary Applications.
- IGC Doc 121/14 – Hydrogen Pipeline Systems.
- CGAG 5.5 Hydrogen Vent systems 2014 edition
- CGA G 5.4 – Standard for Hydrogen Piping Systems at Consumer Locations, 2012 Edition
- CGA H-5, Standards for Bulk Hydrogen Systems
- NFPA 55 – Compressed Gases and Cryogenic Fluids
- NFPA 2 – Hydrogen Technologies Code.
- NASA NSS 1740.16 – Safety Standard for hydrogen and hydrogen systems – Guidelines for Hydrogen System Design, Materials Selection, Operations, Storage, and Transportation.
- OSHA 1910.103, Hazardous Materials – Hydrogen.
- ASME B31.12, Hydrogen piping and Pipelines.

Further to the norms and standards directly related to hydrogen systems, several other areas are concerned, such as

- **Explosion Prevention and Protection** – NFPA 497, EN 1127-1, IEC 60079-10, IEC 61241-10, NFPA 68, NFPA 69
- **Machinery risks and safety** – EN 1050, EN ISO 12100, ISO 14122-1, ISO 14122-2, ISO 14122-3, ISO 14122-3, EN 60204-1, IEC 60073, IEC 60204-1, ISO 13849-1, EN 1050, EN ISO 12100, ISO 14122-1, ISO 14122-2, ISO 14122-3, ISO 14122-3, EN 60204-1, IEC 60073, IEC 60204-1, ISO 13849-1:2015,
- **Risk assessment** – IEC 61508, IEC 61511.IEC 61882
- **Electricity** – EN-IEC 61936, IEC 62305, EN 50272-2
- **Pressure equipment** – EN ISO 13455-3, EN 764-7:2002, ISO 4126-1, ISO 4126-2

- **Fire prevention and Protection** – ISO/IEC 17020, NFPA 1, NFPA 3, NFPA 10, NFPA 11, NFPA 11A, NFPA 11C, NFPA 17, NFPA 17A, NFPA 30, NFPA 30A, NFPA 56, NFPA 505, NFPA 850, NFPA 853,
- **Standards ASME (piping & boilers)** – ASME II, ASME VIII div 1, ASME B16.5, ASME B31.12, ASME B31.3

4.4.3 Hydrogen related standards and norms in Kenya

In Kenya, the main applicable standard is – *KS ISO 14687:1999 – Hydrogen fuel – Product specification*. The standard provides specifications for quality characteristics of hydrogen fuel in order to assure uniformity of the hydrogen product as produced and distributed for utilization 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 2003-05-30. Other applicable standards are:

i KS 2340-1:2011 Hydrogen – Specification Part 1: Industrial hydrogen/Gases

ii KS 2340-2:2011 Hydrogen – specification part 2: High purity hydrogen/Gases

Some of the currently applied international standards are:

i ISO 14687:2019 – Hydrogen fuel quality — Product specification

ii ISO/TR 15916:2015 – Basic considerations for the safety of hydrogen systems

iii ISO 19880:2020 – Gaseous hydrogen — Fuelling stations

iv ISO 19881:2018 – Gaseous hydrogen — Land vehicle fuel containers

v ISO 22734:2019 – Hydrogen generators using water electrolysis — Industrial, commercial, and residential applications

vi 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 the international standards in line with expected growing needs in production, transportation, handling, dispensing, safety and use of green hydrogen as an energy source.

4.4.4 Assessing and preventing the risks of hydrogen usage applications

There are proven concepts for risk management for industrial plants, construction sites, also linked to norms and standards, and general ESIA / SHE requirements.

The following is an exemplary list of general measures for risk prevention for an installation using H2

1. Limitation of ignition sources
2. Consideration of external influences in the design of the installation
3. Measures in case of loss of electricity
4. Access control and perimeter security
5. Control of process deviations

6 Presence of air during start-up / restart

7 Staff training

8 Operations and maintenance procedure

In the context of this study the assessment of specific risks is limited due to the multiple usages of hydrogen and situations and sites where it might be used in Kenya and the high-level scope of this study. For that reason, such assessment can only be done in a general and qualitative way to deliver an indication on the risk of a usage in comparison with others.

4.5 Research Development and Innovation and Education

R&D for green H2 is a cross cutting subject. Its focus is on process engineering and chemicals with detailed studies for particular processes in the heavy industry (chemistry etc.) and manufacturing / material science. But it needs to look into many other subjects including (renewable) energy and power system technologies, transport / infrastructure as well as related economics and policy topic.

The development of knowhow is usually served by i) academic sector (public and private) which also is the key provider of higher education for necessary staff and ii) private sector. The latter with own R&D departments / centres and projects or cooperation. Specialized companies are necessary (implementation and operation of green H2 facilities as well as R&D), e.g. in the field of certification, laboratories as well as other service companies for maintenance etc.

Kenya – compared to other countries in the region / Sub-Saharan Africa – shows a quite advanced stage in terms of R&D in various subjects, including engineering, economics etc. various international companies have chosen Kenya (mainly Nairobi) as a hub for Eastern Africa due to the strategic location but also the level of education. Various large local and regional companies exist. On the academics all relevant sciences are covered and laboratories etc. exist.

Below some examples are listed from academic and other sphere

- Strathmore University:
  - Offers a BSc. Electrical and Electronics Engineering and MSc. Sustainable Energy Transitions among other science-based courses.
  - Strathmore University has a unique place in the energy sector as they were the first grid-connected solar energy producer after the institution signed a PPA to feed electricity to the grid.
  - Strathmore University hosts the Strathmore Energy Research Centre (SERC) that offers training to renewable energy professions such as on Energy Management, Solar PV training (entry level to grid tie and hybrid systems).
  - Specifically, on Hydrogen and power generation, SERC in collaboration with Steamology are working on a Water to Water (W2W) system in energy generation and storage. The W2W system splits water into hydrogen and oxygen gases through electrolysis. The gases are compressed and stored in pressurized cylinders from where they can be combined later to produce steam to turn turbines to generate electricity. The steam is condensed as water and the process repeats. The system is modular, so larger storage is possible.

- Dedan Kimathi University of Science and Technology
  - Located in Nyeri County has a Research, Technology Management and Community Linkages Directorate that leads in coordinating research, publications, knowledge transfer among others.
  - The University hosts the Dedan Kimathi and Technology Park. Anchor clients at the Technology Park include the Semi-Conductor Technologies Limited (STL). STL and The University have a Public-Private Partnership where they have commissioned a Thin Films Nanotechnology Lab at the University, one of four advanced laboratories at the site. The other three are: Advanced Lithography Lab, Testing and Environmental Lab, and Back End of Line (BEOL) Final Manufacturing and Packaging Lab. The President of Kenya was a chief guest in the commissioning of the plant. There was a shortage of semi-conductors in the global market in 2020-2021. STL with Dedan Kimathi University have situated themselves perfectly to take advantage of the situation and export their products across the globe. Semi-conductors play also as role in electrolysis process.
- Jomo Kenyatta University of Agriculture and Technology (JKUAT)
  - JKUAT provides several research and engineering courses. The main campus is located in Juja, Kiambu County, with constituent campuses across the country.
  - JKUAT offers degree courses in Material science, energy engineering among others.
- Kenya Private Sector Alliance (KEPSA): KEPSA signed a Memorandum of Understanding (MoU) with Fortescue Future Industries (FFI), a wholly owned subsidiary of Australian iron ore company Fortescue Metals Group Limited (Fortescue). FFI is attempting to assess a proposed integrated large scale green hydrogen and green ammonia production facility, utilising renewable energy in Kenya. The MOU is to help facilitate its members participation in new large scale green energy projects in Kenya.
- Kenya Bureau of Standards (KEBS)
  - KEBS' main role is to promote standardization in industry and commerce, and to provide facilities for the testing and calibration of precision instruments to determine their accuracy, and issue certificates in that regard.
  - KEBS has a Research Function where it carries out surveys to determine the status and trends of quality practices in Kenya and assesses the impact of its services to industry while identifying the needs of industry with respect to quality matters.
- Kenya Petroleum Refineries Limited (KPRL)
  - The KPRL has is a refinery complex with distillation, hydrotreating, catalytic reforming, and bitumen production units.
  - The KPRL laboratory offers services to certify or verify if a particular oil product meets the stipulated standards and a certificate is issued on the same.
- Kenya Industrial Research and Development Institute (KIRDI)
  - KIRDI is a national research institution located in Nairobi and mandated to undertake multidisciplinary research and development in industrial and allied technologies including; Mechanical Engineering, Energy and Power Resources, Leather Technologies, Textile Technology, Industrial Chemistry Environment, Chemical Engineering, Electrical Engineering, Food Technology, Ceramics and Clay Technologies, Information Communication & Technology (ICT) and Mining[4].

- KIRDI has a Laboratory Services Centre (LSC) whose mission is to enhance quality and productivity in local industries and support Micro, Small and Medium Enterprises (MSMEs). KIRDI's strength lies in the testing and analysis of water, wastewater, food, animal feeds, chemicals, leather, textiles, minerals and related materials

- In the past 10 years research and education for RE subjects were introduced in numerous projects and organisations (e.g. solar PV and productive uses of energy industries). This may offer a basis and lessons learnt to build up green H2 related RD&I

5 ENERGY LANDSCAPE KENYA

This section describes the energy landscape Kenya and the East African region for green H2, which is a summary of the main frame conditions for the future production of green H2 based on RE:

- **Key challenging and facilitating factors** with regard to demand and supply of electricity;
- Quantitative **analysis of potentially available electricity and respective costs for green H2 production from possible scale up of RE supply** (wind, PV, geothermal, hydro/import) on top of the planned power system (LCPDP), including consideration of current and future excess energy, mainly from geothermal, as well as potential demand flexibility of H2 generation;
- Qualitative **analysis of water availability and requirements** as one main further input for green H2;
- **Policy frame** with focus on RE.

5.1 Key challenging and facilitating factors for future green H2

Key challenging and facilitating factors of the energy landscape as relevant for future green H2 / PtX application can be summarized as follows:

1 **Towards 100% green electricity**: Most relevant for this study, Kenya is an almost unique position with above 90% RE based electricity generation already today based on a very diversified mixed (including future expansion capacities) which – and there it differs largely from many other high RE share country low risk seasonality and climate risk due to the high share of dispatchable geothermal energy.[16]

16 It should be noted that geothermal fields can be also exhausted if too much steam is extracted. This is of particular importance for Olkaria field

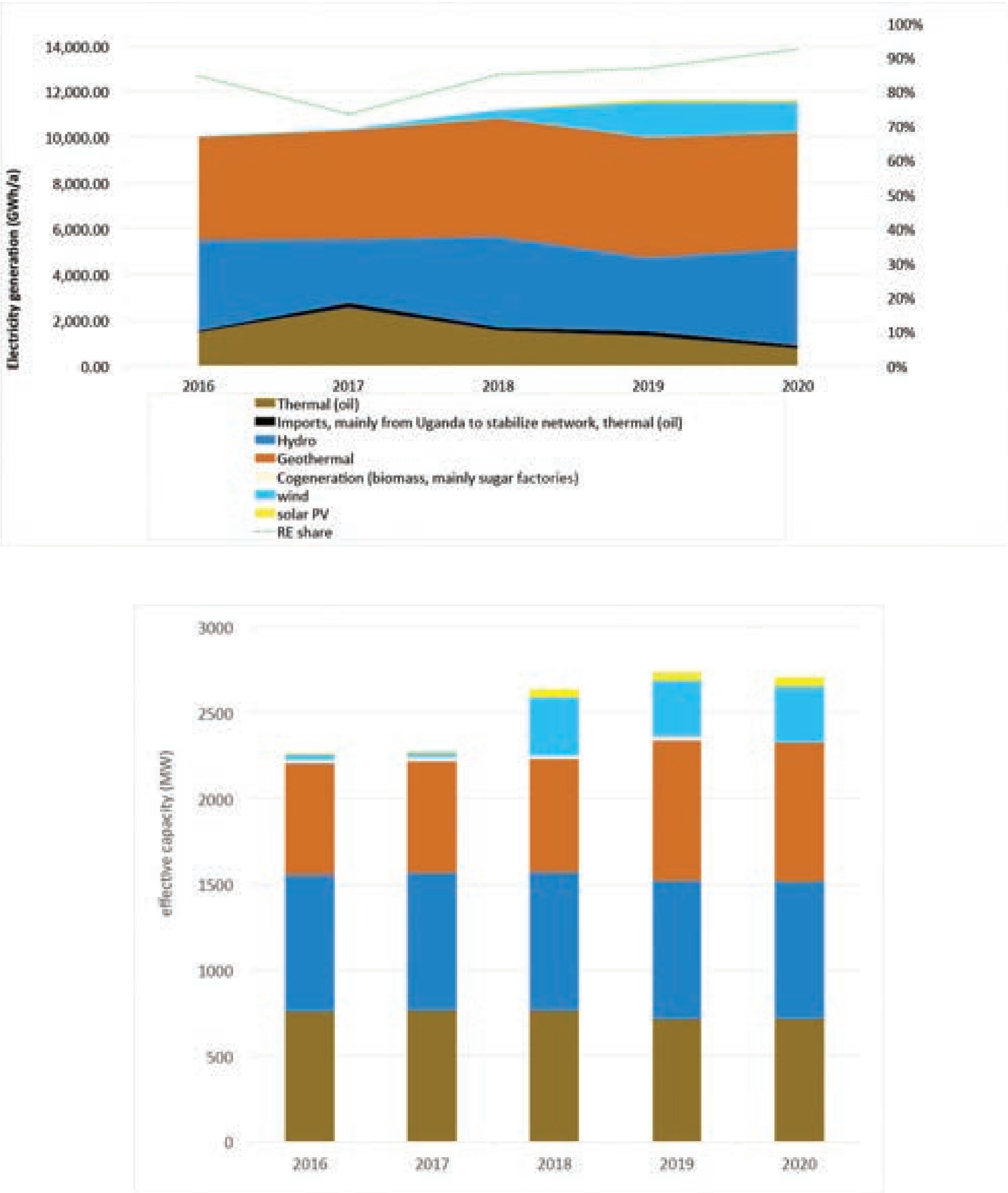


Figure 5-1: Annual power generation and capacity by source (2016 to 2020)

2 Excess energy: currently some 10% of total available geothermal energy (i.e. some 400 GWh of some 4,000 GWh per year) or 4% of total system demand is currently not used because available geothermal capacity exceeds actual demand in the night and other (non-dispatchable) RE plants operate on a take or pay agreement. In 2020/21, this energy has been available continuously nearly every day/night (only during 6% of the days/nights the energy was below 10% of the average surplus). On weekends the surplus increases by some 50 to 90% above weekday surplus. This excess is expected to decrease with growing demand but to increase with every new geothermal plant as well as further take or pay plants (e.g. the 400 MW base load import from Ethiopia). Despite this, geothermal energy is still least cost for the Kenyan power system and respective excess energy is forecasted in the LCPDP of Kenya and the adapted reference scenario of this study in the long term and may increase fivefold in the medium term and up to tenfold in the long term (if no more flexible geothermal technology is applied and if no above average increase of base load demand can be achieved; considered rather unlikely). This excess energy may facilitate alternative technologies like green H2 production but also battery energy storage systems. However, any utilisation has to consider i) its fluctuation throughout the day and week (due to demand fluctuation), ii) medium to long term upwards and downwards trends as well as ownership of this energy (mostly KenGen).

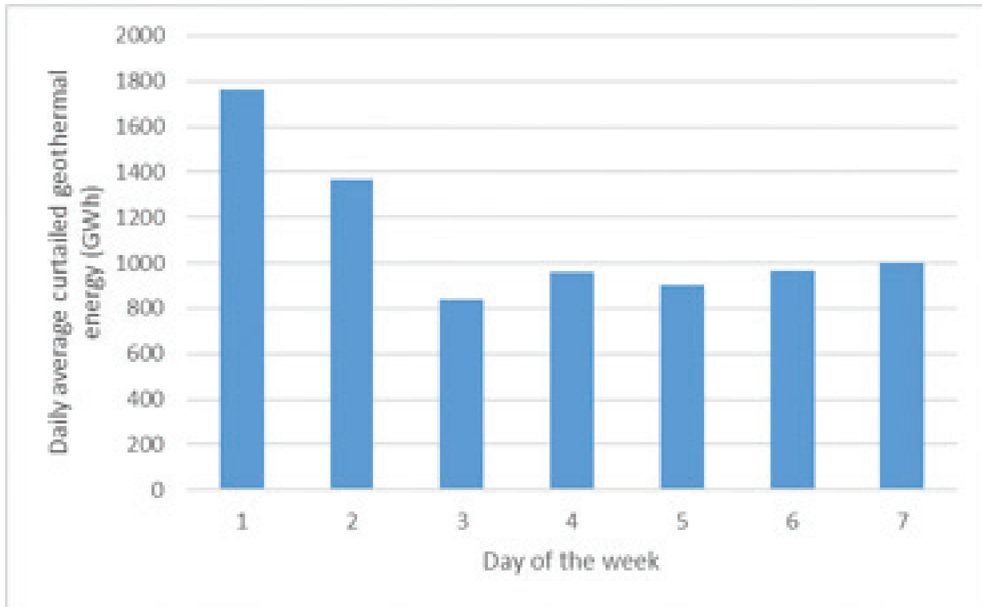
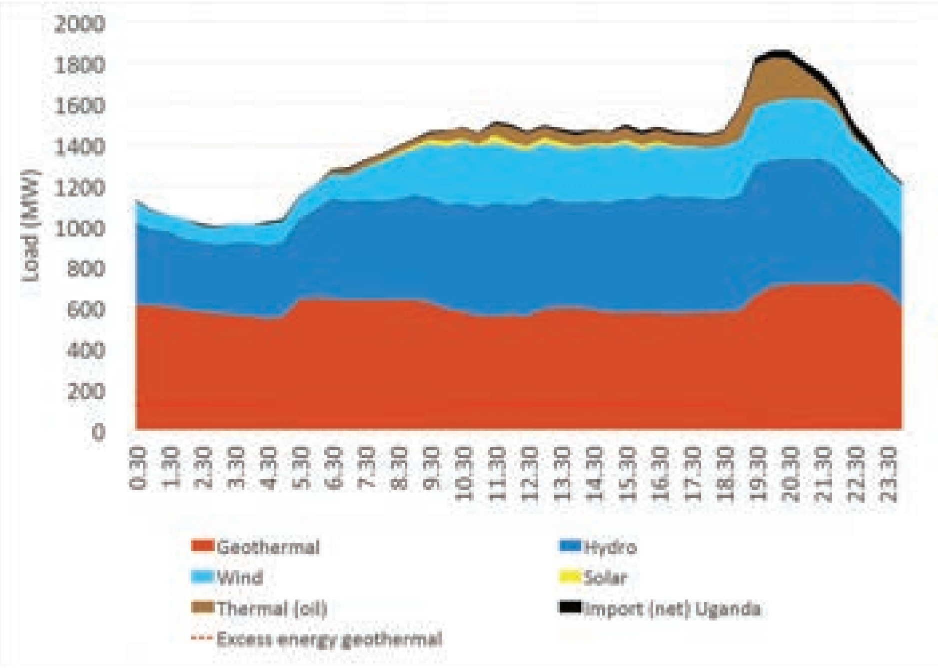


Figure 5-2 Average daily curtailed (excess) geothermal energy 2020/21

3 **Demand for electricity in Kenya** is quite predictable: no considerable seasonal variations, demand curve with low demand in then night (below geothermal must run capacity), quite straight shoulder demand throughout the day and distinctive evening peak (+20% of daytime demand) between 6pm and 9pm, mainly peak 7pm to 8pm only. This is the main challenge for the RE-only power dispatch as RE peaking capacity is limited. The first figure with exemplary load curves shows that the described load curve characteristic is more distinctive for western and central regions while the coastal load curve is relatively straight due to the base load from the harbour area and the AC induced higher daytime load. The second figure shows the dispatch for peaking with fossil fuelled gensets and import as well as hydropower and geothermal (which on that day was curtailed throughout the day except for the evening peak)



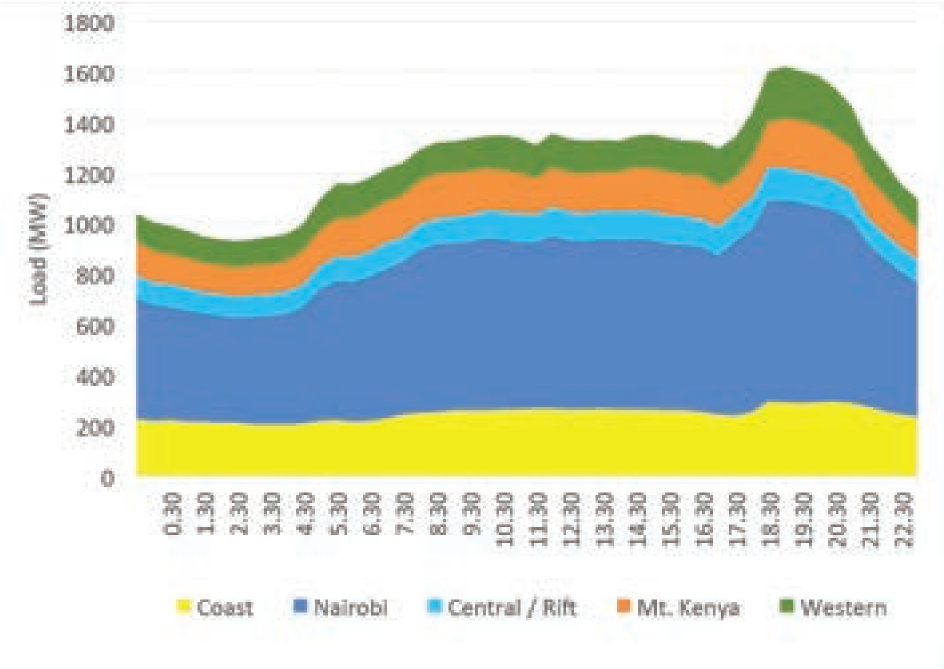


Figure 5-3: Exemplary dispatch by source

Demand has been growing at around 5.5% in pre-Covid19 years (slightly below the low demand scenario of the Master Plan 2016). The reference demand scenario foresees 4% average growth in the medium term (also due to Covid19) and 5 to 6% in the long term up 2030/40. Despite ambitious government visions and flagship projects, there is no basis to assume further increase of demand growth beyond this reference path, rather lower demand growth with continuous installation of PV plants at consumers' sites. Losses remain very high, loss reduction plans are not met. This however relates mostly to the distribution system, not relevant for green H2. Base load demand from the largest consumers does only grow marginally. The 20 largest consumers

of electricity contribute some 20% of total commercial / industrial consumption. By far the largest is cement (more than 50%), 25% mining and equal share food and steel within some 12% (or 2% of total industrial and commercial consumption). Green H2 as a potential to support demand growth and balance the load curve.

4 **Regional potential for RE – and hence competition – is high**, with the two "heavy weights" with highest RE shares and surpluses: i) Ethiopia with 100% RE share in electricity generation (most from some 4,000 MW of hydropower, growing) and ii) Uganda with 98% (most from some 1,000 MW of hydropower, growing). Other countries offer a lesser completive rate of RE exploitation: Tanzania 35%, Rwanda 54%[17], Somalia 5%, South Sudan around 0% and DR Congo 99%[18]. Interconnections have been reinforced in recent years, enabling cooperation. Kenya's key advantages – compared to Ethiopia and Uganda – are i) the more diversified RE mix with less reliability on hydropower and by this being less exposed to climate change ii) the current surplus of RE based electricity but also iii) its central location within the region and power network with strategic access to the sea (crucial for regional trade and supply of most goods), this advantage expands also to some basic economic activities and availability of services which could be useful for the development of green H2. However, in the regional market for green H2 and related derivates Ethiopia and Uganda may likely become strong competitors as they are active in other economic sectors already.

5 **High RE share of primary energy consumption of 85%** due to the predominant use of biomass (wood and charcoal) for cooking (some 68% of total energy), which – despite being RE – is having negative environmental and social impact like deforestation and respiratory diseases. Only some 9% of cooking energy comes from cleaner but carbon emitting LPG and a small share from (mostly renewable) electricity. All fossil energy sources (some 14% of total energy demand and equal to about 70% of electricity generation) are imported, mainly i) petroleum products (5.2 million tons pre-Covid19) for land mobility (private and public; about 70% of all petroleum energy or 4 million tons) ii) aviation (some 13% or 0.7 million tons) and industrial use including power generation (some 12% or 0.6 million tons) ii) LPG for residential and industrial uses (some 5% of fossil energy) iii) coal/coke (some 12% of fossil energy). Kenya has plenty of fossil and renewable domestic primary energy sources available with only RE sources developed to commercial stage. Challenges of a sustainable future energy sector is the future supply for transport and cooking.

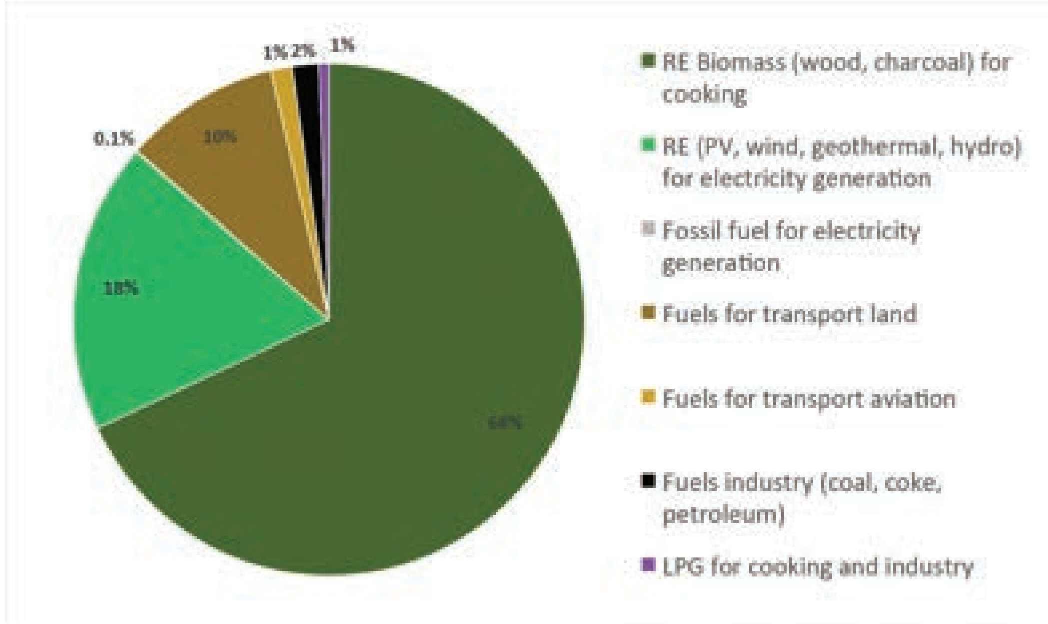


Figure 5-5: Energy balance Kenya

17 IRENA, *Renewable energy statistics 2021*

18 Suffering from high biomass consumption and low network capacities

6 **There is no relevant infrastructure** which may facilitate future (ramping up) large scale production, processing, transport and export of green H2 or derivatives.

a Natural gas (H2 can be mixed to a certain percentage into natural gas infrastructure depending on material and end use): There is no gas infrastructure. A gas pipeline which would supply gas from Tanzania is under discussion; however, it is on a very early political stage and relevant information (e.g. connection of Nairobi AND/OR Mombasa) still have to be analysed and fixed. Hence, any implementation (if at all) is in the far future and not relevant for ramping up green H2. If implemented, it may be a competition in to green H2 in some sectors.

b Petroleum products (H2 is of relevance for refining): all petroleum products are imported. Export of crude has been stopped. A former refinery stopped operation many years ago (technically outdated) and is only used as storage site. It is however a potential site to build up green H2 related infrastructure. In the past there was domestic hydrogen production through electrolysis in combination with the refinery. There is no other large scale H2 related industry to base any green H2 development on but only small scale uses of imported products.

c Transport of commodities by three ways: i) mainly by road with standard trucks, ii) by the new standard gauge railway (SGR) from Mombasa via Nairobi to Naivasha (to be expanded to Kisumu and Uganda), iii) old railway line (initially connecting Mombasa via Nairobi with Uganda) which urgently needs rehabilitation to remain available. Whether transport of H2 and e.g. ammonia are possible by railway needs to be assessed. In any case security standards have to be (further) developed.

7 **Basic commodities for industrial production** and other uses are imported, mainly through the Mombasa port. Commodities relevant for this study are: hydrogen (16 to 30 tons/year, no growth trend), ammonia (anhydrous 60 to 100 tons/year, no growth trend; in hydrous solutions 100 to 250 tons/year, growing), methanol (4,500 to 6,600 tons/year, slight upwards trend), LPG (0.32 million tons/year, strong growth) as well as nitrogen content fertilizer. A large part of the commodities is further exported to neighbouring countries underlying Kenya's importance as a trade hub in region but on a very small scale, except basic petroleum products including LPG

Concluding, the key challenging and facilitating factors of energy landscape Kenya for future green H2 provide good opportunities with regard to (proven) RE supply, strategic location within the region also with regard to energy, huge potential to replace energy imports by domestic production but also strong competition in the region and no relevant infrastructure to build on except for the former (down-graded) refinery as well as some experience with import and distribution of commodities (large scale for petroleum products but small scale for H2 and derivatives.

5.2 Green H2 supply and costs through RE supply analysis

Based on the optimisation with LIPS-XP (methodology as described in section 3.2) the following additional capacities have been found optimal to supply the increased load for the Green H2 electrolysis and associated ancillary loads (such as Haber-Bosch process) (in addition to the reference expansion path) based on exclusively renewable resources:

	Difference in Installed Capacity [MW]															
Technology	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Geothermal	0	0	0	30	-65	-5	-105	-205	-375	-440	-10	160	430	365	85	285
Natural gas	0	0	0	0	0	0	0	0	0	0	-375	-375	-750	-750	-750	-750
Import	0	0	0	0	0	300	300	300	300	300	600	600	600	1,100	1,100	1,100
Wind	100	200	200	200	200	200	200	400	600	850	950	1,050	1,150	1,150	1,750	1,750
PV	0	0	0	0	0	50	100	150	200	250	300	350	400	450	500	550
Gas turbines (LNG)	0	-200	0	0	0	0	0	0	0	0	0	-280	-280	-280	-280	0
TOTAL	100	0	200	230	135	545	495	645	725	960	1,465	1,505	1,550	2,035	2,405	2,935

Regarding imports, 300 MW in 2030 and another 300 MW of flexible imports as well as 500 MW baseload imports in 2038 have been found optimal.

Energy mix

Based on the optimisation, in the short-term (2025-2030) the new green H2 load will be supplied by geothermal power (incl. formerly excess generation) for approximately one half (45%) and by wind power for the other half (52%). 2% of green H2 demand will be covered are based on imports and another 1% by PV.

Throughout the study period, in the long term (2025-2040), again, roughly one half (48%) will be supplied by wind power. One quarter (25%) of the green H2 electricity demand can be sourced from geothermal power which in the reference scenario would have been in excess. Another 21% will be supplied by imports, 5% by PV and only 1% by additional geothermal power plants. Nota bene: The figures given represent net figures for the total period. Through the temporary delay of geothermal power additions (due to heavy wind power additions, see above) they will contribute less in the period 2030-2035 but more afterwards. E.g. in 2040, the share of geothermal power supply for the green H2 electricity demand is around 15%.

The following figures shows the electricity mix for the periods 2025-2030 and 2025-2040.

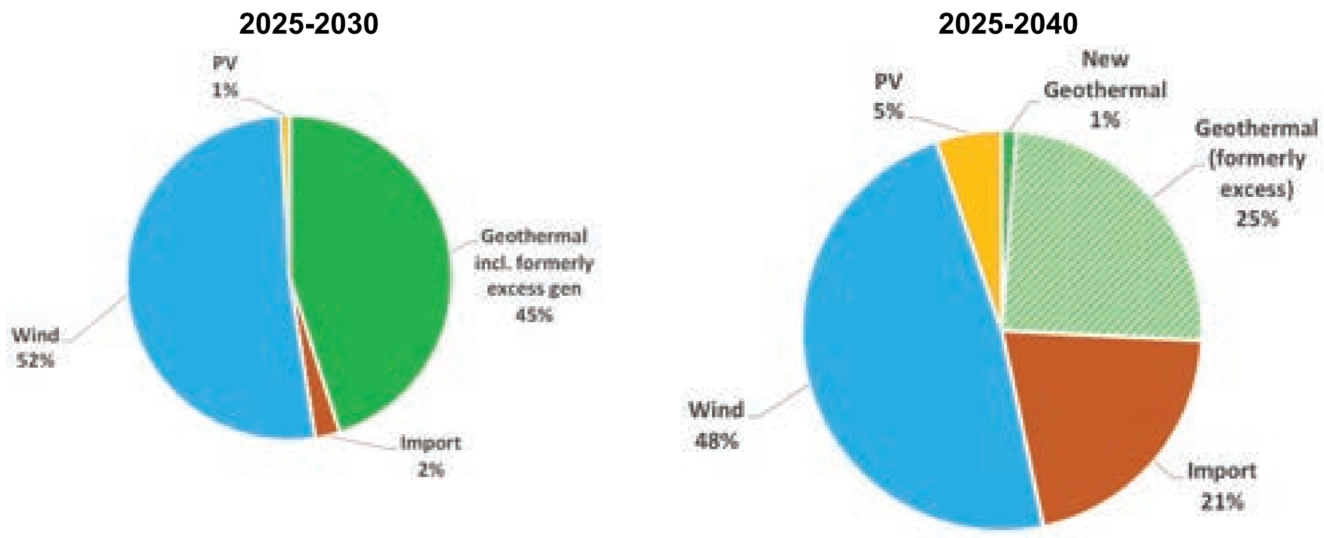


Figure 5-6: Electricity mix for Green H2 production

Usage of Excess Generation[19]

For the production of the green H2 43.9% of total excess electricity generation in the period 2025-2040 can be used. The usage of excess generation steadily increases from 2025 on until 2034, in which around 70% can be used. With the excess generation generally getting smaller, also its usage is declining in the years after 2034. The following graph shows the annual evolution of excess usage.

19 For the purpose of the study the notion "excess generation" is considered as the sum of generation in excess (based on technical and/or commercial must-run capacities) and the "vented geothermal steam production" as both types of generation are not used and can possibly be made use for the supply of the green H2 electricity demand.

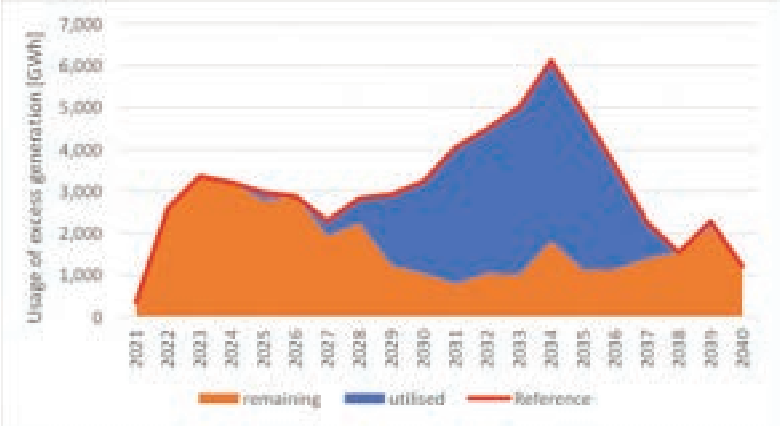


Figure 5-7: Usage of "excess" generation

Green H2 demand electricity supply costs

In the beginning years of the planned green H2 activities (2025-2028), they will be mainly powered by wind power, which brings the specific costs to a level of approximately 40-50 USD/MWh. Already here, some parts of the electricity demand can be powered by geothermal generation, which – without the green H2 demand – would be in excess.

In the period 2029-2034, the most essential part of the green H2 triggered electricity demand is sourced from geothermal power which in the reference case would be excess. This generation is theoretically for free, as it is anyways there. For this reason, the specific costs of supply for the green H2 electricity demand go down to levels of 10-20 USD/MWh. If the usage of excess power should be financially compensated, then the specific cost will be in the range of up to 40 USD/MWh depending on the level of compensation tariff. For the rest of the study a compensation at a range of 10-20 USD/MWh has been assumed to estimate the feasibility of the industrial pathways.

In the period 2035-2040, less excess power can be used and thus the specific costs go up again to a level of 40-50 USD/MWh. It has to be mentioned, that the specific costs in the beginning rise only because the considered H2 demand is quite high in those years. If the green H2 demand picks up less fast, then here, less wind power is needed and it can be supplied to a larger extent by excess generation. This means, that then also the specific costs would be essentially lower, comparable to those in the period 2029-2034. The following graph (right) shows the evolution of the annual specific green H2 electricity demand supply costs for the period of the carried-out expansion planning. The table (left) gives the average specific supply costs in 5-year intervals. The costs for the years after 2040 are considered to be 50 USD/MWh.

Specific electricity costs [USD/MWh]					
		2025	2030	2035	2040
without compensation		40.9	18.5	25.3	47.2
with compen-sation	5 USD/MWh	41.8	21.2	27.0	47.2
	10 USD/MWh	42.7	24.5	29.2	47.3
	20 USD/MWh	44.6	31.2	33.6	47.3
	30 USD/MWh	46.5	37.8	37.9	47.3
	40 USD/MWh	48.4	44.5	42.3	47.4

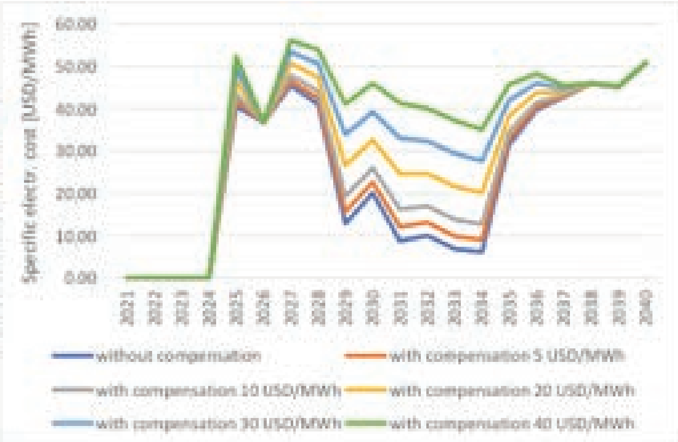


Figure 5-8: Evolution of average electricity supply costs for powering the green H2 demand

It has to be noted that the above costs are average costs of RE supply for aggregated green H2 production (and related derivatives/products) but do not have to represent actual costs (tariffs) for particular projects or investors. These may of course be higher or lower depending on project specific agreements. Further, due to the immediately available excess energy there is a "window of opportunity" for lower costs at the beginning for smaller scale applications if part or all of this energy can be used (which also depends on compensation).

5.3 Cost estimate outlook for green H2 and ammonia

Below production costs for green H2 and ammonia in Kenya are provided. They are rough estimates according to best possible assumptions based on the power generation system analysis of the previous section and consultant internal cost data base. They may vary when projects are implemented as they strongly depend on frame conditions such as technological innovations, learning curves and regulatory environment.

Table 5-1: Cost estimate outlook for green H2 and ammonia (assumption: plant in that year)[20]

Cost item	Scenario	Unit	2025	2030	2040	2050
Green H2	Base (likely) incl. compensation 1 USDc/kWh	USD(2020)/ kg H2	3.90 (RE share: 60%)	2.50 (RE share: 54%)	3.30 (RE share: 77%)	3.40 (RE share: 80%)
	Base (likely) incl. compensation 2 USDc/kWh	USD(2020)/ kg H2	4.00	2.80	3.30	3.40
	Lower range incl. compensation 1 USDc/kWh	USD(2020)/ kg H2	3.50	2.20	3.20	3.30
	Higher range incl. compensation 1 USDc/kWh	USD(2020)/ kg H2	4.00	2.60	3.40	3.40
Network costs (indication of cost increase for green H2 production at listed sites)	Olkaria	% (increase)	Vicinity/central to most generation sources, losses below average, cost increase for transmission 5 to 6%			
	Western Kenya	% (increase)	Distance to most generation sources, losses above average, cost increase for transmission 7% (medium) to 6% (long term)			
	Nairobi	% (increase)	Vicinity/central to most generation sources, losses below average, cost increase for transmission 5% (medium) to 6% (long term)			
	Mombasa	% (increase)	Far distance to most generation sources, losses above average, cost increase for transmission 7% (medium) to 6% (long term)			
	Lamu	% (increase)	Far distance to most generation sources, losses above average, cost increase for transmission 9%			

20 As stated in section 3.2, the electrolysis process is considered with a load factor of 70% to accommodate its system absorption. Consequently needed H2 buffer storage facilities have been priced in at specific costs of 1,400 USD/kg H2 to be stored. Due to the maturity of this technology, no cost decreases are considered here. Besides, CAPEX for electrolysis equipment of between 960 (larger scale) and 1,540 USD/kW (smaller scale) in 2025 have been assumed to decrease down to between 150 and 240 USD/kW until 2050. The efficiency of the electrolysis process is considered at 67%. Fixed operational costs of the mentioned technologies as well investment & operational costs for water desalination & demineralisation equipment have been considered at market standard costs. Costs for the Haber-Bosch (with Air separation unit) have been considered between 184-564 USD/ktpd for the various cases.

Cost item	Scenario	Unit	2025	2030	2040	2050
Ammonia	Base (likely)	USD(2020)/ kg NH3	830	570	730	740
	Lower range	USD(2020)/ kg NH3	720	470	660	670
	Higher range	USD(2020)/ kg NH3	890	620	760	770

For the ammonia production in large scale (lower price range), equipment costs are already mature. For this reason, no cost degression is expected here. The changes in LCOA here stem mainly from the differences in the cost of the required hydrogen (LCOH). The market for smaller ammonia production plants (higher price range) is still new, which is the reason, why here learning effects are also considered for the equipment.

5.4 Water needs, costs and restrictions

The most relevant information and assumptions for water for green H2 in Kenya are summarized below:

- In general, **water is technically and economically less critical compared to other parameters of green H2** (e.g. RE electricity supply requirements and H2 storage / transport issues). For water as input for green H2 there are clear technical requirements and solutions with a relatively low cost share between 1% and 5% of costs of green H2.
- However, **locally and temporally water supply can be an issue for green H2 in Kenya** due to i) climate induced water supply shortages as some 90% of Kenya is classified as semi-arid or arid lands (ASAL, i.e. 6 to 12 months evaporation exceeds precipitation) as shown in the graphic ii) strong seasonality iii) expected deterioration of the situation from climate change with more frequent and severe drought and flood events iv) competing water needs from local population and established private sector. For instance, although Nairobi is located in a non-ASAL area and gets water from outside dams, there is a supply shortage due to the size and growth of population, industry and commerce.
- **Electrolysis for H2 requires on average 14 litres of water per kg H2**. For a 50 MW electrolyser (common project size) this could be in the range of 300 to 400 m³ per day. For comparison, this is less than 0.1% of daily production for Nairobi and less than 1% of daily water abstraction by commercial farms from lake Naivasha. The water is however "lost" and not fed back to the water system, similar to the virtual water export of through cut-flowers (the water loss of such an electrolysis plant would equal about 1% of the water loss through export of flowers from Naivasha basin).

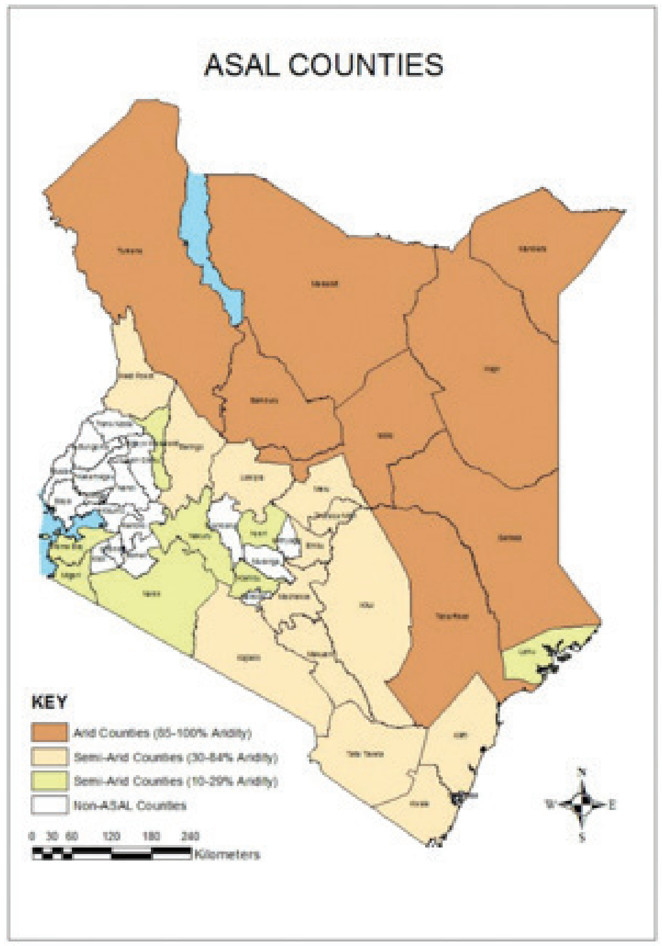


Figure 5-9: Arid and semi-arid lands, Kenya (www.asals.go.ke)

- The **electrolysis requires the supply of purified, deionized process water**. The water quality requirements are comparable to boiler feed water used in steam generators of thermal power plants. Water needs depend on the water quality.
- **Supply sources** for electrolysis may vary. As standard for electrolysis plants, tap water is supplied from an industrial or municipal water network and is further purified inside the electrolysis plant using reverse osmosis and electro-deionization units to provide the required process water quality. More treatment is required for surface water (e.g. from local water bodies). If neither tap water network nor surface water is not or not sufficiently available due to for instance remote plant sites without existing infrastructure or in regions with water scarcity, then additional water supply can be provided through sea water or brackish water desalination plants. The cost of water desalination from medium or large-scale seawater reverse osmosis plants is today in the range of USD 1 per m³ of desalinated water, for small scale plants this can exceed USD 2 to 3. Considering the small share on the total cost related to the water supply on the production cost of hydrogen the impact on the total cost because of additional water desalination is expected to be small. However, the use of seawater desalination plant needs to be considered in the site selection process for future electrolysis plants. Naturally, seawater desalination plants need to be located in coastal areas with direct access to the sea. Considering the cost of water transport short distances between an electrolysis plant and seawater desalination facilities can be (cost-wise) justified by the installation of direct supply pipelines or bulk transport per road truck. This restricts the use of seawater to potential areas around the coastal sites of Mombasa and Lamu. In Olkaria or other geothermal areas the extraction of water from steam is possible, though it has to be analysed whether technical effort and impact on geothermal resources is feasible and recommendable, in particular if a reduced reinjection reduces the finite underground water resources. Alternatively, storage facilities (e.g. dams or basins) may allow to use the surplus of flood seasons in some areas in Kenya. They are technically feasible for the above specified demand (e.g. from flood protection or wastewater treatment). This must however be part of an overall water management plan of the area (considering population and other users, such as agriculture and commerce) and does not solve the loss of water if green H2 or derivatives are exported from the region.
- **To considering the above, for this study the following is done**
  - A **water related differentiation is done in the evaluation of the different potential sites** / site candidates (in terms of a general categorization of the water supply situation and competing water needs) under "environmental" of the PESTEL analysis.
  - **Higher water costs in the range of USD 3 to 4 per m³ are assumed** for any site, not differentiating between provision of water from desalination plants or inland water. This margin could facilitate a more sustainable water use in the respective area. This could include desalination in coastal areas including surplus desalination capacity to supply tap water for municipal network, thus reducing existing water stress and providing social benefit. For inland areas this could include storage and flood protection infrastructure to level water supply fluctuations, including a potential surplus to the local community.
  - A general recommendation is provided to thoroughly **assess the impact on water supply for any green H2 project** and to require overall water management plans and systems for the area considering all water users to mitigate water stress for the area and the project in particular. This should go beyond the legal requirements[21] for water permits, abstraction and royalties which of course have to be assessed and

21 The Water Act (2016) provides the overall frame, transferring considerable power to county level. Other legal entities are the Water Resources Authority (WRA) and the National Drought Management Authority.

observed for each individual project. By this not only the social and environmental sustainability of the project will be improved but also its economic sustainability by reducing the risk of resistance from local communities as it is not uncommon in Kenya.

5.5 Renewable Energy policy issues in Kenya

Policy development for the integration of renewable energy sources in Kenya have developed over the last years. A Feed-in-tariff system for RE has been in place since 2008.

RE policy for the power sector has been updated by the Ministry of Energy recently in 2021 by means of

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

Both policies apply in parallel setting the frame for RE power procurement. FIT is applicable for installations up to 20 MW while REAP applies to RE power projects greater than this threshold of 20 MW.

The FIT establishes a pre-determined tariff for a defined period; hence the off-take of electricity is guaranteed to the producer of RE electricity for such term. The total contracted capacity additions to the system by RE generation projects according FIT shall not exceed 10% of total system-wide generation capacity. At that moment the policy makers will conduct a review.

The objectives of the FIT are: (i) The facilitation of mobilization of resource by providing investment security and market stability for investors in electricity generation from renewable energy sources. (ii) the reduction of transaction and administrative costs and delays associated with the conventional procurement processes; (iii) to encourage private investors to operate their power plants prudently and efficiently and (iv) to encourage local investors to participate in power generation.

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 MoE on the appropriate timing and for targeted capacity. Geothermal projects will be procured not within these schemes, but according to the Policy on Licensing of Geothermal Greenfields.

The objective of the REAP is the procurement of RE electricity at competitive prices and in line with the LCPDP and the INEP.

Possible impact on H2 sector development: The consultant does not expect any competition for RE generation sources between the projects eligible under the RE procurement policies (FIT and REAP) on the one hand and a green H2 sector on the other hand. In Kenya there are plenty of RE opportunities including wide areas for wind power and solar PV projects.

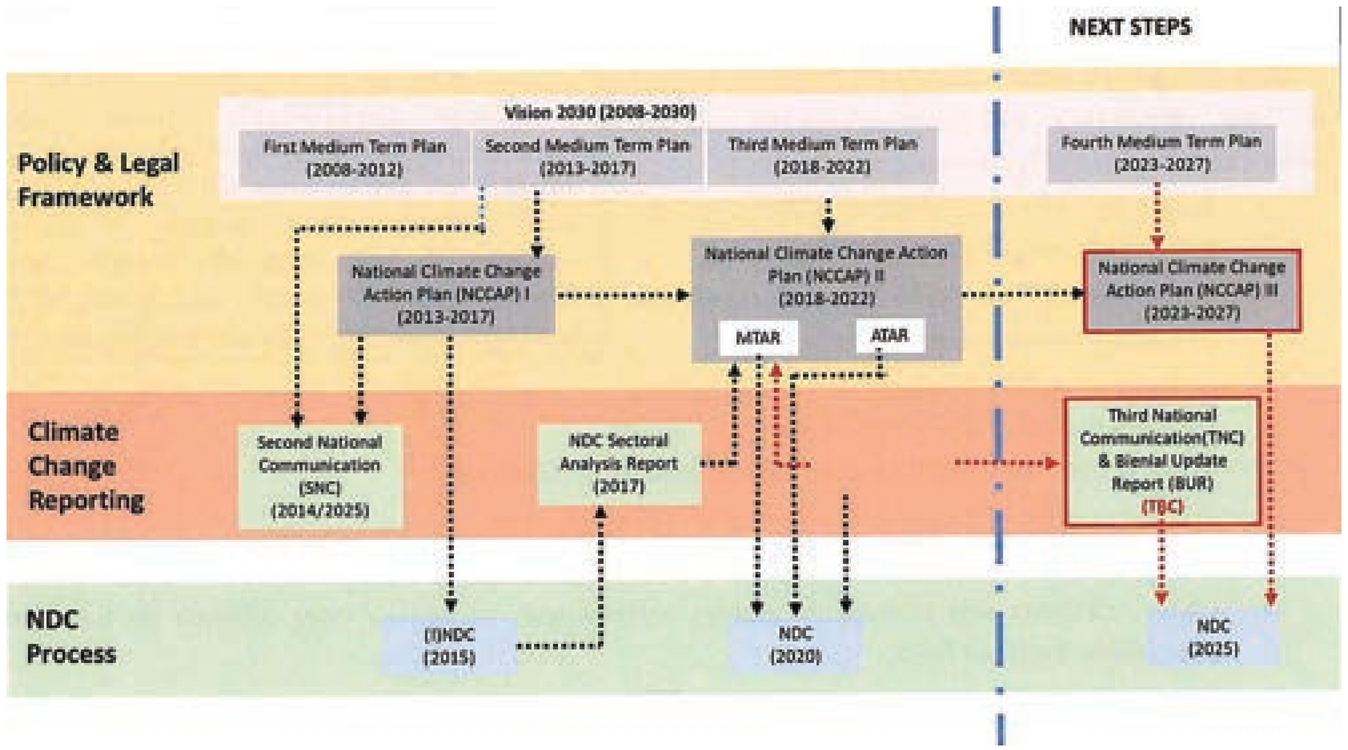
The existence of the RE policies and related regulation is estimated rather to be a positive factor for the future green H2 development, because a regulatory framework for RE projects is existing and it is developing further.

5.6 Abatement of Greenhouse Gases in Kenya

Kenya’s history in engaging in climate change mitigation is listed below, becoming party to the Paris Agreement as the recent important milestone. This requires also the definition of Nationally Determined Contributions (NDC), i.e. the intention of efforts to reduce national emissions and to adapt to the impacts of climate change.

- Ratification of Kyoto Protocol 25 Feb 2005
- Submission of INDC 23 Jul 2015
- Signature of Paris Agreement 22 Apr 2016
- Approval of Ratification of PA 13 Oct 2016
- Ratification of PA 28 Oct 2016
- Transformation of INDC to NDC 28 Dec 2016
- Effectiveness of PA 27 Jan 2017
- Submission of updated NDC 24 Dec 2020

The evolution from the policy and legal framework to the targets in the form of NDCs – for the past, present and future – are presented in the following figure:[22]



Source: Kenya’s Updated NDC

Figure 5-10: Document Review for NDC Update

22 Source: Ministry of Environment and Forestry, 24/12/2020, Kenya’s Updated Nationally Determined Contribution (NDC)

Being vulnerable to climate change, the Government of Kenya has implemented climate-related regulatory framework consisting of laws, policies and plans (see list of milestones below) as response to climate change. **It is noted that none of them mentions green hydrogen or Power to X**. It will be required that the according framework will be harmonised with the implementation and applicability of green H2/PtX in due time. In this context, it is noted that a Climate Change Long-Term Strategy and a Green Incentives Policy[23] is under development during the preparation of the present report expected to consider carefully green H2/PtX.

- National Climate Change Response Strategy (NCCRS) 2010
- (First) National Climate Change Action Plan (NCCAP) 2013-2017 2013
- National Adaptation Plan (NAP) 2015-2030 2015
- Climate Change Act[24] 2016
- Kenya's Intended Nationally Determined Contribution (NDC) 2015
- Kenya's Nationally Determined Contribution (NDC) 2016
- Kenya Climate Smart Agriculture Strategy (2017-2026) 2017
- National Climate Change Policy 2018
- National Climate Finance Policy 2018
- (Second) National Climate Change Action Plan (NCCAP) 2018-2022 2018
  (incl. Adaptation Technical Analysis Report and Mitigation Technical Analysis Report)
- Kenya's Updated Nationally Determined Contribution (NDC) 2020

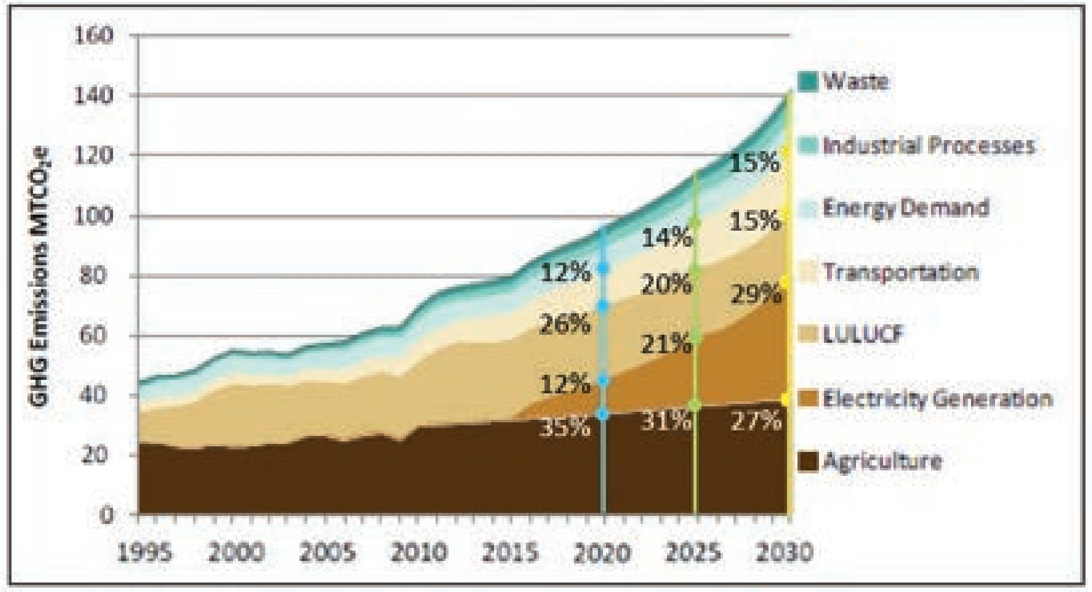
In its latest submitted updated NDC, Kenya commits to abate 32% of its BAU GHG emissions by 2030[25], with additional milestones in 2025 at total estimated cost of USD 62 bn (of which 13% are committed to be covered domestically and 87% will be required from international support). Based on Figure 5-11, the sectors agriculture, electricity generation, LULUCF and transportation contribute to the highest GHG emission shares (From 2020 on: growing shares for electricity generation[26] and transport; decreasing shares for agriculture and LULUCF). In its capacity as low GHG emitter, Kenya prioritises adaptation to the effects of climate change. However, Figure 5-12 shows a low carbon pathway with a GHG emissions abatement potential of GHG, demonstrating the highest potential for GHG emissions mitigation in the forestry sector. 50% of this potential was considered as INDC (i.e. 30% GHG reduction) and adjusted to a total of 32% (Updated NDC).

23 Key aspects of these documents could not be disclosed during the preparation of the present report.

24 Constituting main legislation for guiding the country's climate change response, being managed by the National Climate Change Council whereas the Climate Change Directorate (CCD) is in charge of technical aspects as the NCCC's secretary.

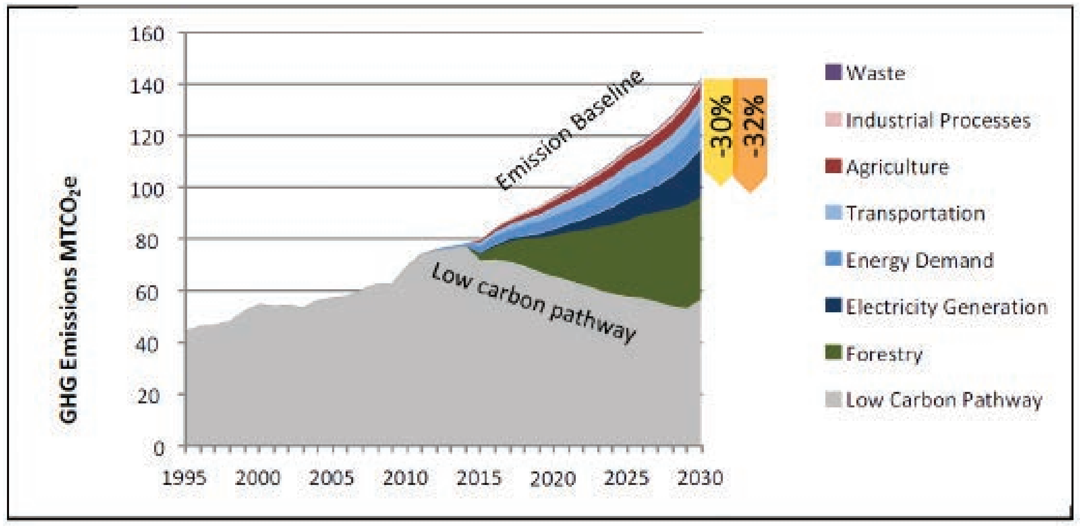
25 The business-as-usual (BAU) greenhouse gas (GHG) emissions were based on Kenya's Vision 2030 development targets and would amount to 143 MtCO2e in 2030 if pursuing the BAU development.

26 Actual development and latest LCPDP indicate a much lower fossil fuel-based generation and respective GHG emissions. Though official obligations remain the same, in reality this likely reduces the expectations on the actual development.



Source: Second National Communication + Consultant's derivations

Figure 5-11: BAU GHG Emissions Development



Source: Second National Communication

Figure 5-12: GHG Emissions Abatement Potential

GHG emission reductions from green H2/PtX are expected to accrue in the following sectors / applications:

- Local production of fertiliser, incl. by-products ammonia, H2 to other industrial processes
  (Sector: Agriculture / Industrial Processes)
  - Use of green hydrogen instead of grey hydrogen
  - Avoidance of transport emissions for import
  - Reduction of transport emissions for import of Kenyan fertiliser to riparian countries

- Use of green H2 as fuel for transportation (Sector: Transportation)
  - Use of low-emitting combustion technology
  - Use of green hydrogen vs. grey hydrogen
  - Use of locally generated fuel vs. imports
- Use of green H2 in the steel production (Sector: Industrial Processes)
  - Use of green hydrogen vs. coke
  - Use of locally generated hydrogen

Whereas however some of the actions resulting from the PtX/green H2 may not result in national abatement of GHG emissions, they result however in the reduction of global GHG emissions, as for instance locally produced fertiliser vs. imported fertiliser. A certain share of non-domestic emission reductions (and thus no contribution to NDCs) is in general the case when imported goods are replaced by products of the PtX/green H2 project opportunity. Both aspects however are expected to attract funding dedicated to GHG mitigation measures.

As one of the actions after implementation, it should be monitored that a facilitated access to fertilizer – due to local availability – will not result in a more excessive and thus increased GHG emissions therefrom.

Due to a lack of reliable cost for CO_2, no consideration is foreseen in this context – given also the related efforts to quantify potential emission reductions for the green H2 potential compared to the BAU sources. Assuming however cost applied to grey hydrogen, they will enhance the acceleration of cost competitiveness of green hydrogen. The challenge to quantify potential emission reductions affects also a classification of the potential green H2/PtX project opportunities regarding their leverage from climate change mitigation. Therefore, the opportunities are classified based on the Consultant's perception in the PESTEL analysis.

6 PTX OPPORTUNITIES

This section provides the assessment results on sectors and sites for potential future supply and demand for green hydrogen, the actual baseline study (long list) and reducing it to a short list.

6.1 Site and industry identification (= long list)

This is based on the overview of potential uses of section 4.2 Potential uses of green H2 combined with potential sites / areas in Kenya.

6.1.1 Agriculture, fertilizer production (ammonia)

Fertilizer production candidates are differentiated by

- Fertilizer production only
- Fertilizer production plus H2/ammonia and other derivatives to industry (see 6.1.2.1)
- Fertilizer production plus (as above) and additional benefit (reduction harming substances)

Green H2 Use Candidate	**1.1 Fertilizer production (ammonia) plus additional uses/benefits** Sector: **Agriculture/manufacture**	
Potential sites	Olkaria, Mombasa, Nairobi, Lamu / LAPPSET, 7-Forks dam area / Thika, Western Kenya	
Relevance of sector for green H2		
■ Fertilizer production is seen as one of the key sectors where today large volumes of (grey) H2 are used to derive nitrogen fertilizers, mainly through the intermediate product of ammonia ■ Fertilizers with nitrogen content are the dominant products worldwide with continuous growth trends expected to continue in future; nitrogen is one of the three primary nutrients for plant growth and the one plants demand the most e.g. for photosynthesis and protein production and growth. Hence, it is essential to for food production / nutrition and often the limiting factor in agriculture ■ Globally, the fertilizer industry is responsible for about 1.1% of annual carbon emissions due to using fossil energy as feedstock (mainly natural gas). There is need to curb the enormous carbon emissions by replacing the grey hydrogen used with green hydrogen through the electrolysis process. ■ At the same time overall demand from African countries is low compared to other regions.		
Current use of H2 (grey): **HIGH** (highest share of grey H2 demand)	Future green H2 use: **HIGH probability / LARGE volumes**	Time horizon: **MEDIUM TERM**
Sector relevance in Kenya		
■ Agriculture is by far the largest sector in terms of GDP share but also in terms of providing employment and food (as subsistence to individual farmers / families but also the overall population). Fertilizer do play a crucial role to sustain this role. However, distribution and use of fertilizer is far from optimal due to transport/distribution failures, quality, lack of knowhow (farmers and suppliers). ■ Majority of fertilizer in Kenya is imported from Europe, USA, South Africa and North Africa. (AFO) ■ Fertilizer regulations in Kenya are under the mandate of the Ministry of Agriculture, Livestock, and Fisheries (MoALF), Kenya Plant Health Inspectorate Service (KEPHIS), and Kenya Bureau of Standards (KEBS)		

Green H2 Use Candidate	1.1 Fertilizer production (ammonia) plus additional uses/benefits Sector: **Agriculture/manufacture**

- Industry is mainly driven by the private sector, which imports most of the fertilizers:
  - Major fertilizer importers include; Yara East Africa, Mea Ltd, Export Trading Ltd, Kenya Tea Development Agency (KTDA), Turbo Highways, Louis Dreyfus Commodities Ltd, Elgon Kenya Ltd, Devji Meghji Bros Ltd, Athi River Mining (ARM)etc.
  - Fertilizer blending is mainly done by MEA Ltd and Athi River Mining (ARM) company with a blending capacity of up to 100,000 MT and 30,000 MT of fertilizer per year respectively. Other major blending fertilizer companies include; Toyota Tsusho Fertilizer Africa and Export Trading Company Limited
  - Fertilizer and Soil Amendments Committee of Kenya Bureau of Standards (KEBS) develop standards for fertilizers in use in Kenya and includes representatives from the fertilizer industry, the Ministry of Agriculture, universities, KARLO, KEPHIS and the Government Chemist
  - Private fertilizer analysis labs include: SGS LABS (K), GMP/ACCL LABS, INTERTEK, MEA Ltd Nakuru.
- Fertilizer distribution systems:
  - Commodity-based interlinked input-credit-output marketing systems – Smallholder farmers given credit in form of physical farm inputs purchased in bulk by supporting agency that also distributes the fertilizer.
  - Network of private, independent importers, wholesalers, and retailers operating on a demand and supply basis
  - Government procurement of fertilizer, distribution and sale of fertilizer to targeted needy farmers at subsidized prices under the fertilizer price stabilization plan
- Fertilizer sector growth perspective / recent additions
  - Construction of Kes 3 billion NPK Compound Granulation plant in Nakuru; supply 100,000 tonnes of fertilizer, serve up to 2 million farmers annually, uses latest steam granulation technology.
  - Construction of a $1.2 billion (Sh123 billion) fertiliser plant in Uasin Gishu by Toyota Tsusho; plant will cut the cost of fertiliser by about 40 per cent.
  - Plan for a renewable energy-to-fertilizer plant at Oserian Development's industrial park at Naivasha; to be located near the country's largest geothermal energy basin, planned to be partly powered by solar energy sources produced on-site. The project is expected to reduce dependency of imported nitrogen fertilizers and substitute around 25%, of which the total accounts for around 800 kt/a.
- Fertilizer subsidy summary - two main fertilizer subsidy programs:
  - NAAIAP (National Accelerated Agricultural Inputs Access Program)- The GoK through agriculture ministry initiated the NAAIAP program to address low productivity. It concentrated on giving subsidies in form of inputs to farmers to boost their output levels, meet household food security and possibly generate surplus for the household income. Target beneficiaries; Farmers unable to afford farm inputs at commercial prices; Farmers growing maize/rice and had at least 2.5 acres of land; Farmers who had not received similar support in the past; Implemented through vouchers redeemable at private agro-dealers; Reached 537,218 farmers
  - National/general subsidy- Government procures and distributes fertilizer at subsidized prices to farmers across the country through NCPB

Beyond domestic fertilizer production there are additional uses/benefits possible

1. Fertilizer production plus H2/ammonia and other derivatives to industry (see 6.1.2.1)
2. Fertilizer production plus (as above) and additional benefit (reduction harming substances)

- In addition to the production of green H2 from electrolysis there is the potential for extraction and use of H2 from H2S and H2 as non-condensable gases of flue gases from Olkaria geothermal plants, currently released in atmosphere with strong environmental impact (H2S)
- Volume of these gases is small compared to e.g. volume needed for industrial scale fertilizer production. Therefore, only feasible if combined with other production of H2 (green H2 from electrolysis)

Ministry of Energy, Kenya, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH Complete Study Report

Green H2 Use Candidate	1.1 Fertilizer production (ammonia) plus additional uses/benefits Sector: **Agriculture/manufacture**

- External benefit of reducing environmental harm may justify process but very likely need to be compensate (e.g. preferential financing)
- Possibly, to be combined with extraction and use of CO2 as potential feedstock for methanol production (see 6.1.2.2)
- This option is of high relevance in Kenya due to large scale of current and future use of geothermal resources which for most sites and technologies continuously cause harmful gases (mainly H2S), currently released into atmosphere with strong negative environmental and social impact
- It may improve "standard" green H2 / fertilizer production overall benefit/cost ratio, if non-monetary benefits of reduced negative impacts are included (reduction of immediate negative impact and improvement of geothermal energy as environmental friendly energy)
- Current use of non-condensable gases: released into atmosphere; gas treatment consisting of various stages: H2S extraction technically possible through membrane technology (similar as with natural gas); CO2 extraction by monoethanolamine stripping; H2 extraction

Sector: **Manufacture**	Sub-sector: **all manufacturing**	Relevance of green H2: **HIGH**
Kenya: Exists, **HIGH** relevance (GDP share 8%)	Kenya: **Exists, HIGH relevance**	CO2 effect: **LOW**
	HIGH relevance of use (various)	Growth perspective: **MEDIUM to HIGH**

Key facts and volume estimates

- Kenya fertilizer consumption:
  - As of 2018, total fertilizer import was 0.63 million tons, consumption was 0.55 million tons, and export was 0.08 million tons and no production.
  - Over 95% of the fertilizers are used for crop production (5% for fodder and pasture production).
  - As of 2016, top fertilizer-consuming crops included Maize (290,507 MT), Tea (98,984 MT), Wheat (29,621). Top fertilizers consumed include; Di-Ammonium phosphate (DAP), Urea, CAN, NPK, Calcium Nitrate, Ammonium Sulphate.
  - Average growth of fertilizer consumption 2010 to 2019 was 5%
  - Nitrogen content of all fertilizers is estimated 25% of weight
- Regional fertilizer consumption (Uganda 4% share, Rwanda 4% share, Tanzania 26% share, Ethiopia 66% share): 1.6 million tons with average annual growth of 8%
- Potential green H2 need: 10,000 tons H2 per year (for 25% of Kenyan market, 1% of regional market in 2025) plus 60 GWh per year for ammonia synthesis etc., 30,000 – 40,000 tons H2 per year (for 60% of Kenyan market, 6% of regional market in 2030), , 90,000 – 100,000 tons H2 per year (for 100% of Kenyan market, 16% of regional market in 2040),
- Strong demand growth expected based on the historic demand growth of 5% (Kenya) to 8% (region).
- Use of (grey) H2: (abroad)
- Water need: 300 to 400 m3 per day for initial production in 2025

Key players (stakeholders, companies) in sector:

- Listed above

Green H2 Use Candidate	1.1 Fertilizer production (ammonia) plus additional uses/benefits Sector: **Agriculture/manufacture**
PESTEL	Rank: **6** (Mombasa) (out of 46); Obstacles: **SOME**; Enablers: **VERY HIGH**

	Olkaria fertilizer only	**Olkaria fertilizer plus** (additional use)	**Olkaria fertilizer plus and additional benefits**	**Mombasa fertilizer plus**	Lamu fertilizer plus	7-Forks fertilizer plus	Nairobi fertilizer plus	Western Kenya fertilizer plus	**All Candidates:** Min.	Av.	Max.	- 2 = insufficient, - 1 = sufficient (but rather negative) 0 = satisfactory (neutral), + 1 = good, + 2 = very good **Gap analysis**
Rank **Force**	14	17	11	6	38	20	21	41				
Political	**1.6**	**1.6**	**1.7**	**1.6**	**1.6**	**1.6**	**1.6**	**1.5**	0.4	1.1	1.8	No/little
Economic	**1.2**	**1.5**	**1.5**	**1.3**	**0.1**	**1.2**	**1.4**	**1.0**	-0.6	0.4	1.5	Market access
Social	-0.5	-0.5	0.5	-0.3	**-0.5**	**-0.5**	**-0.3**	**-0.5**	-0.5	-0.1	0.5	No/little but establishing standards/norms for large volume harmful substances
Technical	0.9	0.5	-0.4	0.5	-0.2	0.5	0.5	0.2	-0.8	0.2	1.2	Downscaling
Environment	**-1.2**	**-1.2**	**-0.2**	**0.8**	**0.0**	**-0.5**	**-1.2**	**-1.5**	-1.5	0.3	1.8	No/little
Legal	**0.5**	**0.3**	**0.0**	**0.7**	**0.7**	**-0.3**	**-0.3**	**-0.3**	-0.3	0.6	1.4	No/little

Conclusion and recommendation

- The combined sector of agriculture and fertilizer production is the most relevant for green H2 in Kenya as it could be competitive considering import / transport costs, foreign exchange and other supply risks as well as subsidies in the sector and additional benefits (e.g. for food security and potential to improve quality and adapt products to local needs, job creation, additional supply of commodities such as hydrogen and ammonia to other manufacturing sectors)
- However, it is a small market for normal industrial size production and needs downscaling of fertilizer production processes which increases the specific costs. Even a small size plant would rely on a large share of the domestic market, which is served by established production, trade, blending and distribution streams where the income of various stakeholders will be affected by such a new plant. Widening the market by export in particular to neighbouring countries could be an additional benefit but may also come at offtake risks. Therefore, such plant has to be set up in close cooperation with existing network for fertilizer distribution from government, non-government / farmer organisations, laboratories. A secure investment environment is needed which may include functioning regulations for the currently not optimal fertilizer market and subsidies.
- For the location various areas could be feasible (the best site depending on a site selection / feasibility study outcome): Olkaria and Nairobi as central areas to distribute products within the country and region, Mombasa close to import facilities of necessary supplements and with existing distribution network for the country and the region.
- Various Environmental concerns have to be addressed, large scale ammonia production and handling, water needs and the fertilizer production process of nitric acid which could be harmful for the climate. Additional, benefits from reducing harmful substances from geothermal plants may increase the potential funding options but these come with technical challenges.

Green H2 Use Candidate	1.1 Fertilizer production (ammonia) plus additional uses/benefits Sector: **Agriculture/manufacture**

- There are certain obstacles with regard to the implementation in Kenya: environmental concerns ("new" harmful commodity ammonia, wrong / over use of fertilizers) may not be sufficiently addressed, the established and subsidized but still malfunctioning fertilizer market with established distribution processes with corruption likely immanent may try to avoid new products even if more beneficial, distribution problems to reach the remote consumers in need of the products, necessary supply of electricity at reliable tariffs at risks, etc.
- Recommendations
  - The implementation requires a market study including market regulations / subsidies, feasibility study to decide about site, size, products etc.

6.1.2 Manufacture

6.1.2.1 Light industry / commodities (use of chemical products H2, ammonia, etc. to supply regional industries)

Green H2 Use Candidate	**2.1 Light industry / commodities** (use of chemical products H2, ammonia, etc. to supply regional industries) Sector: **Manufacture** Sub-sector: **Light industry**
Potential sites	Olkaria, Mombasa Nairobi, Lamu / LAPPSET, 7-Forks dam area / Thika, Western Kenya

Relevance of sector for green H2

- Hydrogen is one important feedstock for refining / petrochemical and overall heavy chemical industry, mostly produced from fossil fuels. It is the basis for many derivatives with equal importance in chemical industry and many manufacturing processes as well as pharmaceutical uses. These are for instance ammonia, syngas or methanol (see 6.1.2.2) or more complex products such as urea or hydrogen peroxide.
- As alternatives are limited / non-existent for many chemical processes this sector is expected to be one of the main future consumers of green H2 with various (pilot) projects started or in planning. In addition, there is a strong impact of the substitution of grey hydrogen by green hydrogen in relation to the limited effort of implementation.

Current use of H2 (grey): **HIGH**	Future green H2 use: **HIGH probability / LARGE volumes** (aggregated, each special use may be small)	Time horizon: **MEDIUM** to **LONG TERM**

Sector relevance in Kenya

- Kenya imports basic chemical products including hydrogen and its derivatives (small volumes of hydrogen and methanol, larger volumes of ammonia (in various forms) and hydrogen peroxide. In addition, LPG is an important product which is used as energy source but also chemical product.
- Kenya offers a wide range of manufacturing processes which due the above listed products and may make additional use of them if domestic supply with higher volumes and lower prices could be realized.
- For example, Associated Battery Manufacturers (ABM), one of the main battery manufacturers in Kenya, which manufactures solar batteries and automotive batteries currently uses Liquid Petroleum Gas (LPG) to bond lead terminals. Previously, this process was done using hydrogen gas because it did not introduce any impurities to the bonding area. The high cost of hydrogen forced ABM to switch to the more affordable alternative, LPG. Affordable green hydrogen would find ready use in this sector as it will provide a clean and uncontaminated means for hot-bonding.
- Various other manufacturing processes in Kenya (as listed in Table 4-4) would require or may benefit from hydrogen or derivatives such as food processing, material processing. Other processes not common in Kenya such as flat glass production (so serve the growing construction industry) may be (only) possible if hydrogen is available on the local market.
- In addition, Kenya would be strategically well positioned to become a regional hub for distribution of green H2 and derivatives as it is already re-exporting these products to neighbouring countries.

Green H2 Use Candidate	**2.1 Light industry / commodities** (use of chemical products H2, ammonia, etc. to supply regional industries) Sector: **Manufacture** Sub-sector: **Light industry**

- Mombasa as the import hub together with the site of the former refinery could be well positioned for such distribution as would Nairobi be as a central location with considerable manufacturing activities

Sector: **Manufacture** Kenya: Exists, **HIGH** relevance (GDP share 8%)	Sub-sector: **all manufacturing** Kenya: **Exists, HIGH relevance** **HIGH** relevance of use (various)	Relevance of green H2: **HIGH** CO2 effect: **LOW** Growth perspective: **MEDIUM to HIGH**

Key facts and volume estimates

- Potential green H2 need: currently small e.g. some 25 tons of imported (grey) H2, 4000 – to 7,000 tons of methanol and 100 tons of ammonia (in various forms) would result in potential production of 1,500 to 2,000 tons of H2 per year (some 15 MW electrolyser capacity plus electricity needs for CO2 extraction / methanol synthesis and ammonia synthesis). Assuming a competitive price of domestically produced commodities (compared to the high price import, except for relatively low priced methanol) a considerable growth of demand can be expected, also if supply by domestic production is more secure and price fluctuations are lower. This may induce further economies of scale respective impact for new or ramped up manufacturing processes (volumes difficult to estimate)
- Strong demand growth expected due to continuous growth of ammonia demand in the past and expected growth due to local availability
- Use of (grey) H2: (abroad for H2, methanol, ammonia production)
- Water need: 60 m3 per day

Key players (stakeholders, companies) in sector:

- Kenya Petroleum Refineries Limited
- BOC and other importers

PESTEL	Rank: **1** (out of 46); Obstacles: **LOW** ; Enablers : **VERY HIGH**							
	Olkaria	Mombasa	Nairobi	Lamu / LAPPSET	7-Forks dam area / Thika with lower hydropower costs	Western Kenya (Kisumu/Eldoret)	**All Candidates:** Min. Av. Max.	- 2 = insufficient, - 1 = sufficient (but rather negative) 0 = satisfactory (neutral), + 1 = good, + 2 = very good **Gap analysis**
Rank Force	8	1	3	24	7	28		
Political	**0.9**	**0.9**	**0.9**	**0.7**	**0.7**	**0.7**	0.4 1.1 1.8	No/little
Economic	**1.3**	**1.3**	**1.5**	**0.3**	**1.2**	**0.8**	-0.6 0.4 1.5	No/little, market assessment necessary
Social	0.2	0.2	0.2	0.2	0.2	**0.2**	-0.5 -0.1 0.5	No/little but establishing standards/norms
Technical	**0.8**	**1.2**	**1.2**	**0.2**	**1.0**	**0.5**	-0.8 0.2 1.2	No/little
Environment	-0.7	**1.3**	**-0.2**	**0.5**	**0.0**	**-1.0**	-1.5 0.3 1.8	No/little (in particular if site in Mombasa or established sites in Nairobi are used)
Legal	**0.7**	**0.7**	**0.7**	**0.7**	**0.2**	**0.2**	-0.3 0.6 1.4	No/little (see environment)
Conclusion and recommendation								

Green H2 Use Candidate	**2.1 Light industry / commodities** (use of chemical products H2, ammonia, etc. to supply regional industries) Sector: **Manufacture** Sub-sector: **Light industry**

- Smaller scale green production of H2 and derivatives could be already competitive today/ in near future (e.g. until 2025), also to build up know how
- There are certain obstacles with regard to the implementation in Kenya: market with established distribution processes with corruption possibly trying to avoid new products even if more beneficial, necessary supply of electricity at reliable tariffs at risks, necessary know-how and standards (and respective laboratories / certification) for sufficient quality of products, etc.
- Recommendations
  - Detailed market assessment with companies of existing and potential new manufacturing processes / uses of green H2 / derivatives to be conducted
  - Strong domestic and international partners (with existing distribution systems, laboratories)
  - Combination with other uses, e.g. fertilizer production as this process may likely already provide 3 to 4 chemical commodities

6.1.2.2 Light industry / methanol (power to liquid)

Green H2 Use Candidate	**2.1 / 3.5 / 4.5 / 5.5 Light industry / methanol (power to liquid)** Sector: **Manufacture** Sub-sector: **Chemical and chemical products**
Potential sites	Olkaria, Western Kenya, Mombasa
Relevance of sector for green H2	

- Methanol can be used as fuel for a wide range of uses: as the basis for chemical processes, as fuel supplement or substitute of gas oil for transport such as maritime or road transport or for residential cooking (though not common), as an energy carrier which is relatively easy to transport and store and by this also as a fuel in fuel cells
- Methanol (currently produced from grey H2) production with green H2 requires external supply of CO2 of CO2 which is technically more sophisticated but also geographically restricted to sites with non-fossil fuel based CO2 emitters.

Current use of H2 (grey): **HIGH**	Future green H2 use: **HIGH probability / LARGE volumes**	Time horizon: **MEDIUM TERM**
Sector relevance in Kenya		

- Kenya imports some 4,000 to 7,000 tons of methanol annually at relatively low specific costs of USD/kg 0.5. Further, there are many sectors with potential demand for methanol, e.g. cooking fuel (replacing LPG but at certain health risks), fuel cells (off grid), fuel supplement
- Production of methanol from green H2 – though sophisticated – should be possible in Kenya but needs supply of CO2 which could be biomass (bagasse or biogas) plants, geothermal plants (if extraction economical) and natural wells. Unfortunately, this process is hardly cost competitive against low price imports, the green H2 cost share would be USD/kg 0.5 with (relatively low) green H2 costs of USD/kg 3.

Sector: **Manufacture** Kenya: Exists, **HIGH** relevance (GDP share 8%)	Sub-sector: **Chemical and chemical products** Kenya: **Exists, LOW relevance** Wide range of use (cooking fuel, transport, chemical products)	Relevance of green H2: **LOW to MEDIUM** CO2 effect: **MEDIUM** Growth perspective: **MEDIUM**

Green H2 Use Candidate	2.1 / 3.5 / 4.5 / 5.5 Light industry / methanol (power to liquid) Sector: **Manufacture** Sub-sector: **Chemical and chemical products**

Key facts and volume estimates

- Potential green H2 need: current methanol demand would equal 1,000 to 1,500 tons of H2 per year (some 10 MW electrolyser capacity plus electricity needs for CO2 extraction and methanol synthesis)
- Strong demand growth expected based on the historic demand growth of above 10%, green H2 based methanol depending on economic feasibility and market regulation / protection
- Use of (grey) H2: (abroad for methanol production)
- Water need: 40 m3 per day

PESTEL	Rank: **29** (out of 46); Obstacles: **LOW**; Enablers : **LOW**				
	Olkaria (CO2 from geothermal or natural wells)	**Western Kenya (CO2 from bagasse)**	**Mombasa (Coast)** (CO2 from bagasse)	**All Candidates:** Min. Av. Max.	- 2 = insufficient, - 1 = sufficient (but rather negative) 0 = satisfactory (neutral), + 1 = good, + 2 = very good **Gap analysis**
Rank **Force**					
Political	**0.8**	**0.8**	**0.8**	0.4 1.1 1.8	No/little
Economic	**0.2**	**-0.2**	**-0.1**	-0.6 0.4 1.5	Likely not competitive as raw product
Social	**-0.3**	**-0.3**	**-0.3**	-0.5 -0.1 0.5	Residential use requires safety measures
Technical	**0.3**	**-0.1**	**0.1**	-0.8 0.2 1.2	CO2 extraction / availability
Environment	**-0.2**	**0.3**	**1.8**	-1.5 0.3 1.8	No/little
Legal	0.3	0.2	**-0.3**	-0.3 0.6 1.4	No/little

Conclusion and recommendation

- Methanol based on green H2 may hardly be competitive if not combined with other production processes and benefits; however a detailed market assessment for such benefits and niches should be conducted (obstacles are similar to the previous candidate)

6.1.2.3 Heavy industry (steel / metallurgy)

Green H2 Use Candidate	**2.2.1 / 2.2.2 Heavy industry (steel / metallurgy)** Sector: **Manufacture** Sub-sector: **Basic metals / fabricated metal products**
Potential sites	Mombasa, Nairobi

Relevance of sector for green H2

- Steel production process uses fossil fuels as reduction agent, which could be replaced by GH2;
- Some metallurgy processes already use (grey) hydrogen (as protective gas / controlled atmosphere for heat treatment, e.g. hardening//carbonitriding/sintering/annealing), typical hydrogen consumption in this type of plant is estimated between 36 and 720 tonnes per year
- The common process to draw out oxygen from iron is burning coke combined with the iron ore resulting in the production of carbon dioxide (CO2). Coke can be substituted with hydrogen which acts as a reducing agent to drive out oxygen from iron ore. This process is known as direct reduction of iron (DRI) and its main by-product is water in the form of steam. The technology of DRI / iron sponge exists for many decades but has not been pursued so much due to the more feasible coke based iron production. The use of green H2 requires new processes but seem to be manageable. First pilot plants are running (some on natural gas to be converted to grey and later green H2). First large-scale outputs are expected for 2025.

Current use of H2 (grey): **MEDIUM for metal processing** (LOW / pilot for raw iron production)	Future green H2 use: **HIGH probability / LARGE volumes**	Time horizon: **MEDIUM TERM**

Sector relevance in Kenya

- Steel making / steel processing in Kenya exist but restricted only to processing of imported iron billets.
- Billets are the main raw material used by steel manufactured in Kenya which are either imported or produced from the recycling of locally-sourced scrap metal. Most of the local steel manufacturers supply the construction industry and therefore the products are made through the steel-rolling processes. Steel-rolling from billets occurs in two processes; hot-rolling and cold-rolling. Hot rolling heats the steel billets making them malleable. Two types of furnace oils, CST 125 and CST 180, are commonly used for firing up of the blast furnace. Fuel Oil 125 CST is good for higher altitudes, mainly used in Nairobi, while Fuel Oil 180 CST is ideal for lower altitudes. Cold rolling requires no heat when forming the product, however, electricity is used for arc welding.
- The production of raw iron would be totally new not only to Kenya but the entire region. Only parts of the processes already exist in Kenya and some sophisticated processes have to be newly established. Further, such a plant (though scaling down to smaller sizes is possible at higher specific costs) would require relatively large investment amounts which require a stable market. Reducing the import dependency and foreign exchange risks and using domestic or regional iron ore (e.g. from Uganda or Tanzania) and supplying the regional market may be sufficient for such a plant.

Sector: **Manufacture**	Sub-sector: **Basic metals / fabricated metal products**	Relevance of green H2: **MEDIUM**
Kenya: Exists, **HIGH** relevance (GDP share 8%)	Kenya: **Exists, MEDIUM relevance**	CO2 effect: **HIGH**
	LOW relevance of use (iron reduction, metal processing)	Growth perspective: **MEDIUM to HIGH**

Key facts and volume estimates

- Potential green H2 need: first step e.g. start by 2030 5,000 to 10,000 tons H2 and additional electricity need of 50 to 100 GWH / year for electric arc furnace and ancillaries covering some 2 to 3% of domestic demand for raw iron; typical industrial sizes (e.g to be established until 2035 to 2040) would be ten times in terms of output and energy input
- Strong demand growth expected based on the historic demand growth, green H2 based methanol depending on economic feasibility and market regulation / protection
- Use of (grey) H2: small / medium for some metal processing
- Water need: 200 – 400 m3 / day

Green H2 Use Candidate	**2.2.1 / 2.2.2 Heavy industry (steel / metallurgy)** Sector: **Manufacture** Sub-sector: **Basic metals / fabricated metal products**

Key players (stakeholders, companies) in sector:

- DEVKI Steel, Apex Steel etc.

PESTEL	Rank: **16** (Mombasa) (out of 46); Obstacles: **LOW**; Enablers : **HIGH**			
	Mombasa	Nairobi	**All Candidates:** Min. Av. Max.	- 2 = insufficient, - 1 = sufficient (but rather negative) 0 = satisfactory (neutral), + 1 = good, + 2 = very good **Gap analysis**
Rank Force	16	22		
Political	**1.8**	**1.8**	0.4 1.1 1.8	No/little (considerable reduction of import dependency)
Economic	**0.7**	**0.9**	-0.6 0.4 1.5	Certain investment risks due to investment volume
Social	**0.0**	**0.0**	-0.5 -0.1 0.5	No/little
Technical	**-0.1**	**0.2**	-0.8 0.2 1.2	Technology close to commercial operation but application in Eastern Africa challenging
Environment	**0.8**	**-0.7**	-1.5 0.3 1.8	No/little
Legal	**0.1**	**0.1**	-0.3 0.6 1.4	No/little

Conclusion and recommendation

- This candidate is uncertain due to technology readiness and size but poses also enormous environmental but also overall economic benefits through this industrial shift towards domestic and green domestic steel production for local and regional demand, a novum as both the technology (non-coke based) and the location (not in emerging or industrialized countries).
- There are certain obstacles with regard to the implementation in Kenya: necessary support and supply of electricity at reliable tariffs at risks to be available over a long period.
- Recommendations
  - Further investigate this candidate together with industrial partners (domestic and international with pilot plants)
  - Identify funding options as CO_2 reduction would take place outside Kenya
  - Identify necessary frame as it would be a considerable industrial shift from import to domestic production (however in line with one Vision 2030 objective)

6.1.2.4 Heavy industry – cement and other high temperature industrial process heat

Green H2 Use Candidate	**2.2.3 Cement and other high temperature industrial process heat** Sector: **Manufacture** Sub-sector: **Manufacture of other non-metallic mineral products**
Potential sites	Mombasa, Nairobi

Relevance of sector for green H2

- Cement production worldwide is responsible for 5% of CO2 emissions, production and emissions considerably growing with the construction sector. However, the largest share of emissions due to chemical reactions and cannot be reduced but with alternative methods to new cement, e.g. recycling or alternative construction materials such as wood or lime plaster.
- However, cement has massive energy consumption for process heat and equipment (e.g. conveyer belts, crushing/mining and transport). In general, it is possible to use green hydrogen for substituting fossil fuels in the production process (as fuel for process heat / burning). However, this is considered to be a less effective way for CO2 emission reduction compared to alternative uses of the green H2 and potential alternatives for process heat such as electricity. Electrification of other processes with RE (if not already done) is also more feasible than the use of green H2. Heavy duty vehicles may be a niche (see 6.1.3.1)
- International cement companies have set GHG reduction targets (e.g. Lafarge Holcim who are active in Kenya).

Current use of H2 (grey): **not yet** (development stage for green H2)	Future green H2 use: **MEDIUM probability / LARGE volumes**	Time horizon: **LONG TERM**

Sector relevance in Kenya

- Cement only contributes 1% of total GDP but as a basic product for the construction sector it is of relevance for Kenya's economy. Further, it is among the largest of the largest energy consuming sectors (both electricity and (fossil) fuels)
- The raw materials in cement production are bulky rock materials mined from various parts of Kenya and transported by road to the nearest factory where they are mixed, ground and heated to form clinker. Clinker, the main component of cement, is further heated and ground to produce cement. Cement manufacturing is therefore highly energy-intensive due to the high temperatures required in a kiln furnace for the decarbonation of limestone and production of clinker. Currently, cement factories in Kenya use oil-based fuels such as CST 125 and heavy fuel oil (HFO) boosted with biomass to produce the required temperatures in the kilns.
- Some cement manufacturers have expanded across the country but they retain one location where the primary process is making clinker which is transported by road in semi-liquid form to other factories where the finishing process is done. Transportation of raw materials, clinker and finished products is mainly done by road using heavy-duty trucks and trailers.
- In addition, cement factories heavily consume electricity which is used for preheating raw materials used in the manufacturing processes, running motors, drivers and conveyors, cooling, water pumping and many other uses.
- The biggest players in the cement industry are Bamburi Cement, East African Portland Cement (EAPC), Savannah Cement, Mombasa Cement and National Cement. There are plans to set up new cement plants, one by Delta International FZE in Mavoko and another by Mashujaa Cement who will be investing Ksh 3.9 billion to a grinding plant with a capacity to produce one million tonnes of cement annually (Macharia, 2021). Despite manufacturing most of the cement locally, Kenya still imports cement clinker. In 2019, 1.8 million tonnes of cement clinker valued at Ksh 8.3 billion was imported (Kenya National Bureau of Statistics, 2020, pg.99).
- Practically, hydrogen could be used to enrich the combustion process and consequently reduce carbon emissions. Further, hydrogen-powered heavy duty trucks could replace the current diesel-powered transport trucks which travel along predictable routes for sourcing the raw materials, disposing off the by-products and transportation of the finished products. However, the uses look less economic compared to other uses of green H2 as well as alternatives, mainly electrification or sustaining fossil fuels unless international companies are willing to pay for the reduction of their emissions.

Sector: **Manufacture** Kenya: Exists, **HIGH** relevance (GDP share 8%)	Sub-sector: **Manufacture of other non-metallic mineral products** Kenya: **Exists, MEDIUM relevance** (1% of GDP) **HIGH** relevance of use (process heat)	Relevance of green H2: **LOW** CO2 effect: **SMALL** Growth perspective: **MEDIUM**

Green H2 Use Candidate	**2.2.3 Cement and other high temperature industrial process heat** Sector: **Manufacture** Sub-sector: **Manufacture of other non-metallic mineral products**

Key facts and volume estimates

- Potential green H2 need: -
- Use of (grey) H2: no
- Water need: -

Key players (stakeholders, companies) in sector:

- See above

PESTEL	Rank: **26** (Mombasa) (out of 46); Obstacles: **SOME**; Enablers : **LOW**			
	Mombasa	**Nairobi**	**All Candidates:** Min. Av. Max.	- 2 = insufficient, - 1 = sufficient (but rather negative) 0 = satisfactory (neutral), + 1 = good, + 2 = very good **Gap analysis**
Rank Force	26	36		
Political	**1.0**	**1.0**	0.4 1.1 1.8	No/little
Economic	**-0.1**	**0.0**	-0.6 0.4 1.5	Use of green H2 costly compared to alternatives
Social	**-0.4**	**-0.4**	-0.5 -0.1 0.5	No/little
Technical	-0.3	**0.0**	-0.8 0.2 1.2	No feasible technology readily available
Environment	**1.8**	**0.3**	-1.5 0.3 1.8	No/little
Legal	**0.8**	**0.8**	-0.3 0.6 1.4	No/little

Conclusion and recommendation

- Although emissions are high, cement (and other high temperature heat requiring industries) may not be the most effective and efficient use for green H2 (also compared to alternatives of electrification or increased use of biomass). Further, the alternatives to the conventional cement industry (recycling, alternative materials) may provide better emission reduction potential.

6.1.2.5 Refinery / petro-/heavy chemical industry

Green H2 Use Candidate	**2.2.5 / 2.2.6 Refinery / petro-/heavy chemical industry** Sector: **Manufacture** Sub-sector: **Chemical and chemical products**
Potential sites	Mombasa

Relevance of sector for green H2

- Hydrogen is one important feedstock for refining / petrochemical and overall heavy chemical industry, mostly produced from fossil fuels
- As alternatives are limited / non-existent for many chemical processes this sector is expected to be one of the main future consumers of green H2 with various (pilot) projects started or in planning. In addition, there is a strong impact of the substitution of grey hydrogen by green hydrogen in relation to the limited effort of implementation.
- The oil refining process – for instance - has a substantial demand of H2 which is used for hydrocracking and for desulphurization of crude oil. There is high potential for achieving significant quantity of GHG reduction by green H2 is concentrated on an individual refinery site.

Current use of H2 (grey): **HIGH**	Future green H2 use: **HIGH probability / LARGE volumes**	Time horizon: **MEDIUM TERM**

Sector relevance in Kenya

- Grey hydrogen has been in production in Kenya by electrolysis of water from the 1940s supplying hydrogen to the now defunct Kenya Refineries, the East African Industries and the Associated Battery Manufacturers among others. When some of these companies closed operations in Kenya, the demand for hydrogen plummeted and the need to locally produce hydrogen was not economically viable. Currently most of the hydrogen consumed in Kenya is imported and then resold to various manufacturing companies and research laboratories.
- BOC used to produce hydrogen in Kenya by electrolysis of water but reverted to importation after the demand for hydrogen plummeted. It is part of the Linde group, a leading global industrial gases and engineering company founded in Germany with subsidiaries across the globe.
- A former refinery, operated by Kenya Petroleum Refineries Limited, has stopped operation 2013 ago and is considered technically outdated. Today it is only used as storage site and for laboratory services. It is however a potential site to build up green H2 related infrastructure and expertise.

Sector: **Manufacture** Kenya: Exists, **HIGH** relevance (GDP share 8%)	Sub-sector: **Chemical and chemical products** Kenya: **Exists, LOW relevance** (1% of GDP) **UNCERTAIN** relevance of use (chemical products)	Relevance of green H2: **LOW** CO2 effect: **SMALL** Growth perspective: **MEDIUM**

Key facts and volume estimates

- Potential green H2 need: small / none
- Use of (grey) H2: no
- Water need: -

Key players (stakeholders, companies) in sector:

- Kenya Petroleum Refineries Limited
- BOC

Green H2 Use Candidate		2.2.5 / 2.2.6 Refinery / petro-/heavy chemical industry Sector: **Manufacture** Sub-sector: **Chemical and chemical products**
PESTEL	Rank: **34** (out of 46); Obstacles: **VERY HIGH**; Enablers : **SOME**		
	Mombasa	**All Candidates:** Min. Av. Max.	- 2 = insufficient, - 1 = sufficient (but rather negative) 0 = satisfactory (neutral), + 1 = good, + 2 = very good **Gap analysis**
Rank Force	34		
Political	1.8	0.4 1.1 1.8	No/little
Economic	**-0.4**	-0.6 0.4 1.5	No relevant industry
Social	**-0.2**	-0.5 -0.1 0.5	Little (safety/security concerns)
Technical	**-0.3**	-0.8 0.2 1.2	No relevant industry / refinery not functional
Environment	**0.8**	-1.5 0.3 1.8	No/little (designated site of chemical industry)
Legal	**0.8**	-0.3 0.6 1.4	No/little (designated site of chemical industry)
Conclusion and recommendation			

- Although Kenya has a relevant chemical sector there is no petro-/heavy chemical industry in Kenya relevant for use of green H2. However, the site of the former refinery with its facilities, licences and knowhow including laboratory could be a starting point for other use candidates, including production of green H2 (see 6.1.2.1)

6.1.3 Mining and quarrying

This section deals with the specific use of H2 fuelled heavy duty vehicles in open pit mining as one use already in pilot phase.

The other potential uses within mining are dealt with in other chapters

3.2 Mining of metal ores and other – power supply - see 6.1.4.5

3.3 Fuel exports (hydrogen, ammonia / methanol as energy commodities) – see 6.1.5.2

3.4 Mining of metal ores and other – materials - blasting agent (ammonia nitrate) - see 6.1.2.1

3.5 Fuel liquid, methanol as fuel – see 6.1.2.2

6.1.3.1 Open pit mining of metal ores and other – heavy duty vehicles

Green H2 Use Candidate	3.1 Open pit mining of metal ores and other – heavy duty vehicles Sector: **Mining** Sub-sector: **Various according to raw material**
Potential sites	At mining sites, rough differentiation for Coast, Western Kenya / Rift Valley and Lamu / LAPPSET
Relevance of sector for green H2	

- Mining sector has immense energy consumption in general (i) liquid fuels for vehicles/equipment and machinery, ii) electricity for machinery (grid connected or off-grid) iii) process heat or H2 for chemical processing of materials)
- Possible use of H2 in heavy duty trucks; substitution of fossil fuels; already pilot projects in development with H2 production on-site supplied by solar PV plants.
- Mining sub-sectors: The more material is moved the higher the energy consumption. Sub-sectors with big quantities of mass: Limestone, marbles, dolomites. Soda ash. Titanium (ilmenite, rutile). Rare earth minerals
- Material processing: Energy consumption in the chemical processing of material in mining (for process heat). Potential for usage of H2 in the future for substituting fossil fuels (economics may be worse in comparison with alternatives, e.g. electrification), same for electricity supply (which could be provided off-grid with H2, see 6.1.4.5)
- Usage of hydrogen or oxygen in the chemical processing of material: Thus potential for substituting hydrogen from fossil origin by green hydrogen in the future; or usage of oxygen from electrolysis.
- International mining companies have committed to GHG reduction targets

Current use of H2 (grey): **LOW** (Pilot (with green H2, experimental)	Future green H2 use: **MEDIUM probability / SMALL-MEDIUM volumes**	Status: **Pilot** (with green H2, experimental e.g. Anglo American) Time horizon: **MEDIUM TERM**

Sector relevance in Kenya

- Kenya's mining and quarrying sector accounts for only 1% of GDP but has some outstanding operations and potential resources (see below)
- It contributes a relevant share of total energy consumption in Kenya (e.g. one mine is largest single electricity consumer in Kenya and mining contributes 25% of consumption of 20 largest consumers of electricity in Kenya; high share for fossil fuels assumed).
- The use of heavy vehicles / machinery is common. With international companies active and pilots internally under development and discussed (also to reduce carbon footprints), this is possible and probable area for green H2 application. Sophisticated processing of minerals (which may require H2 or derivatives) is not known. Most mines are grid connected, hence green H2 based power supply not needed.
- The following sub-sectors are most relevant, based on data from (Republic of Kenya Ministry of Mining, 2015) and (Kenya National Bureau of Statistics, 2020).
  - **Soda ash**: Kenya is the third largest producer of soda ash in the world (Republic of Kenya Ministry of Mining, 2015, Kenya National Bureau of Statistics, 2020, pg.146). Tata Chemicals Magadi operating in the Lake Magadi region (Western Kenya, Rift Valley) is Africa's largest soda ash producer and one of Kenya's leading exporters.[27] Kenya produced **230,355 tons** of soda ash valued at Ksh 5 billion in 2019.
  - **Diatomite:** Africa Diatomite Industries Limited (ADIL) established in 1942 has been exploiting diatomite in Gilgil (Rift Valley). ADIL has access to good quality diatomite deposits estimated at over 6 million tons (Republic of Kenya Ministry of Mining, 2015). However, **only 921 tons** of diatomite valued at Ksh 52 million was produced in 2019 (Kenya National Bureau of Statistics, 2020, pg146).
  - **Fluorspar**: Kenya Fluorspar Company Limited had been mining fluorspar for export in the Rift Valley System since 1971.
  - **Limestone, marbles and dolomites**: Kenya also has sizeable deposits of limestone, marbles and dolomites mostly utilized in cement manufacturing and construction industries. Among the large cement manufacturers present in Kenya are Bamburi Cement (Lafarge Group) with an installed annual capacity of 2.3 million tons; East Africa Portland Cement Company (EAPCC) with 1.4 million tons. Both Mombasa Cement and Savannah Cement have nearly 1.5 million tons of manufacturing capacity

27 (Republic of Kenya Ministry of Mining, 2015)

Green H2 Use Candidate	**3.1 Open pit mining of metal ores and other – heavy duty vehicles** Sector: **Mining** Sub-sector: **Various according to raw material**

- **Titanium**, **gold and iron** ore are the only metallic deposits being mined in Kenya at the moment. The first large scale mining venture in Kenya is being carried out by Base Titanium, the local subsidiary of Australian-based Base Resource Group, in Kwale county. It acquired the Kwale Mineral Sands Project (Coast) from Tiomin Resources in 2010. Mining was initially done with a dozer mining unit which was later upgraded to exclusive hydraulic mining. (Base Resource, n.d.). The final product is transported 50 km via road tankers to the company's Likoni Port facility inside the Mombasa Port . Electricity used in the plant is from Galu Substation. 486,152 tonnes of titanium ore minerals were produced in 2019 that had a value of Ksh. 19.6 billion.
- **Coal**: Commercial coal deposits that have been discovered in the north eastern region of the country are under review. In 2010, Aviva Corporation Ltd. of Australia signed a joint-venture agreement with Lonmin plc of UK to explore for copper, gold, silver, and zinc in 2,800km² of the Ndori Greenstone Belt (Republic of Kenya Ministry of Mining, 2015).
- **Rare earth minerals**: Cortec Mining Kenya Limited and Stirling Capital Limited, who intended to mine niobium and rare earth minerals at Mrima Hills in Kwale had their license revoked in 2013 by the Kenya Government (Otieno, 2021). It is estimated there is a deposit of 680 million kilogrammes of niobium, held in 105 million tonnes at 0.7% niobium pentoxide, which is the world's top six deposits (Republic of Kenya Ministry of Mining, 2015). There are 30 million tons of rare earth minerals estimated to be worth $62.4 billion. It is said the State will seek other firms to mine the minerals.
- **Iron ore:** While Kenya has confirmed deposits of iron ore, there has been no meaningful exploitation so far. For example, Nairobi-based heavy construction equipment dealer Shaneebal Limited has announced plans to set up an iron ore extraction mine at Mbaru in West Pokot County (Western Kenya). Other plans concern iron ore at Taita Taveta.

Sector: **Mining** Kenya: Exists, **LOW** relevance (GDP share 1%)	**MEDIUM** relevance of use	Relevance of green H2: **LOW** CO2 effect: **LOW** Growth perspective: **HIGH**

Key facts and volume estimates

- Potential green H2 need: low volume tom supply for heavy vehicles; for power supply see 6.1.4.5
- Demand growth uncertain
- Use of (grey) H2: no
- Water need: low

Key players (stakeholders, companies) in sector:

- Ministry of Mining,
- Large scale: Tata Chemicals Magadi, Africa Diatomite Industries Limited (ADIL), Kenya Fluorspar Company Limited. Base Titanium (Australian-based Base Resource Group),
- Smaller scale/potential: Aviva Corporation Ltd. of Australia, Lonmin plc, Cortec Mining Kenya Limited, Stirling Capital Limited, Shaneebal Limited
- Cement (limestone): Bamburi Cement (Lafarge Group), East Africa Portland Cement Company (EAPCC), Mombasa Cement and Savannah Cement,

Green H2 Use Candidate	**3.1 Open pit mining of metal ores and other – heavy duty vehicles** Sector: **Mining** Sub-sector: **Various according to raw material**

PESTEL	Rank: **10** (Mombasa), (out of 46); Obstacles: **LOW**; Enablers : **LOW**				
	Western Kenya / Rift Valley	Lamu / LAPPSET	Mombasa	**All Candidates:** Min. Av. Max.	- 2 = insufficient, - 1 = sufficient (but rather negative) 0 = satisfactory (neutral), + 1 = good, + 2 = very good
Rank Force	32	23	10		
Political	**0.4**	**0.4**	**0.4**	0.4 1.1 1.8	
Economic	**0.1**	**0.0**	**0.1**	-0.6 0.4 1.5	
Social	**0.0**	**0.0**	**0.0**	-0.5 -0.1 0.5	
Technical	**0.1**	**-0.2**	**0.3**	-0.8 0.2 1.2	
Environment	0.3	**1.8**	**1.8**	-1.5 0.3 1.8	
Legal	**1.0**	**1.0**	**1.0**	-0.3 0.6 1.4	
Conclusion and recommendation					

- Green H2 heavy duty vehicles / machinery is a potential use candidate in particular when international companies are involved (to reduce carbon footprints), Other uses are less likely.
- Opportunity: fossil fuel replacement for heavy duty vehicles
- Challenges are (despite costs) the new technology (incl. services/knowhow)
- Recommendations
  - Approach mining companies for potential pilots / exchange of knowhow and support need

6.1.4 Electricity

6.1.4.1 Base load electricity supply

Green H2 Use Candidate	**4.1 Base load electricity supply** (national grid) Sector: **Electricity**	
Potential sites	At grid important nodes (for demand and/or supply): Olkaria, Nairobi, Mombasa, Lake Turkana (RE supply wind), Lamu / LAPPSET, 7-Forks dam area / Thika Western Kenya	
Relevance of sector for green H2		
Green and grey H2 can be used as fuel in conventional thermal power plants (gensets and (combined cycle) gas turbines) with increasing shares (e.g. 30%) mixed with fossil fuels (natural gas) as well as fuel cells (100%) Due to high conversion losses of far above 50% (electrolysis and power generation efficiency) and low availability of H2 it is not an option for large scale base load		
Current use of H2 (grey): **LOW** (Pilot (with green H2, experimental)	Future green H2 use: **LOW probability / LARGE volumes**	Status: **Pilot** (with green H2, experimental) Time horizon: **LONG TERM**
Sector relevance in Kenya		
Base load in Kenya is supplied by geothermal and hydropower plants which will are operated at lower costs than any H2 fuelled base load plant, hence not further studied		

Green H2 Use Candidate	**4.1 Base load electricity supply** (national grid) Sector: **Electricity**	
Sector: **Electricity** Kenya: Exists, MEDIUM relevance (GDP share 2%)	**LOW** relevance of use (base load supply)	Relevance of green H2: **NO** CO2 effect: **NO** Growth perspective: **MEDIUM**
Conclusion and recommendation		
Candidate not relevant for Kenya and study due to high costs compared to available alternatives		

6.1.4.2 Back-up / peaking electricity supply

Green H2 Use Candidate	**4.2 Back-up / peaking supply of electricity** (national grid) Sector: **Electricity**
Potential sites	At grid important nodes (for demand and/or supply): Olkaria, Nairobi, Mombasa, Lake Turkana (RE supply wind), Lamu / LAPPSET, 7-Forks dam area / Thika Western Kenya

Relevance of sector for green H2

- Green and grey H2 as well as ammonia can be used as fuel in conventional thermal power plants (gensets and (combined cycle) gas turbines) with increasing shares (e.g. 30%) mixed with fossil fuels (natural gas) as well as fuel cells (100%)
- Due to high conversion losses of far above 50% (electrolysis and power generation efficiency) and low availability of H2 it is not an option for large scale base load but for back-up / peaking (incl. ancillary services such as black start capability)
- As back-up it is only feasible if considerable storage of H2 is available

Current use of H2 (grey): **LOW** (Pilot (with green H2, experimental)	Future green H2 use: **MEDIUM probability / SMALL volumes**	Status: **Pilot** (with green H2, experimental) Time horizon: **LONG TERM**

Sector relevance in Kenya

- While there is surplus capacity in the Kenyan power system which allows nearly 100% RE based power generation it relies on fossil fuel based generation (gensets, gas turbines and import) for peaking capacity (to supply power in the evening), back-up capacity (e.g. to balance fluctuating supply from wind, PV and hydropower) and for regional network stability (e.g. Western Kenya and Coast)
- Peaking and back-up is also provided by hydropower and to some extent geothermal plants with adverse effects on economics, technical and environmental implications since they are not made for flexible operation (see description and figures in section 5.1)
- There are limited non-fossil candidates to supply the increasing demand for above needs: hydropower (mainly Karura and High Grand Falls, both considered in LCPDP and the analysis of section 5.2) and batteries (in addition import of flexible hydropower is a technical option but not secured yet) as well as some flexibility options of biomass (bagasse cogeneration, as detailed in the 2016 master plan)
- Green H2 based generation (fuel cells, gensets or gas turbines) is an additional peaking candidate, fuelled with short term stored H2 from regular surplus RE generation. Whether this candidate with high losses makes technical and economic sense has to be analysed against alternatives such as batteries. Due to a lack of gas transport and storage system and high storage costs H2 fuelled back-up capacity is not feasible.
- Mombasa is the most beneficial area for such a plant due to its location at the eastern fringe of the power system with limited power generation resources (very few RE based) combined with base demand of strategic importance at the port area and related industries. For that reason, various studies for new generation capacity (CCGT Dongu Kundu with import terminal) has been conducted in recent years with no final investment decision. An H2 based power plant may be an alternative technology for such a plant improving power quality and security of supply and additional benefits for the harbour area (e.g. peak demand of berthing ships if connected to the grid in future). However, whether it makes technical and economic sense (in terms of supply of RE for local electrolysis, H2 storage capacity, etc.) in comparison with alternatives (including strengthening of transmission backbone) has to be analysed (including system / expansion planning study).

Green H2 Use Candidate	**4.2 Back-up / peaking supply of electricity** (national grid) Sector: **Electricity**	
Sector: **Electricity** Kenya: Exists, MEDIUM relevance (GDP share 2%)	**HIGH** relevance of use (peaking)	Relevance of green H2: **LOW** CO2 effect: **LOW** Growth perspective: **HIGH**

Key facts and volume estimates

- Potential green H2 need: for 100 MW peaking capacity (daily 200 MWh generation): some 10 to 15 tons H2 and 150 m3 water per day (water could be reused, extent depending on technology) and 600 to 900 MWh of RE base generation (i.e. some 90 to 140 MW geothermal capacity running 6 hours full load or the average generation from 110 to 160 MW of solar PV.
- Costs: fuel costs alone would be in the range of 150 to 180 USD/MWh (H2 storage costs of several millions of USD not included). These costs may only be justified if additional benefits or externalities could be factored in (e.g. heat supply, CO2 costs)
- Use of (grey) H2: no
- Water need: e.g. 150 m3 water per day (water could be reused, extend depending on technology)

Key players (stakeholders, companies) in sector:

- KenGen, IPPs to provide generation KPLC as single buyer and Ketraco to allow sufficient transmission capacity, EPRA / MoE for regulation / policy

PESTEL — Rank: **4** (Mombasa), (out of 46); Obstacles: **LOW**; Enablers : **SOME**

	Olkaria	Nairobi	Mombasa	Lake Turkana	Lamu / LAPPSET	7-Forks / Thika	Western Kenya	**All Candidates:** Min. Av. Max.	- 2 = insufficient, - 1 = sufficient (but rather negative) 0 = satisfactory (neutral), + 1 = good, + 2 = very good
Rank Force	18	15	4	30	33	13	25		
Political	0.7	0.7	0.9	0.7	0.7	0.7	0.7	0.4 1.1 1.8	
Economic	0.0	0.0	0.6	-0.4	-0.6	-0.2	0.0	-0.6 0.4 1.5	
Social	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.5 -0.1 0.5	
Technical	0.8	0.6	0.6	0.3	-0.4	0.5	0.3	-0.8 0.2 1.2	
Environment	0.3	0.8	1.8	0.8	1.8	1.8	0.8	-1.5 0.3 1.8	
Legal	1.1	1.1	1.3	1.0	1.1	0.6	0.5	-0.3 0.6 1.4	

Conclusion and recommendation

- Green H2 (or ammonia) based peaking supply is a potential candidate for power system expansion, best site is likely in Mombasa due to power system needs (including port with (peak-)supply of berthing ships), water availability and potentially available infrastructure
- Opportunity: replace thermal based power plant by peaking plant based on RE
- Challenges are (despite costs) the storage need (cost and technology challenge)
- Recommendations
  - Analyse peaking plant in Mombasa (beyond screening curve also detailed expansion planning study in comparison with alternatives) in comparison with storage / peaking alternatives

6.1.4.3 Energy storage

Green H2 Use Candidate	**4.3 Energy storage** (national grid) Sector: **Electricity**
Potential sites	At grid important nodes (for demand and/or supply) Olkaria, Nairobi, Mombasa, Lake Turkana (RE supply wind), Lamu / LAPPSET, 7-Forks dam area / Thika Western Kenya and where storage is possible (sub surface geological conditions / caverns): not known

Relevance of sector for green H2

- H2 could potentially be stored to level seasonal demand variations, similar to natural gas where large scale storage has been technically and commercially viable and politically imposed in particular in many gas dependent countries
- Technology is under development

Current use of H2 (grey): **NO**	Future green H2 use: **HIGH probability / LARGE volumes**	Status: - Time horizon: **LONG TERM**

Sector relevance in Kenya

- There is no need for energy storage for power supply in Kenya due to the negligible seasonal variations of demand and supply (mainly hydropower but share decreases)
- No need for energy storage beyond power sector as H2 could be produced continuously and as required

Sector: **Electricity** Kenya: Exists, MEDIUM relevance (GDP share 2%)	**NO** relevance of use (energy storage)	Relevance of green H2: **NO** CO2 effect: **NO** Growth perspective: **NO**

Conclusion and recommendation

- Candidate not relevant for Kenya and study as there is no need in Kenya, technology not available (yet) and costs would be high

6.1.4.4 Combined (low) heat and power supply

Green H2 Use Candidate	**4.4 Combined (low) heat and power supply residential and commercial buildings, industry** (off grid and on grid / captive power) Sector: **Electricity/ energy** Sub-sector**: Heat**
Potential sites	At demand sites all over Kenya, mainly industrial, commercial sites with heat demand

Relevance of sector for green H2

- H2 could be used in fuel cells or other Combined Heat and Power (CHP) to provide electricity and heat. Further H2 production in electrolysers also provides surplus heat
- This is low heat in fuel cells (below 90°C) and from electrolysers (<60°C) and higher heat from CHP plants based on gensets or gas turbines.
- Special electrolyser work with higher temperature to achieve higher efficiencies with lower quality materials (mostly in US and South Korea, suppliers are Doosan (PAFC), Bloom Energy (SOFC), Sunfire (SOFC) and FuelCellEnergy (MCFC). Although possible for some of these electrolysers to provide high temperature heat it is however not common practice.

Current use of H2 (grey): **LOW** (with natural gas)	Future green H2 use: **LOW probability / LARGE volumes**	Status: pilots / commercial start with green H2 Time horizon: **LONG TERM**

Sector relevance in Kenya

- There is no large scale need for low temperature heat in Kenya which could not be better supplied with alternatives (e.g. the little heating is done with ACs/heat pumps; solar heat)
- Since green H2 fuelled base load supply of electricity will by far not be cost competitive, higher heat supply from CHP will likely not make this base load supply competitive

Green H2 Use Candidate	**4.4 Combined (low) heat and power supply residential and commercial buildings, industry** (off grid and on grid / captive power) Sector: **Electricity/ energy** Sub-sector**: Heat**

Sector: **Electricity** Kenya: Exists, MEDIUM relevance (GDP share 2%)	Sub-sector: **Heat,** Kenya: **exists, LOW relevance** **LOW** relevance of use (low heat supply)	Relevance of green H2: NO/**LOW** CO2 effect: NO/**LOW** Growth perspective: **NO**

Conclusion and recommendation

- Candidate not relevant for Kenya and study as there is no large scale (which may justify such installation) need in Kenya (niche applications may develop or uses of surplus heat from electrolysis)

6.1.4.5 Off-grid supply of electricity

Green H2 Use Candidate	**4.5 Off-grid supply of electricity** (single consumers and isolated grids) Sector: **Electricity** Sub-sector: **Off-grid supply**
Potential sites	All Kenya, mainly North and South of "West-East network backbone", in distance to MV grid (e.g. few km from line, ~20 km from substation AND/OR low load)

Relevance of sector for green H2

- Green H2 offers an alternative or complement for the common energy supply for isolated (off-grid) sites: better (potentially easier to handle, lower cost and longer term) storage of H2 (or ammonia or methanol) compared to PV and battery or diesel so that longer periods with low PV generation (e.g. during rainy season) could be bridged, higher night loads supplied or where space (for PV) is limited
- Two solutions differentiated: i) on-site H2 production, storage and use (electricity generation with fuel cells) advantages: higher level of independence from fuel transport; disadvantage: requires more sophisticated and expensive equipment on site ii) on-site use of ammonia or methanol (produced from green H2) advantage: easier to maintain and cheaper equipment on site, fuel could be produced at higher scale at central spots; disadvantage: regular transport necessary though storage allows several months' supply
- Pilot plants are in operation and under development
- Commercial solutions for small scale supply are available worldwide for various supply options (e.g. Base Transceiver Stations (BTS, mobile phone network), single households) but no break-through yet

Current use of H2 (grey): **LOW** (pilots with green H2, methanol, ammonia)	Future green H2 use: **MEDIUM probability / SMALL volumes** (mostly generated on site)	Status: **piloting, few commercial suppliers** Time horizon: **MEDIUM TERM**

Sector relevance in Kenya

- Despite doubling of connections within 4 years and reaching about 75% access of all households (grid and off-grid electrification including Solar Home Systems) there is continuous need for off-grid supply (for new electrification or to enhance existing supplies)
- There are over 100 isolated grids (serving communities: isolated consumers such as antennas in addition) in Kenya with a wide variety of size, operation / ownership modes (e.g. some 50 operated by KPLC and REREC) and supply sources (previously diesel only, conversion to / amending with PV battery ongoing. This is expected to further increase as GoK support electrification
- In addition, there are off-grid commercial / industrial sites, mainly (small-scale) Base Transceiver Stations currently running mainly on diesel, which need regular fuel supply with imported fossil fuel (other off-grid sites such as small scale mines etc. may exist).
- RE is becoming the dominant supply source, mostly PV in combination with battery which is lower cost than diesel
- Sector less relevant for overall Kenya but for local population (for reliable power supply) and overall balanced development (including SDGs)

Sector: **Electricity** Kenya: Exists, MEDIUM relevance (GDP share 2%)	Sub-sector: **Off-grid supply** Kenya: Exists, LOW relevance (<1% of total electricity supply), HIGH relevance of use	Relevance of green H2: **LOW** CO2 effect: SMALL but effective (fuel replacement) Growth perspective: HIGH

Green H2 Use Candidate	**4.5 Off-grid supply of electricity** (single consumers and isolated grids) Sector: **Electricity** Sub-sector: **Off-grid supply**

Key facts and volume estimates

- Isolated grids:
  - Estimated > 100 isolated grids, mainly diesel or PV battery based, many diesel (to be) replaced / amended with PV battery; Growing due to electrification efforts (GoK through agencies, development partners) and reducing PV and battery costs; up to 450 new isolated grids planned
  - KPLC, REREC: 60 GWh/year with 35 MW installed capacity, in total some 100 GWh demand estimated, (<1% of total electricity generation), growing;
- Single consumers:
  - Mainly Base Transceiver Stations (BTS, mobile phone network): estimated 1000 to 2000 off-grid stations (in total 7,500, growing (e.g. double) to meet demand), majority Safaricom sites; most uses: diesel generators, battery hybrids, some solar PV hybrids, few PV solar only (fuel cells considered by stopped: Safaricom with BOC Kenya aimed at using hydrogen-powered fuel cells to power base transceiver stations (BTSs). The project ceased due to shortage of hydrogen in Kenya, a pre-developed potential demand for green hydrogen)
  - Total off grid energy need: 15 million liter diesel, equivalent to 70 GWh
- Potential green H2 need: isolated grid demand equal to some 5,000 t H2 / year (but produced / consumed locally, unlikely to be largely replaced with green H2 technology); Base Transceiver Stations' demand some 2,000 to 4,000 t H2 (e.g. if some 2,000 antennas to be supplied with green ammonia / methanol)
- Strong demand growth expected due to expansion n of isolated grids, demand fro green H2 based demand uncertain
- Use of (grey) H2: no
- Water need: to some extent water can be reused; for above exemplary ammonia / methanol supply some 100 m3/day

Key players (stakeholders, companies) in sector:

- Isolated grids: power sector agencies (KenGen, KLPC, KenGen, EPRA, REREC, MoE as operators / regulators); development partners (World Bank, AFD etc.), private companies/initiatives
- Single consumers: network operators (Safaricom (carbon target: net zero 2030; committed to phase out diesel and increase RE share, project considerations: ESCO, fuel cells), Airtel Kenya incl. Telkom Kenya); technology providers: Adrian Kenya Ltd. e.g. for Safaricom with several project ideas in the past but all skipped)

PESTEL	Rank: **5** (out of 46); Obstacles: **LOW**; Enablers : **HIGH**		
Force		All Candidates: Min. Aver. Max.	- 2 = insufficient, - 1 = sufficient (but rather negative) 0 = satisfactory (neutral), + 1 = good, + 2 = very good **Gap analysis**
Political	**0.8**	0.4 1.1 1.8	No
Economic	**1.3**	-0.6 0.4 1.5	No (cost competitive due to current remote (high cost) application and little dependence on infrastructure)
Social	0.2	-0.5 -0.1 0.5	No/little negative effects, but positive local benefits
Technical	**0.6**	-0.8 0.2 1.2	No/little (new but commercial solutions available)
Environment	**0.2**	-1.5 0.3 1.8	No/little (rather little harm, but remoteness may have impact)
Legal	**1.4**	-0.3 0.6 1.4	No

Green H2 Use Candidate	**4.5 Off-grid supply of electricity** (single consumers and isolated grids) Sector: **Electricity** Sub-sector: **Off-grid supply**
Conclusion and recommendation	

- Green H2 based off-grid supply will likely not replace current standards (PV battery and diesel) due to higher costs and more sophisticated technology.
- Opportunity
  - Complement existing solutions for longer term storage as long as batteries have limitations (e.g. several days to weeks)
  - For some commercial operators good solution to be green or to replace reliance on transport
- Challenges are (despite costs) availability of suppliers (including reliable service in remote areas)
- Recommendations
  - To identify areas and uses (e.g. rather humid/rainy season affected than arid) where green H2 supply could be advantageous and study on break even requirement (technical innovation, costs, etc.); develop pilot case / showcase
  - To support pilots e.g. for antennas with commercial partners in particular i) for CO2 reduction and ii) potential power supply to neighbouring communities, iii) potentially combined with green ammonia or methanol production at other sites (and antennas as reliable off taker) iv) building up know how in the country

6.1.5 Transport / mobility

6.1.5.1 Ports and maritime - logistics and material handling

Green H2 Use Candidate	**5.1 Ports and maritime - logistics and material handling** Sector: **Transport** Sub-sector: **Maritime transport**
Potential sites	Mombasa (Lamu)
Relevance of sector for green H2	

- Maritime logistics are an essential part of maritime transport. Emissions at ports contribute a large share of overall emissions of maritime transport. Though largest part is related to fossil fuelled generation on ships while berthed, an emission reduction potential better reduced by grid electricity. There are various initiatives to "green" under the International Maritime Organization (IMO). World Port Climate Action Program (WPCAP), Rotterdam Climate Agreement (European ports)
- Heavy duty trucks at port could be operated using green H2, substituting fossil fuels (diesel). Example vehicle types: reach stacker, fork lifts, empty container stacker, terminal tractors (trucks), shunter locomotives.
- Pilots are implemented for this potential carbon neutral fuel and various equipment available from commercial manufacturers
- The compound of a port does provide a relatively closed "ecosystem" suitable to implement a new fuel supply structure
- Port is relevant for export case of green hydrogen products. It is key in the transport chain. Development depends on existing loading and storage facilities as well as connection by rail and road.

Current use of H2 (grey): **LOW** Status: **pilots / commercial equipment** available (green H2)	Future green H2 use: **HIGH probability / MEDIUM volumes**	Time horizon: **NEAR to MEDIUM TERM**

Green H2 Use Candidate	5.1 Ports and maritime - logistics and material handling Sector: **Transport** Sub-sector: **Maritime transport**

Sector relevance in Kenya

- Mombasa is the leading port for the supply of Eastern Africa (Ethiopia, Uganda, South Sudan, Rwanda, Burundi, norther Tanzania, democratic republic of Congo) with double turnover compared to 2[nd] large port Dar es Salam, Tanzania. It serves also for exports (e.g. coffee, tea, minerals) but with much lower volumes, i.e. many ships leaving (half) empty. The alternative port of Lamu (as part of LAPPSET) is insignificant.
- There is already a Green Port Policy (GPP) under implementation by the Kenyan Port Authority (e.g. power supply to ships from new sub-stations, water management plan, implementation of ISO standards, RE, efficient gas oil fuelled equipment, tree planting); power supply to ships could be supported by H2 based peak power supply (see 6.1.4.2)
- As the port is further expanded and modernized this offers an opportunity to switch to alternative local fuel supply and replace fossil fuel imports. This may be integrated into a wider concept for a "greener" port starting from the Green Port Policy. There are however little incentives. But Mombasa would be among the first movers in Africa.

Sector: **Transport** Kenya: Exists, **HIGH** relevance (GDP share 12%)	Sub-sector: **Maritime transport** Kenya: **Exists, MEDIUM relevance HIGH** relevance of use (logistics)	Relevance of green H2: **HIGH** CO2 effect: **MEDIUM** Growth perspective: **HIGH**

Key facts and volume estimates

- Potential green H2 need: low
- Low demand growth expected
- Use of (grey) H2: no
- Water need: low and to be supplied from desalination

Key players (stakeholders, companies) in sector:

- Ministry of Transport, Kenya Ports Authority (KPA)
- Suppliers of equipment and port expansion (e.g. from Japan)
- International Maritime Organization (IMO) responsible for emission reduction (delegated from UNFCC); *World Port Climate Action Program* (WPCAP)

PESTEL	Rank: **2** (Mombasa), (out of 46); Obstacles: **LOW**; Enablers : **VERY HIGH**		
	Mombasa	**All Candidates:** Min. Av. Max.	- 2 = insufficient, - 1 = sufficient (but rather negative) 0 = satisfactory (neutral), + 1 = good, + 2 = very good **Gap analysis**
Rank Force	2		
Political	**1.7**	0.4 1.1 1.8	No/little (but potential resistance of established fuel supply system)
Economic	**0.9**	-0.6 0.4 1.5	Likely not directly competitive with fossil fuels (due to infrastructure etc.) but very suitable for financing etc.
Social	**0.5**	-0.5 -0.1 0.5	No (if water is not taken from surrounding but desalination)
Technical	**0.7**	-0.8 0.2 1.2	No (but infrastructure to be build up)
Environment	**1.5**	-1.5 0.3 1.8	No
Legal	**1.3**	-0.3 0.6 1.4	No/little

Green H2 Use Candidate	5.1 Ports and maritime - logistics and material handling Sector: **Transport** Sub-sector: **Maritime transport**

Conclusion and recommendation

- Green H2 for logistics may not be directly competitive with (existing) fossil fuel based infrastructure but may become feasible in the short to medium term (if external costs / benefits are factored in)
- Opportunity:
  - Fossil fuel replacement with available technology to reduce port's carbon footprint and reduce exhaust gases; could be one further part of overall concept towards a "greener" port in Eastern Africa
  - Defined area (with short distances) is of benefit for infrastructure, modular technology to some extend possible
- Challenges: costs and technology for infrastructure, resistance from existing fuel supply system. There are certain obstacles with regard to the implementation in Kenya: necessary know-how and standards (and respective laboratories / certification) for sufficient quality of products, etc.
- Recommendations
  - Analyse and implement (smaller scale) show case / project (also as an opportunity to initiate hydrogen technology in Mombasa)
  - Evaluate existing policy for green port of Mombasa whether and how this can be aligned

6.1.5.2 Ports and maritime - maritime fuel (ammonia as fuel for ships and export commodity)

Green H2 Use Candidate	**5.2 Maritime fuel (ammonia as fuel and export commodity)** Sector: **Transport** Sub-sector: **Maritime transport**
Potential sites	Nairobi, Mombasa (Lamu), Olkaria

Relevance of sector for green H2

- Maritime transport (which make up some 90% of global transport) contributes some 2 to 3% to global GHG emissions, half of them while ships are in ports. For comparison: if maritime transport were a country it would rank number six of largest polluters, hence showing the huge impact and potential. There is a strong upward trend. Fuel is mainly heavy fuel oil (switched during oil crisis from gas oil);
- Efforts and commitments by organisations and companies exist to reduce emissions and apply carbon neutral fuels (e.g. newly ordered dual fuel ships based on methanol, initiatives for standards on ammonia as bunker fuel, emission reduction targets by the International Maritime Organization (total 50% by 2050 and carbon intensity 40% by 2030) but so far no agreement on CO2 prices but ongoing initiative by ICS (International Chamber of Shipping) initiated by German shipping companies, to achieve carbon neutrality already by 2050 .
- Green H2 provides one of the few alternatives to decarbonize this sector. Due to storage and transport technology and costs implications this is rather through its derivatives ammonia (cheaper but still under development) and methanol (dual fuel ready with gas oil) mainly for large-scale container and tanker ships and special purpose ships (not relevant for Kenya). It should be combined with grid electricity supply to ships while berthed in ports (already under implementation worldwide, including Mombasa)
- Supplied at the port, ammonia is one of the most prominent energy / hydrogen carriers for export of green H2.
- Standards and technical solutions for ammonia (vessels and bunker infrastructure) are still under development with various challenges (e.g. security; lacking standards for bunker, though ammonia transport is common; potential threat for very harmful GHG N2O for incomplete combustion)

Current use of H2 (grey): **LOW** (Pilot (with ammonia, methanol, experimental)	Future green H2 use: **MEDIUM probability / LARGE volumes**	Time horizon: **MEDIUM to LONG TERM**

Green H2 Use Candidate	**5.2 Maritime fuel (ammonia as fuel and export commodity)** Sector: **Transport** Sub-sector: **Maritime transport**

Sector relevance in Kenya

- Mombasa is the leading port for the supply of Eastern Africa (Ethiopia, Uganda, South Sudan, Rwanda, Burundi, norther Tanzania, democratic republic of Congo) with double turnover compared to 2nd large port Dar es Salam, Tanzania. It serves also for exports (e.g. coffee, tea, minerals) but with much lower volumes, i.e. many ships leaving (half)empty. The alternative port of Lamu (as part of LAPPSET) is insignificant.
- There is already a Green Port Policy (GPP) under implementation by the Kenyan Port Authority (e.g. power supply to ships from new sub-stations, water management plan, implementation of ISO standards, RE, efficient gas oil fuelled equipment, tree planting)
- Turnover of ships provide a potential for (green) fuel supply. However, with low transport costs, Mombasa has to compete with other ports on the ships' routes worldwide. This is possibly the reason why in Kenya bunker fuel supply is small. In addition, it has to compete with established bureaucratic and private sector system of fuel supply and start from the mentioned underdeveloped bunker fuel supply (which could however be also an advantage as ammonia supply must have to start with a new infrastructure)
- Export of green H2 through ammonia is less likely given the cost disadvantage (see 5.3) compared to countries closer to worldwide demand (e.g. Northern Africa, Norther Europe to Central Europe) and with stronger infrastructure to build on
- Methanol as an alternative (as maritime fuel or energy / hydrogen carrier for export) is not considered in this study as price competitiveness is low for Kenya (lacking economies of scale e.g. with limited availability and higher costs for CO2 supply)
- Ferry boats for short distances (in coastal areas and on Lake Victoria) should from today's point of view powered by batteries and not hydrogen or ammonia.

Sector: **Transport**	Sub-sector: **Maritime transport**	Relevance of green H2: **MEDIUM**
Kenya: Exists, **HIGH** relevance (GDP share 12%)	Kenya: **Exists, MEDIUM relevance**	CO2 effect: **HIGH**
	LOW relevance of use (fuel supply)	Growth perspective: **HIGH**

Key facts and volume estimates

- Potential green H2 need:
  - KNBS reported turnover of maritime fuels in Kenya is astonishingly low (0.1% of total petroleum products 2016-2019, compared to 13% for aviation and equivalent to 1,000 tons H2 per year only) indicating that ships mostly bunker at other ports.
  - IEA estimated need of H2 worldwide (million tons per year) is: ~90 in 2030, ~140 in 2040, 280 in 2050 (gradually to be sourced from green sources). Today's view is that most of this volume cannot be produced in countries of main demand and has to be sourced from other countries, offering a huge export potential for countries with competitive RE sources and export infrastructure. Transport technology and costs are a huge obstacle for far distance transport. Since solutions are in piloting stage only a reliable estimate on future potential for countries in regions like Kenya (which is in far distance to demand compared to other countries) cannot be made.
  - Demand growth uncertain as it strongly depends on international competition
- Use of (grey) H2: no
- Water need: low and to be supplied from desalination

Key players (stakeholders, companies) in sector:

- Ministry of Transport, Kenyan Port Authority
- Fuel supply companies (various)
- Shipping companies active in Mombasa and environmental pilots (e.g. Maersk)
- International Maritime Organization (IMO) responsible for emission reduction (delegated from UNFCC); *World Port Climate Action Program* (WPCAP); ICS (International Chamber of Shipping)
- Various international initiatives and organisations for green H2 trade (e.g. import to Europe in particular Germany and Asia, in particular Japan; African Hydrogen Partnership Trade Association etc.)

Green H2 Use Candidate	**5.2 Maritime fuel (ammonia as fuel and export commodity)** Sector: **Transport** Sub-sector: **Maritime transport**

PESTEL Rank: **31** (Mombasa), (out of 46); Obstacles: **SOME**; Enablers : **LOW**

	Nairobi	Mombasa	Olkaria	All Candidates: Min. Av. Max.	- 2 = insufficient, - 1 = sufficient (but rather negative) 0 = satisfactory (neutral), + 1 = good, + 2 = very good **Gap analysis**
Rank **Force**	44	31	46		
Political	0.9	**1.0**	**0.9**	0.4 1.1 1.8	No/little
Economic	**-0.4**	**-0.1**	**-0.3**	-0.6 0.4 1.5	Adverse economics due to international competition
Social	-0.2	**0.2**	**-0.2**	-0.5 -0.1 0.5	No/little if in Mombasa
Technical	**-0.3**	**-0.3**	**-0.4**	-0.8 0.2 1.2	Technology still in piloting, beyond control of GoK but strategic partnerships possible
Environment	-0.7	**0.8**	**-1.2**	-1.5 0.3 1.8	No/little if in Mombasa
Legal	**-0.1**	**0.9**	**0.4**	-0.3 0.6 1.4	No/little if in Mombasa

Conclusion and recommendation

- Potential supply of green H2 through ammonia as maritime fuel
- Opportunity: fossil fuel replacement to reduce carbon footprint of international shipping companies (e.g. companies supplying CO2 conscious companies in EU, e.g. for agricultural products)
- Challenges: high competition with other ports worldwide (also in low RE cost areas) and established fossil fuel supply system (though small); ammonia as transport fuel technically still under development (standards / security) with no readily available solution / demand. There are certain obstacles with regard to the implementation in Kenya: necessary know-how and standards (and respective laboratories / certification) for sufficient quality of products, etc.
- Recommendations
  - Support detailed market assessment, e.g. for particular shipping companies (e.g. Maersk) and exploring pilot project, considering existing policy for green port of Mombasa whether and how this can be aligned
  - Engage with international initiatives to supply green H2 to Europe/Japan in order to monitor technological developments, requirements (e.g. additionality) and identify potential niches for Kenya which may overcome e.g. transport cost related disadvantages

6.1.5.3 Aviation

Green H2 Use Candidate	**5.3 Aviation fuel (hydrogen or e-fuel /PtLiquid)** Sector: **Transport** Sub-sector: **Air transport**
Potential sites	Nairobi, Olkaria, Mombasa

Relevance of sector for green H2

- Aviation contributes some 5% to global GHG emissions, from direct combustion of fossil fuels to other effects. Efforts and commitments by organisations and companies exist to reduce emissions including higher efficiencies and low carbon or carbon neutral fuels (so called SAF sustainable aviation fuels, e.g. biomass-based e-kerosene). Increasing numbers of countries require a certain (and increasing) share of SAF (e.g. Germany, Netherlands, United Kingdom, California), this is expected to expand e.g. to all EU countries. Private initiatives of the airports and carriers try to match this demand.
- Green H2 is one option to reduce aviation induced carbon emissions. Others are biomass based SAF, which are already at commercial stage though at very high costs and with supply limitations on the feedstock (estimated max. of 5 to 7% of total fuel demand) and battery powered planes, which is still under development and may be limited to shorter distances and smaller planes.
- The limitations of alternatives may be a potential for green H2. However, as direct fuel it faces similar technical obstacles as batteries and may be only available in the long term (Airbus announced a H2 fuelled plane by 2035) and relevant for smaller planes for medium distance (i.e. regional).
- Liquid SAF from green H2 (i.e. e-kerosene from PtLiquid) may offer an opportunity as it could be used in established fuel supply infrastructure. Only one pilot plant recently started operation in Germany (others under development), current costs are more than 10 times of fossil kerosene. With commercial scale prices are expected to decrease but rather unlikely below the (untaxed) fossil kerosene so will not be competitive without subsidies or the mentioned requirements

Current use of H2 (grey): **LOW** (pilot (experimental) for e-Kerosene (green H2) just started, others under development	Future green H2 use: **MEDIUM to HIGH probability / LARGE volumes**	Time horizon: **LONG TERM**

Sector relevance in Kenya

- Nairobi Jomo Kenyatta International Airport JKIA) is a regional and international hub (4th largest airport in Sub-Saharan Africa). Other airports (Nairobi Wilson, Mombasa, Kisumu, Eldoret) are mostly for national and regional connections and other general aviation purposes (e.g. agriculture) and of much lower relevance).
- In general airlines heavily rely on refuelling at (almost) every stop (this is different from maritime fuels); one reason why 13% of all petroleum products in Kenya are aviation fuels (most supplied to JKIA).
- The largest share of fuel consumption for Kenyan regional aviation and international flights to non-European countries will likely not be relevant for green H2 based aviation as long as it is not cost competitive with existing technologies / fuels. This may be only expected in the very long term if at all and likely applied before in many other preferred regions (where political pressure is higher).
- Due to international flights with destination in countries with (potential) obligations for sustainable aviation fuels (Mainly EU/UK) and the importance of aviation for tourism this could be a niche for the supply of e-kerosene.
- Though this is a fraction of international flights, the respective fuel amounts are high.
- Jet fuel in Kenya is currently procured monthly through an open tender system managed by the Ministry of Energy and Petroleum. Kenya Pipeline Company (KPC) collates orders from oil marketers in the East Africa region. The winning bidders would procure all the jet fuel requirements for the region which is received and delivered to various airports by KPC. KPC supplies all the oil companies at their specific dispensers/hydrants at the major airports while the rest is delivered by tanker-trucks to other smaller airports across the country and in the region. On top of the jet fuel supplied by KPC to the national market it exports some 25% to neighbouring countries.
- Any e-kerosene production would be site restricted to the established transport infrastructure (e.g. Nairobi, Mombasa) and supply of CO2 at sites with non-fossil fuel based CO2 emitters (which could be biomass plants, geothermal plants (if economical) and natural wells). Further products the production process is technically more sophisticated than e.g. ammonia and requires also refining of the raw kerosene which could be a knock-out criterium for the application in Kenya (as this process may not be available in Kenya at reasonable costs).

Green H2 Use Candidate	**5.3 Aviation fuel (hydrogen or e-fuel /PtLiquid)** Sector: **Transport** Sub-sector: **Air transport**	
Sector: **Transport** Kenya: Exists, **HIGH** relevance (GDP share 12%)	Sub-sector: **Air transport** Kenya: **Exists, LOW relevance** **HIGH** relevance of use (fuel supply)	Relevance of green H2: **LOW** CO2 effect: **HIGH** Growth perspective: **HIGH**

Key facts and volume estimates

- Potential green H2 need: 0.7 million tons of aviation fuel per year (annual growth above 5% per year on average; 13% of total petroleum products in Kenya) would equal above 100,000 tons of green H2 or electrolyser capacity of more than 1,000 MW. If only a fraction of 5% is used for relevant international flights (fraction not known) and their obligation stands at 5 to 10% it would mean that few MWs of electrolyser could serve this obligation.
- Strong demand growth expected based on the historic demand growth, green H2 based kerosene depending on economic feasibility and market regulation / protection
- Use of (grey) H2: no
- Water need: for piloting small, to be supplied from desalination if based in Mombasa

Key players (stakeholders, companies) in sector:

- Ministry of Transport, Kenya Airports Authority (airport operator)
- Ministry of Energy and Petroleum. Kenya Pipeline Company (KPC) and fuel supply companies
- Airlines: some 30 regional and international airlines, of which 6 with direct flights from EU/UK

PESTEL — Rank: **19** (Mombasa), (out of 46); Obstacles: **HIGH**; Enablers : **SOME**

	Nairobi	Olkaria	Mombasa	All Candidates: Min.	Av.	Max.	- 2 = insufficient, - 1 = sufficient (but rather negative) 0 = satisfactory (neutral), + 1 = good, + 2 = very good **Gap analysis**
Rank Force	27	40	19				
Political	1.1	1.1	**1.1**	0.4	1.1	1.8	No/little
Economic	**0.1**	**-0.2**	**-0.5**	-0.6	0.4	1.5	Only economic with subsidies
Social	-0.3	-0.3	**-0.3**	-0.5	-0.1	0.5	No/little if in Mombasa
Technical	**0.6**	**0.3**	**0.6**	-0.8	0.2	1.2	Quality requirement of product (kerosene from raw kerosene) is potential knock-out criterion
Environment	-0.2	-0.7	**1.3**	-1.5	0.3	1.8	No/little if in Mombasa
Legal	**0.5**	**1.0**	**1.0**	-0.3	0.6	1.4	No/little if in Mombasa

Conclusion and recommendation

- Potential supply of green H2 as e-kerosene for fraction of international flights from / to EU/UK
- Opportunity: fossil fuel replacement to reduce carbon footprint of aviation
- Challenges: not competitive with fossil fuels in the long-term without subsidies/obligations. There are certain obstacles with regard to the implementation in Kenya: necessary know-how and standards (and respective laboratories / certification) for sufficient quality of products, etc.
- Recommendations
  - Investigate whether pilot project could be feasible in Kenya with international partners (technical e.g. from first pilot plants and development partners) and national partners (e.g. for CO2 supply from biomass, KPC for transport / knowhow), clarifying technical knock out criteria (provision of quality of product, infrastructure for CO2 supply and e-kerosene transport)

6.1.5.4 Road transport - public, heavy duty

Green H2 Use Candidate	**5.4 Road transport - public, heavy duty** Sector: **Transport** Sub-sector: **Land transport**
Potential sites	Nairobi (but also other transport hubs and agglomerations e.g. Mombasa, Kisumu)

Relevance of sector for green H2

- At present there is little usage of hydrogen in road mobility but there is huge potential mainly in heavy-duty applications, such as trucks, busses, utility vehicles because of large energy volume needs and storage limitations of batteries (the more efficient alternative in many cases)
- There are hydrogen pilots and also already commercial products for trucks, busses and utility vehicles (as there are battery electric powered equivalents already on the market). Reoccurring tours combined with longer distances such as refuse collection or metropolitan busses may have an advantage compared to the battery electric alternative. If filling stations with hydrogen are available this could be also the case for long distance transports with busses and trucks.

Current use of H2 (grey): **LOW** (also green H2)	Future green H2 use: **HIGH probability / MEDIUM to LARGE volumes**	Time horizon: **SHORT to MEDIUM TERM**

Sector relevance in Kenya

- Public transport – mostly with busses and coaches of all sizes and heavy road transport by trucks uses a lion's share of the total petroleum for land transport in Kenya which is equivalent to 80% of total consumption of petroleum products (4 million out 5 million tons in recent years) in Kenya and 10% of total primary energy consumption (the largest non-RE share of primary energy). This is due to the long distances and lack of transport alternatives (e.g. railway) but also due to Kenya's geographical position supplying many Eastern African countries from its port (see 6.1.5.2) by road transport.
- Further, there are large Agglomeration to be served, mainly Nairobi but also Mombasa, Kisumu etc.. For instance, the Nairobi Metropolitan Area Transport Authority (NaMATA) is mandated in improving the public transport system in Nairobi Metropolitan Area (NMA) through introduction and implementation of Mass Rapid Transit System (MRTS) comprising Bus Rapid Transit System (BRT), Commuter Rail System and Non-Motorized Transport System (NMT). The Authority aims at using electric busses and diesel powered commuter trains. These modes of transportation could be also converted to run on hydrogen. This may also be relevant for utility vehicles, mainly refuse collection trucks.
- The above depicts potential for hydrogen introduction in this sub-sector: a Nairobi transport case where a defined area with clear and reoccurring routes served by new utility or public transport vehicles could be fuelled with on-site / close by generated hydrogen at limited costs for infrastructure (compared to a large scale and far distance introduction of hydrogen). This could also serve as show case for hydrogen in the transport sector, though with strong need for subsidies or grant. It should however be thoroughly compared to battery-powered alternatives.
- Compared to this, large scale conversion of public and heavy duty transport to hydrogen (including long distance) is not expected to be feasible in the medium and even long term for various reasons: mainly the persistence of the existing system with established fuel supply infrastructure and supply of second hand vehicles, knowhow for maintenance and operation of existing technology would need tremendous efforts to convert; efforts which are likely better invested in more promising sectors. Further for some uses (such as small busses) a technically and economically more feasible technology exists with battery electric vehicles where existing infrastructure of power supply could be tapped.

Sector: **Transport** Kenya: Exists, **HIGH** relevance (GDP share 12%)	Sub-sector: **Land transport** Kenya: **Exists, HIGH relevance** **HIGH** relevance of use (fuel supply)	Relevance of green H2: **MEDIUM** CO2 effect: **MEDIUM** Growth perspective: **HIGH**

Key facts and volume estimates

- Potential green H2 need: rather small for pilots (no use of converting petroleum consumption to green H2 equivalent)
- Strong demand growth expected for sector, green H2 based consumption uncertain
- Use of (grey) H2: no
- Water need: for piloting small

Green H2 Use Candidate	**5.4 Road transport - public, heavy duty** Sector: **Transport** Sub-sector: **Land transport**

Key players (stakeholders, companies) in sector:

- Ministry of Transport, Nairobi Transport Nairobi Metropolitan Area Transport Authority (NaMATA)
- Nairobi City Council

PESTEL	Rank: **9** (Nairobi small scale case H2 for public transport / utility vehicles), (out of 46); Obstacles: **LOW**; Enablers : **HIGH**				
	Nairobi – large scale case	Mombasa – large scale case	Nairobi – small scale case	**All Candidates:** Min. Av. Max.	- 2 = insufficient, - 1 = sufficient (but rather negative) 0 = satisfactory (neutral), + 1 = good, + 2 = very good **Gap analysis** (for Nairobi – small scale case)
Rank Force	43	35	9		
Political	**1.7**	**1.7**	**1.7**	0.4 1.1 1.8	No/little
Economic	0.2	**0.2**	**0.7**	-0.6 0.4 1.5	Only economic with subsidies
Social	**-0.2**	**-0.2**	**0.3**	-0.5 -0.1 0.5	Little (safety/security concerns)
Technical	-0.8	**-0.8**	**0.1**	-0.8 0.2 1.2	Knowhow/service companies
Environment	**0.0**	**1.5**	**0.5**	-1.5 0.3 1.8	No/little
Legal	**0.1**	**0.1**	**1.1**	-0.3 0.6 1.4	No/little

Conclusion and recommendation

- Potential supply of green H2 in a pilot phase for selected public transport / utility vehicles in Nairobi (defined area with clear routes fuelled with on-site generated hydrogen)
- Opportunity: fossil fuel replacement to reduce carbon footprint, reduce of exhaust gases; a show case for hydrogen in the sector/ Kenya, building up knowhow / service in country.
- Challenges (in particular with regard to Kenya): not competitive with fossil fuels without subsidies, knowhow / service / standards to be build up (for this rather small scale use).
- Recommendations
  - Investigate option compared to battery powered alternatives.

6.1.5.5 Rail transport – public, industrial

Green H2 Use Candidate	**5.5 Rail transport - public, industrial** Sector: **Transport** Sub-sector: **Land transport**
Potential sites	Mombasa (Nairobi, Olkaria)

Relevance of sector for green H2

- Commercial solutions exist for hydrogen fuelled railway, through currently this is restricted to few suppliers (though the two largest European among them) of light (passenger) railway and shunter locomotives, i.e. with less power but for ranges up to 1000 km. Main purpose is to replace fossil fuels (gas oil) and save electrification of lines which may not be feasible due to insufficient frequency of use.
- Electrification of long distance railway lines is only common (with a few exceptions) in densely populated and industrialized countries e.g. European countries or Japan. This offers an opportunity for future hydrogen use to replace fossil fuels.
- In additional, e-methanol (produced from green H2) may be used in diesel engines to some extent.

Current use of H2 (grey): **LOW** (commercial public rail (grey H2 to be converted to green H2), shunter locomotives)	Future green H2 use: **MEDIUM to HIGH probability / MEDIUM volumes**	Time horizon: **SHORT to MEDIUM TERM**

Sector relevance in Kenya

- There are three railway lines operated with diesel powered locomotives
  - The newly constructed Standard Gauge Railway (SGR) from Mombasa via Nairobi to Suswa/Naivasha (to be expanded to Kisumu and Uganda), constructed and operated by China Road and Bridge Corporation (CRBC), operation to be fully handed over to Kenya Railways Corporation (KRC). Railway service for passengers and freight (plan to transport all freight cleared at Mombasa port)
  - The old Meter Gauge Railway, which is being revamped (mainly Mombasa via Nairobi to Kisumu and Uganda but various abandoned).
  - Nairobi Commuter Rail (NCR)
  - In addition, there are plans (though no progress) for a line within the LAPSSET project connecting Lamu with the hinterland of Eastern Africa (if realized in future green H2 technology may already be available and competitive)
- All lines are operated with diesel powered locomotives. There have been plans to electrify the SGR with contract for electrification already outlined (at more than USD 200 million) and substations and lines already considered by KETRACO. There is no decision public yet and feasibility of this project may be questionable given the expected frequency of connections as well as technical issues on reliability etc.
- Hence, there is potential for the adoption of green H2 powered locomotives in Kenya on one or more of the lines to switch from imported fossil fuels. However, it needs to be assessed whether suitable locomotives (for gauge and power) will be available to run on Kenyan tracks considering also existing agreements for the lines and their extension. As technology is already available the least challenging could be the Nairobi Commuter Railway (this could be also linked to the previous candidate 6.1.5.4 Road transport - public, heavy duty) although electrification may be a feasible alternative.

Sector: **Transport**	Sub-sector: **Land transport**	Relevance of green H2: **LOW**
Kenya: Exists, **HIGH** relevance (GDP share 12%)	Kenya: **Exists, HIGH relevance**	CO2 effect: **SMALL**
	HIGH relevance of use (fuel supply)	Growth perspective: **HIGH**

Green H2 Use Candidate	**5.5 Rail transport - public, industrial** Sector: **Transport** Sub-sector: **Land transport**

Key facts and volume estimates

- Potential green H2 need: fuel consumption for rail has fluctuated in recent years between 11,000 (2017 and 2020) to 43,000 (2016) tons, with consumption of 19,000 in 2019; if all where to be transferred to green H2 this would require between 20 and 50 MW of electrolyser capacity, though unlikely all demand can be transferred but overall demand will grow.
- Strong demand growth expected for sector, green H2 based consumption uncertain
- A regional commuter train may use between 20 and 40 tons H2 annually,
- Use of (grey) H2: no
- Water need: 100 to 200 m3 per day, to be supplied from desalination if based in Mombasa

Key players (stakeholders, companies) in sector:

- Ministry of Transport, Kenya Railways Corporation (KRC), China Road and Bridge Corporation (CRBC)

PESTEL: Rank: **12** (Mombasa), (out of 46); Obstacles: **SOME**; Enablers : **HIGH**

	Mombasa	All Candidates: Min. Av. Max.	- 2 = insufficient, - 1 = sufficient (but rather negative) 0 = satisfactory (neutral), + 1 = good, + 2 = very good **Gap analysis**
Rank Force	12		
Political	**1.7**	0.4 1.1 1.8	No/little
Economic	**0.5**	-0.6 0.4 1.5	No/little
Social	**-0.2**	-0.5 -0.1 0.5	Little (safety/security concerns)
Technical	**-0.3**	-0.8 0.2 1.2	Availability of suitable technology (potential knock-out criterion)
Environment	**1.5**	-1.5 0.3 1.8	No/little if in Mombasa
Legal	**0.7**	-0.3 0.6 1.4	No/little if in Mombasa

Conclusion and recommendation

- Several candidates for supply of green H2 for locomotives (Nairobi Commuter Railway or long distance railway lines)
- Opportunity: fossil fuel replacement to reduce carbon footprint of railway also considering growing demand for freight transport
- Challenges: specific technology needed (long distance heavy transport not readily available yet but light transport), contractual obligations for existing lines and material. There are certain obstacles with regard to the implementation in Kenya: necessary know-how and standards (and respective laboratories / certification) for sufficient quality of products, etc.
- Recommendations
  - Investigate whether technology (suitable locomotives / trains technology) and suppliers exist for the Kenyan railway lines or are under development, including use of methanol in existing locomotives
  - A (pre-feasibility) techno-economic comparison of electrification and green H2 based operation (for Nairobi Commuter Railway and SGR)

6.1.5.6 Road transport – private

This is not a feasible candidate for Kenya (and most countries and uses) for various reasons: mainly a technically and economically more feasible technology exists with battery electric vehicles. For illustration: for green H2 fuelled vehicles it takes three times the RE input needed due to high losses in the electrolysis, storage, and electricity production in the fuel cell compared to batteries and electric motors with high efficiencies above 90%. From today's point of view only niche uses where high forces / power are needed and battery storage is the limiting factor (e.g. for heavy duty equipment and utility or public transport vehicles with certain mileage distance requirements). This is not the case for private vehicles.

In particular Kenya secondhand cars dominate the market (some 90% of newly registered vehicles in the market) which will rather facilitate the ramping up of battery electric vehicles as it is already the case in some lower/medium income countries.

Further only two commercial vehicle models exist for many years but with low numbers and high prices.

6.2 PtX Opportunities Ranking of Long List (= Short List

The table below shows the highest ranked uses, ranked according to the overall score of the PESTEL analysis. The ranking does not directly imply that one use should be preferred compared to another or is more feasible. It should give a general overview on the basis for potential green H2 use in Kenya for further analysis and discussion where the assessment and ranking could be adapted.

For this report it is the basis to identify recommended PtX pathways for Kenya as well as potential focus / pilot sites in the next section, where detailed information of the PESTEL analysis fed into the identification and ranking of industrial pathways and projects.

Table 6-1: Ranking of long list (= short list)

#	Rank	Use	Site	Obstacles	Enablers	Result
1	**1** (3, 7, 8)	Light industry / commodities (use of chemical products H2, ammonia, etc. to supply regional industries)	Mombasa (Nairobi, 7 Forks/Thika, Olkaria	Low (some)	Very high	1.01 (0.83, 0.67, 063)
2	2	Transport - H2 for port logistics etc.	Mombasa	Low	Very high	0.99
3	4 (13, 15, 18)	Electricity - peaking / storage / back-up	Mombasa (7-Forks, Nairobi, Olkaria)	Low (high)	Very high (high)	0.80 (0.47, 0.46, 0.43)
4	5	Electricity - Off-grid supply	All Kenya	Low	Very high	0.77
5	6 (17)	Agriculture / fertilizer+ (H2/ammonia and other derivatives to industry)	Mombasa (Olkaria)	Very high	Very high	0.74 (0,43)
6	9	Transport – green H2 for public transport, local utility	Nairobi	Some	Very high	0.58
7	10	Mining (on and off grid) heavy duty vehicles	Mombasa/ Coast	Low	Some	0.51
8	11	Agriculture / fertilizer+; additional benefits (H2/ ammonia and other derivatives to industry)	Olkaria	Very high	Very high	0.49
9	12	Transport – green H2 for railway	Mombasa	High	Very high	0.47
10	14	Agriculture / fertilizer only	Olkaria	Very high	Very high	0.46
11	16 (22)	Manufacturing - heavy industry (steel)	Mombasa (Nairobi)	Some	Very high	0.46 (0.37)
12	19	Transport - e-fuels for aviation	Mombasa	Very high	Very high	0.40

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7 POSSIBLE TECHNOLOGICAL AND INDUSTRIAL PATHWAYS FOR KENYA AND FOCUS PROJECTS

This section summarizes the possible technological and industrial pathways for green hydrogen in Kenya as a conclusion of the previous chapters from the short list of ranked long list of use and site candidates. The conclusion and recommendations for implementation are provided in the chapter 9 Action Plan towards a Green Hydrogen Road Map and Strategy.

7.1 Key Technological and Industrial Pathways

The study has identified the following industrial pathways to further pursue the use of hydrogen:

1 Hydrogen as a **commodity for the production of the nitrogen content of fertilizers**, via ammonia. The domestic production of fertilizers from local resources would replace imports and by this shift value chains to Kenya and reduce supply risks. With respective savings of e.g. transport costs and through expected surplus of RE supply it may be already feasible in economic terms in the near future considering a potential implementation time for such a rather sophisticated plant in Kenya, e.g. 2025 onwards. Its probable size is small from global perspective (increasing specific costs) and large from local market perspective (with strong dependence on already mature national market). Therefore, such a project needs a secure investment environment which may include functioning regulations for the currently not optimal fertilizer market and subsidies. Also project related securities or subsidies may have to be considered. Considerable reduction of CO2 emissions (mostly abroad) is only a side effect of this industrial path, including the consideration of emission avoidance for the side product Nitric Acid. A wide range of accompanying measures could and should be taken. For instance, aligning the fertilizer products to the local needs of the farmers and soil. This will improve the competitiveness of the product but also contribute to agriculture as the most important sector in Kenya in general and to food security. Further, combining it with other uses of the intermediate products (see next) or even using part of the harmful exhaust gases from geothermal plants may accelerate the overall benefits.

2 Hydrogen and its derivatives such as ammonia or methanol as a **higher priced commodity for existing and new regional industrial processes,** replacing commodity imports and enabling new industrial production processes**.** Ideally, this is combined with the first industrial pathway. Similar to the previous, this may be implemented already 2025 onwards if a distribution system and other accompanying measures (e.g. basic knowhow, R&D and services) are also in place (through private or public sector). Due to the higher priced product combined with a potential higher volume, this may be also cost competitive if the market frame is given (similar to 1). Various production processes from food processing, processing of materials such as textile or wood up to more sophisticated processes in metal/welding and electronics may benefit from this domestic supply as would the basic demand for ammonia as hygiene or pharmaceutical product. The product range may include methanol or syngas though they may have more difficulties to compete against imported fossil fuel-based products as their production process requires the provision of CO2 which is technically more sophisticated but also geographically restricted to sites with non-fossil fuel based CO2 emitters which could be biomass plants, geothermal plants (if economical) and natural wells. This process could be further expanded

to e-fuels on a small-scale, but the respective high costs require grants or other subsidies e.g. if it concerns e-kerosene to show progress in carbon reduction of aviation.

3 Hydrogen as an **energy carrier for selected transport (mobility) options**: converting logistics equipment at defined areas such as Mombasa port to hydrogen as fuel; a Nairobi transport case where – also at a defined area with clear routes – new utility or public transport vehicles fuelled with on-site generated hydrogen act as a show case for hydrogen in the sector, though with strong need for subsidies or grant. Economies of scale and technological innovations may allow scaling up this option to other transport uses and/or other cities. Another transport option with potentially better economics but technical and policy obstacles is the option to apply H2 fuelled locomotives on the railway lines to replace step by step the current diesel engines, with saving potential of more than USD 200 million for the electrification. Time ranges differ from immediate future for logistics (i.e. even before 2025), medium term (2025 onwards) for local transport and long term for the railway.

4 Hydrogen as **a commodity and energy carrier** for larger scale uses in new technologies with industrial shift e.g. for green domestic steel production, a novum as both the technology (non-coke based) and the location (not in emerging or industrialized countries) would be new and entail certain risks. However, the new technology and processes may allow smaller plant sizes close to further processing (which already exists in Kenya) and growing demand. Time horizon is rather towards 2030, when a smaller scale plant could be operational.

5 Hydrogen or methanol / ammonia **as an energy carrier for off-grid supply** of isolated grids (increasing availability compared to PV battery powered grids) or single consumers such as Base Transceiver Stations (BTS, mobile phone network). As existing supply schemes for these off grid supply are already costly new hydrogen based options could complement the range of off grid electrification solutions. They could immediately serve as a show case for hydrogen use as commercial products are already available but not taken up by the market for various reasons.

Other uses of hydrogen appear currently less suitable for Kenya but may rank higher and more probable in the far future – such as high-volume transport (fuels) or export of energy – if enabled by further development in the country and technical innovations. Monitoring of these developments and continuous update of this analysis will help to identify and develop further industrial pathways.

Key results of the five pathways with regard to their technical, economic and climate change mitigation potential are summarized below.

Table 7-1: Recommended industrial pathways

Pathway	Time frame	**Technical potential** (2025/30 electrolyser)	Commercial potential and trend	Comparative advantages	Limits / challenges	Climate change effect / NDC relevance	**Green H2 emission reduction / unit**	**Volume Kenya**	**Green H2 emission reduction / unit**	**Volume Kenya**
#1 Fertilizer (H2 as a commodity via ammonia)	Medium term (start 2025-30 onwards)	300-400/400-500 MW (~1,200/1,400 MW - region)	(50) - 100 MW Cost decrease expected, but cost shares of RE and non-green H2 remain main factors	Competitive if external costs factored in (e.g. transport and foreign exchange risks)	Established market (risk), suitable size (scale, capex), water avail.	Big but abroad / No	~ 2 t CO_2 /t NH_3 ~ 1 t CO_2 /t nitrogen-based fertilizer	~0.6 mt fertilizer (~ 25% N_2 content)	0.1-0.6 mt fertilizer	0.1-0.6 mt/a CO_2
#2 H2 / derivatives higher priced commodity for existing / new processes (ammonia, methanol etc.)	Short to medium term (now with pilot - 2025 onwards)	10 - 20 MW (depends on methanol techn. feasibility) + growth potential	1 – 10 MW (depends on methanol economic feasibility) Decreasing cost with volume (=market growth)	Competitive, kick-start H2 development (combine with #1, #3, potential for clean cooking)	Small market with established supply chains / standards	Small, abroad / No (methanol in Kenya)	~ 2 t CO_2 /t NH_3 ~10 t CO_2 /t H_2 ~1.5 t CO_2 /t CH_3OH	~100 t/a NH_3 ~25 t/a H_2 ~4-7 kt/a CH_3OH	~50-100% ~50-100% ~10-20%	0.8 – 2.6 kt/a CO_2 (large growth potential)
#3 Transport / mobility: (1) Logistics Port Mombasa (2) Public transportation / utility Nairobi (3) large scale	Short to medium term (now with pilot - 2025 onwards) (3) 2030-2040	(1) 5–10 / > 10 MW (2) X00 MW (uncertain) (3) X000 MW, (uncertain)	Initial 5 – 10 MW, depends on funding, R&D; CAPEX to decrease but not competitive without e.g. CO_2 price	(1& 2) Confined area, kick-start H2 development/ knowhow PR /showcase	(1) Limited demand (2, 3) Technical alternatives (potential lower costs)	(1) Small, (2) Medium (3) Big / Yes	1.4 kg CO_2 /km per bus	3-4 mt diesel / petrol (mainly for transport)	few %	10.0 kt/a CO_2 (potential of millions)
#4 H2 as energy/ commodity for large scale use e.g. steel	Medium to long term (2030-40, but start preparation now)	1,500 – 2,000 MW (3,000 – 4,000 MW region) 3 -7 m t steel / year	Depends on funding, e.g. 50 – 500 MW; huge potential with on-going large scale technological development	Market / knowhow, Technological progress	Technology, scale / size, water, costs	Big, abroad / No	2 t CO_2 /ton steel	~ 3.0–3.5 mt (region: 6.0- 7.0 mt)	~ 0.1-1.0 mt (2030-40)	0.2-2.0 mt/a CO_2 (2030-40) up to 14 mt/a CO_2 regional
#5 H2 energy carrier for off-grid supply	Short to medium term (now with pilot)	Aggregated 20-40 MW (e.g. part of 1000 – 2000 Base Stations)	Depends on funding, uncertain whether niche or mass market	Niche / alternative to diesel and PV-battery	Knowhow / service, costs	Small, Kenya / Yes	3.2 ton CO_2 / ton diesel	~ 15 kt diesel/a	~ 10-50%	4.8-24 kt/a CO_2

7.2 Focus Sites / Projects and Hubs

This section briefly outlines potential candidates (site and use cases) in terms of sites to focus on, pilot projects to pursue with an outlook to combine the into so called hubs. This is also summarized in section 9.4 of the Action Plan.

In is recommended to find a balance between concentrating projects at sites and distributing them among the various possible preferential areas: A concentration at only site is possible but the projects are better split into several geographical sites in order to widen the analysis of an early piloting phase to gain experience on the site-specific advantages and disadvantages. This will allow to initiate different hubs (or “green H2 valleys”) – actually a concentration of projects and infrastructure at one site or area. This will be essential to scale up capacity by bundling expertise and using infrastructure efficiently also across sectors or value chain elements (i.e. electrolysis, storage, use). Opportunities are cross-sector exchange of green H2, balance H2 surplus or deficiencies and develop a domestic and even regional green H2 knowledge hub which could deal as a showcase where decision makers and investors could be informed about different green H2 applications and their pros and cons.

The following list of focus sites and projects does not imply a ranking, i.e. then preference of one project over another. Each site offers particular opportunities and unique features but also certain disadvantages. Mombasa for instance ranked highest mainly due to the availability of water (through desalination) but also the likely availability of suitable or pre-developed areas and sites (within port area) while for Olkaria and Nairobi the water supply may be an obstacle and needs to be solved in a sustainable way.

7.2.1 Olkaria green H2 for Fertilizer / Derivatives Market

Sizes of electrolyser, which determines also the sizing of the successive production line, could be of different range. Lower sizes in the range of 20 MW, currently the largest single electrolyser in the world, may allow higher utilisation of surplus electricity and by this lower RE costs up to 50 MW – a typical size for planned projects or even between 50 MW to 100 MW with reducing economies of scale for the electrolyser but for the successive plants. Storage has to be sizes according to supply arrangements but may need to cover only the continuous demand of 3 to 4 hours of hydrogen supply. Land requirements are manageable with e.g. 4000 to 5000 m^3 for the 100 MW electrolyser and 3-4 hour storage and additional land needs for the downstream production facilities and product storage etc.

Plant location could be anywhere with power supply and water supply. However, vicinity of geothermal plants may allow for future closer links in terms of steam, flue gases with H2S or CO2 etc. Further it may form the core of a later chemical park. The availability of flue gas and potentially other sources of CO2 as well as the geothermal steam is a unique feature compared to all other sites which may allow for a much higher diversification of products in the future. The availability nearby transmission capacity and important network nodes, the on average lowest transmission costs for RE as well as a central location for the distribution of products in the country and the region, ten availability of infrastructure (road, railway) and the vicinity to Nairobi are further enabling a feasible operation.

7.2.2 Nairobi green H2 for Transport and/or Fertilizer / Derivatives Market

A shift of the above described project to the nearby Nairobi area should be also feasible with some opportunities such as vicinity to technical services and expertise, possibly at existing sites with chemical production processes and the opportunity to supply consumers in Nairobi with products. It may however also come with disadvantages with regard to available supply of land, infrastructure, CO2.

7.2.3 Mombasa green H2 for Transport and Fertilizer / Derivatives Market

Similar to the above but possibly at smaller scale a production of green H2 and potentially derivatives could be build up in Mombasa port area to serve hydrogen fuelled logistics and directly replace currently imported commodities. Potentially, fertilizer production could be developed too with certain advantages, e.g. vicinity to import facilities of necessary supplementary products and infrastructure for distribution on the domestic and regional market as well as the opportunity to produce close to the transport hub for the export market. However, limited availability of CO2 (for a diversification of production) and higher RE costs for larger scale expansion may reduce large scale viability.

Mombasa offers various unique advantages, the combined vicinity to existing infrastructure (transport, such as port, railway, road; handling / storage areas and companies for commodities including sites for chemical processes) and the unlimited availability of water through desalination. The main disadvantage is the reliance on electricity transport from Central and Western parts of the country for most of the electricity, with higher transmission costs and transmission capacity restrictions or costs for extension of the existing corridor.

Because of this limitation and the electricity need of the port, green H2 as a peaking / back-up capacity could be an option (compared to alternatives, such as network extension or LNG based gas turbines), see also next.

7.2.4 Off-grid and Captive Power Pilots and Proof of Concept

As depicted in 6.1.4.5 off-grid supply could be immediately feasible and a show cases for green H2 in Kenya with direct fossil fuel reduction (though at small scale) and improved services.

Different technical options exist: i) an isolated grid which would benefits most from better / longer storage, ii) converting base stations from fossil fuel to on-site hydrogen production or green ammonia / methanol produced at another site (see above), iii) a large scale consumers with a need for captive / uninterrupted power supply (in remote areas or vicinity of the grid) iv) smaller scale research / proof of concept applications. Vicinity to Nairobi may accelerate the spread of know how. If successful, this should be rolled out to remote areas which are more in need. With this variety such applications will offer opportunities for a proof of various concepts on a small scale.

Further, it may be the starting point to analyse the benefits and challenges to use this technology as a grid connected capacity for back-up/peaking power also to support regional grids as in the coastal area / Mombasa port area. This may also include how an electrolyser and a fuel cell or other hydrogen to power converting device may contribute to the power system (ancillary services like regulating reserve / demand side management or black start capability).

7.2.5 Other Areas

Other potential areas for green H2 projects and hubs were identified and analysed such as Lamu area / LAPSSET (Coast),7-Forks / Thika (Central) as well as Western Kenya and Lake Turkana area. All these areas offer one or more particular opportunities such as availability of water, land, infrastructure capacity or vicinity to RE resources.

However, the analysis revealed that these opportunities do not outweigh certain disadvantages which are mostly the remoteness in terms of demand and infrastructure. This weighting may change in the far future as regions develop or requirements change.

8 INVESTMENT PERSPECTIVES

8.1 Green Hydrogen Goals

A country's green hydrogen goals can take many forms. Green Hydrogen goals can be categorized by levels of production, type of end use, money invested in supporting infrastructure or even a broader vision statement. For example, Japan has a commitment to becoming "the first country in the world to realize a hydrogen-based society". Australia on the other hand is focused on hydrogen production for export throughout Asia, "Facilitate hydrogen-related foreign direct investment, business migration and business expansion Securing overseas investment in new export-capable industries."

Several countries have hydrogen production goals in terms of volume but also in terms of production method, for example China has the goals of "Increased use of hydrogen derived from clean energies to more than 50 per cent by 2030."

Often an end use goal will center on electricity or mobility. For example, South Africa has the goal to produce 6TW of electricity from hydrogen by 2040. Japan is "targeting the use of fuel cell electric vehicles including 800,000 passenger cars, 12,000 busses and 10,000 forklifts by 2030". One of China's goals focuses on lowering hydrogen cost as an enabler to implementation, "Technological progress in fuel cell systems, key materials and components including a near 90 per cent reduction by 2025 in fuel cell stack costs compared to 2015 prices".

All are valid ways of describing the overall hydrogen vision and establishing short, medium and long term targets in terms of supply, infrastructure and demand.

8.1.1 Kenya's Green Hydrogen Goals

According to the Hydrogen Working Group, Kenya does not yet have established hydrogen goals per say. The development of such goals will likely be part of upcoming hydrogen strategy which is being planned. However, there are several objectives and the outline of a vision of what several stakeholders in Kenya are working towards.

Kenya has abundant sources of renewable energy, though solar and wind are intermittent, geothermal is baseload and produces more electricity that is needed in non-peak hours.

Kenya aims to become a leader in the hydrogen economy in Africa through using off-peak renewable energy to produce green hydrogen which can be used to help decarbonize Kenya's economy.

This overall vision matches well with Kenya's NDC targets of a reduction of GHG emissions by 32% in which green hydrogen could play a role in decarbonizing the economy. Under a normal pathway, increasing GDP through manufacturing to become a middle-income country could lead to increased emissions. However, various stakeholders and sectors in Kenya are looking at hydrogen as a tool to achieve economic growth and become a middle-income country without increasing emissions.

The multiple method(s) on how hydrogen can be used to decarbonize the economy are currently being discussed. It could be as a form of energy storage, to provide for thermal loads or to produce hydrogen-based products such as ammonia for use in decarbonizing industrial processes and fuel cells for heavy machinery mobility.

Long term planning is starting to consider the development of Hydrogen to take an important role in decarbonization as evidenced in the LTS (Long Term Low Emission Development Strategy for Kenya). In which it is forecasted that Kenya can achieve net zero if the electricity system is successfully fully decarbonized and energy consumption in industry and transport shifts from traditional carbon-based fuels towards clean electricity sources including hydrogen fuel. Specifically:

- 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 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.
- Transport - Transition from fossil fuel to electric and hydrogen fuelled vehicles, with 30% of all vehicles on road to be electric or hydrogen powered by 2050. With the extension of 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 percent will consist of state-of-the-art trucks on hydrogen fuel cells.

According to the LTS, in 2050, the total share of gasoline and diesel oil in the fuel mix will be around 45%, whereas electricity will account for 42%. LNG and LPG will make up 12% of the fuel mix, whereas the share of hydrogen will be less than 1% - but it will be quite significant.

The current interest in green hydrogen is driven led by manufactures and industry who want to use it to decarbonize their own operations. In addition, KenGen is considering a number of pilot projects which are still in concept phase.

8.1.1.1 Hydrogen Working Group Stakeholder Objectives

The various non-governmental stakeholders in the Hydrogen Working Group also have their own goals, which together help enable Kenya in reaching their overall objective. Examples of some such objectives include:

- GDC (Germany Development Cooperation) has the objective of through technical assistance, to help enable at least 600GWh/year (100MW electrolyser capacity, 70% capacity factor) of green hydrogen by 2025 and at least 3,000 GWh/year (500 MW electrolyser capacity, 70% capacity factor) by 2030.
- The EU sees green hydrogen as enabling a new vector for decarbonization. Kenya is a stable country in a troubled region and has the opportunity to become a technology leader and act as a catalyst for decarbonization in eastern Africa. The ultimate goal is to help enable the establishment of complete value chains, in order to enable private investment at scale, which will create green jobs and add real value. The EU intends to help create this enabling environment through being the first level risk taker, for example to offer funding for initial risk in pilot projects.
- KfW has a clear mandate to support the public sector, generally aiming for projects in the 20-80 mil euro size. KfW does not yet have a clear policy target for green hydrogen in Kenya. That being said, there are studies currently underway targeting the feasibility for decarbonizing certain industrial sectors in Kenya as well as for providing ancillary services. Furthermore, KfW is willing to provide upfront risk mitigation funds, for example in the area of policy development to better enable private investment in hydrogen.

Other stakeholders are currently in the process of formulating formalized objectives. It is hoped that this Baseline study will assist in this task.

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8.1.2 Potential Green Hydrogen Projects

The Consultant has endeavoured to develop a consolidated list of green hydrogen projects. During the course of the project, the Consultant spoke with a number of potential developers who are currently in early to mid-stage development of potential projects. However, the details of these projects were discussed on the condition of anonymity. Project partners were not willing to disclose information related to business model green hydrogen or derivative product, nor size or estimated cost publicly.

Therefore, the following high-level review of potential green hydrogen projects is based on previously disclosed public information (government, NGO, GHWG, industry announcements). It is noted that the Consultant has observed significantly more interest in green hydrogen development from industrial partners in the country than what is disclosed here.

Project: Power-to-fertilizer plant by Maire Tecnimont S.p.A.[28]

Project Company: Maire Tecnimont S.p.A., an Italian group of 50 companies, through its subsidiaries MET Development, Stamicarbon and NextChem has announced their interests on a commercial scale renewable power–to-fertilizer (nitrate fertilizer) 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 the plant.

Location: The plant will be located at the Oserian Two lakes Industrial Park (100 km North of Nairobi)- a new 150-hectare sustainable industrial development in Nakuru county, Kenya

Energy source: The plant is expected to utilize approximately 70 MW of renewable power, to be sourced from geothermal energy as well as by on-site solar energy production.

Investment volume: Unknown

Volume on H2 (or related products):

The project targets to produce 550 mtpd (metric tons per day) of Calcium Ammonium Nitrate (CAN) and/or NPK fertilizers (fertilizers based on Nitrogen, Phosphorous and Potassium), depending on the demand of local agricultural requirements.

Proposed project timeline: Expected start of commercial operation of the plant in 2025

Status of proposed project: The project has started preliminary engineering works. The Front-End Engineering Design (FEED) was expected to begin by the end of 2021. MET Development is currently engaging with local and international partners to set up the development consortium.

Emissions reductions: The facility will reduce carbon emission with approximately 100,000 tons of CO2 per annum, compared to a gas-based fertilizer plant.

Other benefits: increase agricultural output for farmers and communities; increase fertilizer affordability and availability; reduce the dependency on imported nitrogen fertilizers and substitute around 25% of the total accounts (800 kt/a), over 100 direct job creations.

Project: Green hydrogen and ammonia project by Fortescue Future Industries (FFI)[29]

Project Company: Australian green energy company Fortescue Future Industries (FFI), a subsidiary of Fortescue Metals Group, has signed an MoU with Kenya Private Sector Alliance (KEPSA) for the potential development of a green hydrogen and ammonia project in Kenya. FFI is keen to invest in large-scale green energy projects worldwide. KEPSA is a membership organisation formed in 2003 and an apex body of private sector in Kenya.

Status of proposed project: 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.

28 https://www.mairetecnimont.com/en/media/press-releases/maire-tecnimont-group-starts-preliminary-work-on-renewable-power-fertilizer-plant-kenya

29 https://ijglobal.com/articles/159979/fortesque-signs-mou-for-kenyan-green-hydrogen

Project: R&D/ Demonstration project on zero-emission energy generation and storage technology by Strathmore Energy Research Centre (SERC) and Steamology™ in Kenya[30]

Project company: Strathmore Energy Research Centre (SERC) and Steamology™ will implement and demonstrate a zero-emission energy generation and storage technology in Kenya, funded by DFID through Innovate UK's Energy Catalyst programme. Steamology™ is a technology development company based in the UK and specializes in utilizing steam to generate electricity and will be the lead organization with SERC being the lead development partner in Kenya.

Project scope:

The concept of Water to Water (W2W) system will be used in a closed loop in 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 pressurized cylinders where they can be recombined, on demand, to produce steam in order to re-generate electricity.

The solution also has good potential in replacing traditional battery storage technologies and could be applied in off-grid/ mini-grid electricity generation to provide energy access for productive use as well as offer power back-up alternatives to the traditional diesel generators. Large scale storage is possible since the system is modular and can be expanded to produce up to 1MW of power.

8.2 Financial Landscape for Green Hydrogen Economy in Kenya

The primary requirement to attract private sector capital into green hydrogen investments is an appropriate policy framework. Globally, green hydrogen investments have higher investments costs than alternative carbon intensive options. Therefore, at the current initial stage of green hydrogen market, public institutions have a pivotal role to play in mobilizing public finance along-side policy frameworks that will incentivise private sector to invest in green hydrogen projects and programmes. Clearly, private investments will be mostly driven by the profitability and risk-return profiles of the potential green hydrogen investment.

In particular for green hydrogen economy, public finance can be very effective when it is contributing to pay for the incremental carbon avoidance costs for the project either in the form of investment grants, fiscal incentives, price premiums or a combination of all instruments as needed by the specific intervention.

8.2.1 Climate Finance Landscape in Kenya

Kenya has a very good track record in attracting global climate finance flows into the country especially for low carbon mitigation sector. Investment in green hydrogen economy cannot be set apart from the climate finance sector. Since the Paris Agreement, Kenya has attracted climate finance flows in the country through domestic and international sources. In 2018, KES 243.3 billion (˜EUR 1.9 billion) of public and private capital was invested in climate-related activities both from domestic and international sources. Overall, public investment (from domestic and international providers) led the total climate finance portfolio in Kenya (59.4% of total financing, equivalent to KES 144.3 billion or ˜EUR 1.13 billion), where more than half of it (52%) came via international public funding sources. Overall investment from the private sector was about 40.7% amounting to KES 98.9 billion (˜EUR 0.77 billion), where about 34% came via domestic private companies and the rest as international funding from private sources (CPI 2021).[31]

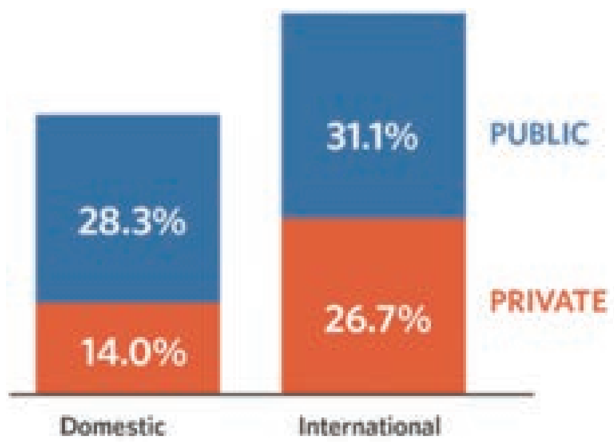
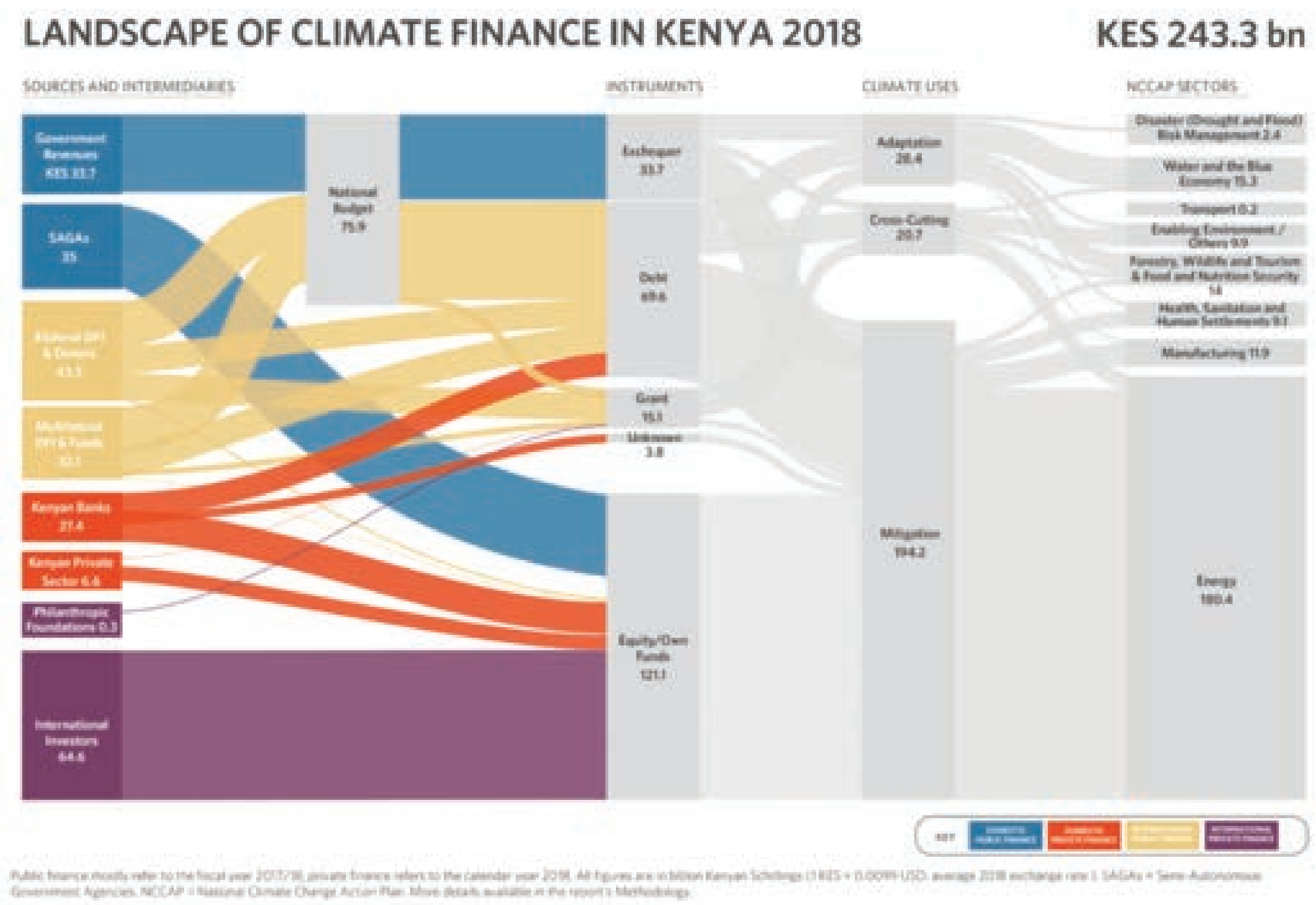


Figure 8-1: Overview of climate finance in Kenya in 2018 (source: CPI 2021)



(Source: CPI 2021)

Figure 8-2: Landscape of Climate Finance in Kenya 2018

The figure above shows a comprehensive overview of climate-relevant expenditures in Kenya by domestic and international, public and private actors in 2018. Domestic private stakeholders include banks, companies, MSMEs. Kenyan public sector stakeholders include Semi-autonomous Government Agencies (SAGAs), National Treasury & Planning, ministries, state departments and international stakeholders include UN agencies, DFIs, private investors, developers and philanthropic foundations.

As per the targeted sectors defined in the National Climate Change Action Plan (NCCAP), use of green hydrogen could be used in the energy, transport and manufacturing sectors. As shown in the figure above, a significant percentage of investments took place in the energy sector mitigation projects amounting to

30 https://strathmore.edu/news/innovation-in-energy-generation-and-storage/

31 Climate Policy Initiative (March 2021), *The Landscape of Climate Finance in Kenya*, https://www.climatepolicyinitiative.org/wp-content/uploads/2021/03/The-Landscape-of-Climate-Finance-in-Kenya.pdf

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KES 180.4 billion (˜EUR 1.41 billion) mainly due to large-scale investments in renewable energy generation in geothermal, solar and wind, whereas climate funding into the manufacturing and transport sectors were seen less significant.

In Kenya, financing for large-scale renewable energy projects was predominantly from DFIs and Development Partners, whereas private equity and venture capital companies were investing in decentralized smaller scale investments (pay-as-you-go solar, microgrid etc.). It can be also seen that of the total financing flows KES 243.3 billion (˜EUR 1.9 billion), the Kenyan government disbursed KES 76 billion (˜EUR 0.59 billion) in climate-related development expenditures in the FY 2017/18, which included government revenues (mainly tax funds and other public funds) as well as a portion of the international funds from DFIs and donor agencies. The remaining financing flows are received by private, public-private, and non-government organizations in Kenya as grants, debt and equity.

Overall, as far as international public funding is concerned, both bilateral development partners[32] (ministries, agencies, and development finance institutions) and multilateral institutions, including development banks, UN agencies and climate funds[33] remain as key stakeholders for Kenya in realizing its NDC goal. Kenya has revised its NDC pledge in 2020 and now targets 32% emission reduction by 2030 relative to Business-as-Usual scenarios with total costs estimated at USD 62 billion (˜EUR 55 billion) between (2020-2030), where, plausibly, contribution from green hydrogen technology is not yet allocated or specified.

8.2.2 Funding needs along the green hydrogen development path

Globally, there is a common perception regarding the time frame of realizing green hydrogen road map by 2050 in line with the Paris Agenda. IRENA defines the pathways to develop green hydrogen economy in three major stages: 1) Technology readiness (2020-2024), 2) Market penetration (2025-2030) and 3) Market growth (2030-2050)[34]

The **technology readiness stage (2020-2024)** can be broadly seen as a combination of R&D and demonstration of pilot projects and applications of green hydrogen technology. At the beginning of this stage, green hydrogen is a niche market with very limited supply and demand. At this stage, the biggest barrier to the production of green hydrogen is its cost – it is currently two to three times more expensive to produce than grey hydrogen. Green ammonia is two or three times more expensive than grey ammonia, and green methanol is three to four times more expensive than grey methanol. Synthetic fuels for aircrafts are up to eight times more expensive than fossil jet fuel. Hydrogen-based industrial processes are not yet fully proven at scale. In simple terms, during this stage, policy framework and incentives will be designed to accelerate technology development and boost up confidence in the market by reassuring long-term commitments for green hydrogen market development. During this stage, focus is given to improve business cases for green hydrogen projects, deploy more electrolysers and identify decarbonizing applications that are relatively easier to adopt i.e. applications where already hydrogen is in use or facilitate green hydrogen in new end-use applications. This stage will raise market awareness about the sustainability of green hydrogen and address the initial market entry challenges such as high production costs through initial policy and support framework that might be also evolving down the line. Private sector participants will be encouraged to implement demonstration projects through the green hydrogen economy support framework.

32 Japan, China, Italy, United Kingdom, Netherlands, France, and Germany as key bilateral partners to Kenya in 2018

33 International Development Association (IDA)/World Bank, African Development Bank, International Fund for Agricultural Development (IFAD) were the main contributors in 2018

34 IRENA (2020), *Green Hydrogen: A guide to policy making*, International Renewable Energy Agency, Abu Dhabi

The **market penetration (2025-2030)** stage will be concentrated on realizing the economies of scale and thereby reducing costs of green hydrogen production and applications. The policy mix could be further adjusted or extended to new areas as both hydrogen technologies and markets mature over time. There will be more private sector participation in green hydrogen projects; some industrial applications will be leading in using green hydrogen or its derivatives than the others, while new demand will be created for existing and new applications. Electrolysis generation capacity will be increased in line with the new demand, infrastructure (i.e. port, in-land transportation, gas pipeline, storage) needed to facilitate domestic production and consumption of green hydrogen will be newly built or repurposed from existing gas grids. Towards the end of this stage, it is also expected that export infrastructure will be setup to facilitate cross-border trade of hydrogen and export to selected international route(s) through established regional and international cooperation.

At the market growth (2030-2050) stage, green hydrogen sector will be rapidly commercialized having a global supply chain and become competitive both on the supply and end-use demand side in a wide range of sectors. By then, green technologies will be fully proven, and its applications will be the most convenient options to adopt among the alternative uses. Relatively hard-to-abate sectors of earlier stages (e.g. aviation, shipping) will be using green hydrogen at large scale. Power sector is expected to be fully decarbonized with green hydrogen contributing to ancillary market. The green hydrogen economy sector will be led private sector and public interventions will be down to the minimum level except for overseeing the policy, regulations, facilitating domestic market and international trade. Infrastructure will be fully equipped to facilitate domestic and international demands for green hydrogen and its derivatives.

The role of **public-private partnership** is to mobilize private investments through public concessions in order to create a commercial market. Public supports are needed in different stages of market maturity and in different segments of the value chain (i.e. hydrogen production, hydrogen infrastructure and hydrogen use). Public-private partnerships can reduce the risks during early deployment, facilitating the transition from demonstration to commercialisation. The objective should be to reach a point where no further public support is needed.

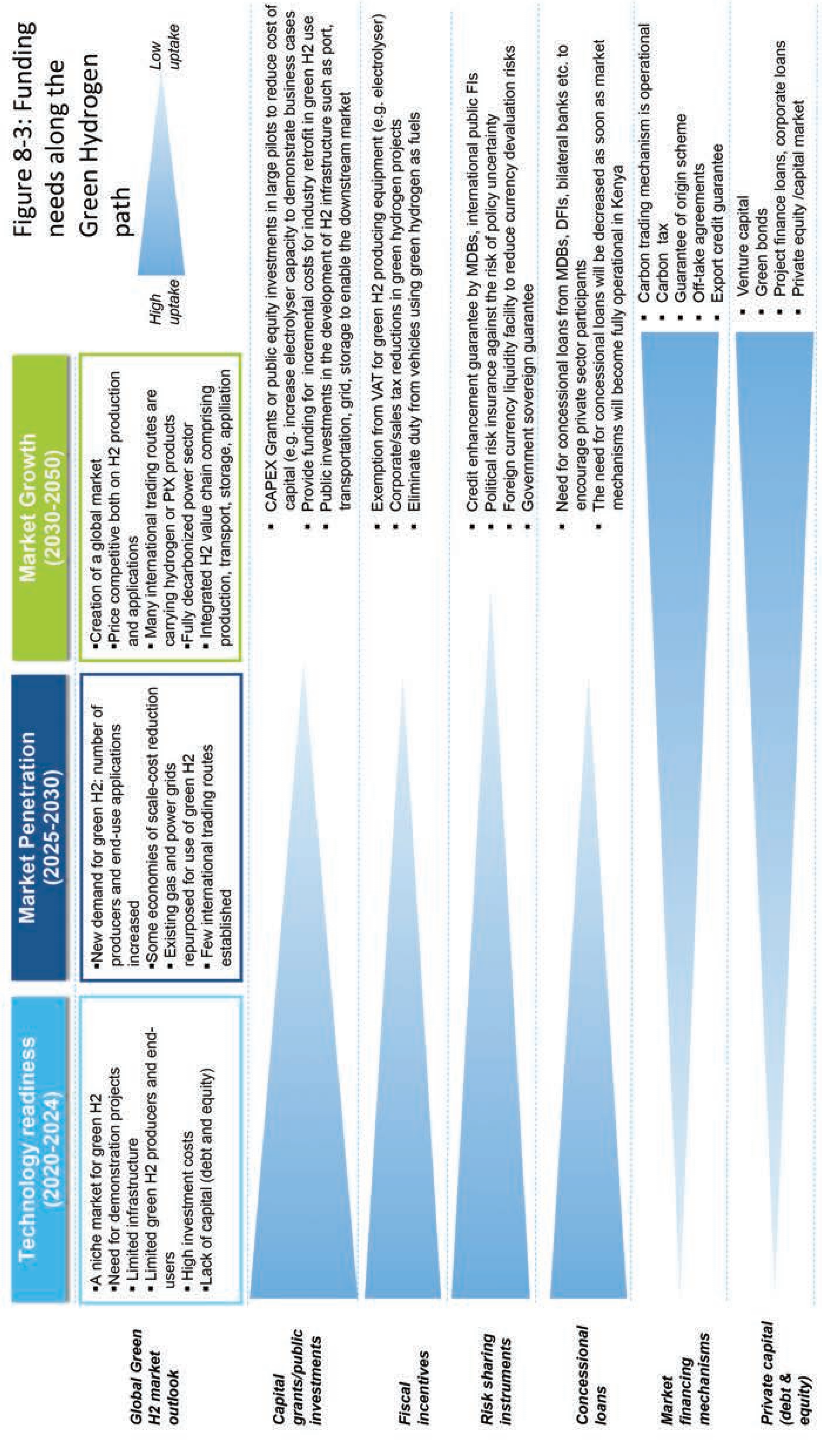

Figure 8-3: Funding needs along the Green Hydrogen path

Different sources of finance will come into play at the different stages of green H2 economy:

- **R&D,** green H2 pilot demonstration projects will typically be funded by government, even if undertaken by the private sector. However, public capital alone is not enough to penetrate the green hydrogen market. Therefore, from the very beginning government shall allow private sectors to participate in implementing demonstration projects. Given that technologies are not yet commercially viable and there is not yet a market or pricing for green products, during the demonstration phase, private sectors need to be incentivised for undertaking demonstration projects. The supports may include CAPEX and operational cost gap reduction through direct or indirect fiscal incentives, price premiums, grants, concessional loans etc. channelled from the international and local public funding sources. Down the line, public funding will be continuously needed in the development of hydrogen infrastructure comprising gas infrastructure, port infrastructure and building new dedicated pipelines for transmission and storage systems for hydrogen, development of demand clusters/ supply centres, and thus lower the overall costs for energy transition.
- Once there is **proof of green H2 concept**, large scale commercial deployment can be predominantly financed by debt and project finance instruments during scale-up and commercial roll-out of the interventions.
- **Risk sharing instruments** such as partial risk guarantees provided by international public financial institutions can be blended with debt instruments and will be useful to reduce the risk to private lenders especially at the beginning of green H2 market where policy incentives for investments are lacking. The intended impact is that the lender is then better positioned to charge a lower interest rate on the loan, thereby lowering its cost of capital i.e. considering concessions on the loans.
- The need for concessional loans will be decreased as soon as **market financing mechanisms** will become fully operational in Kenya. As an example, once established, the carbon trading mechanism can provide a significant revenue source that can help improve the returns of green H2 projects and concessional financing will no longer be needed. Without carbon pricing scheme or greater willingness to pay for the "green" value of green hydrogen and its derivatives, the PtX products will not be competitive with alternative options. It will be important to form direct partnerships with/ between companies or with countries to guarantee the offtake of PtX products. A guarantee of origin certification scheme will guarantee off takers that the PtX products are carbon neutral. Quotas of green hydrogen in end uses will help producers predict the demand.
- **Private capital** flow will depend upon project's commercial viability. Prospective investments are expected to cover the full costs of the project, including the cost of capital and achieve a return commensurate with the risks associated with a specific green H2 project. At some stage of technology development, venture capital firms may be interested in the deployment of H2 technology and taking the portfolio risk with higher return expectations (high first-mover costs and unproven commercial application of green H2).

8.3 Resource Mobilization Strategy

The following section briefly describes the types of funding tools and methods which could be applied for green hydrogen as well as a description of how these tools could be used to encourage implementation of green hydrogen at scale.

Further to that, possible funding mechanisms including targeted incentive measures extendable from domestic as well as international funding sources are listed in sub-sequent sections. A set of policy and financial de-risking incentive measures will be vital to kick-start the green hydrogen market and will be explained in detail.

Globally, around USD 700 billion (~EUR 619 billion) direct investment is required by 2030 to realize the full potential of hydrogen. This is based on over 30 countries which have already introduced hydrogen strategies as well as more than 520 large-scale low carbon and renewable hydrogen projects. Projects and government support worth USD 160bn have been announced, leaving a gap of nearly USD 540bn (Hydrogen Counsel 2021).[35]

As discussed above, Kenya is well positioned in extending its climate finance portfolio to green hydrogen economy. Leveraging the presence of international development partners such as donor countries, MDBs, DFIs that have been playing a key role in fulfilling Kenya's climate agenda, the country can target for developing specific projects and programs on green hydrogen. **In order to attract and mobilize climate funds especially on green hydrogen, utmost importance shall be given to establish an overall economy support framework including policy, regulatory supports and fiscal incentives.**

35 Hydrogen Council (Nov 2021), *Policy Toolbox for Low Carbon and Renewable Hydrogen*, www.hydrogencouncil.com

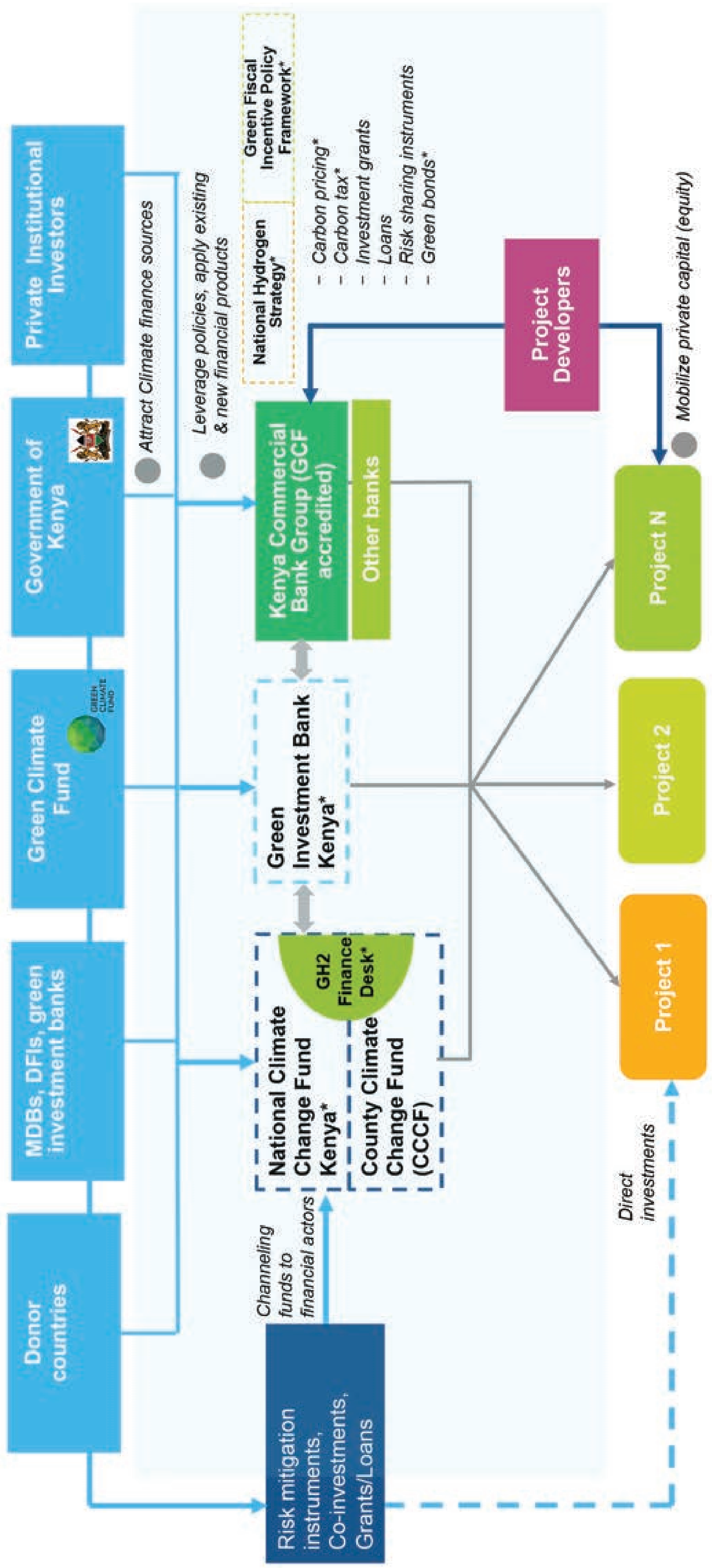

Figure 8-4: Tools for Mobilizing Funds

*Policies underway: National Hydrogen Strategy and Green Fiscal Incentive Policy Framework that will aim to streamline financial incentives, carbon pricing etc.
*National Climate Change Fund (CCF) is yet to be fully functional . Within the CCF, a dedicated Green Hydrogen Finance Desk can be established that will support implementation of priority projects and programs on green hydrogen economy
* Kenya Green Investment Bank is proposed for providing finance for government and private sector projects in renewable energy and low carbon sectors
* Kenya has also plan to issue its first sovereign green bond.

Figure 8-4: Tools for Mobilizing Funds

It is expected that the current green hydrogen/PtX study will lay the foundation for developing a full-fledged **National Green Hydrogen Strategy** for Kenya which will define the road map, milestones and support framework. Currently the **Green Incentive Policy Framework** is in draft stage under the purview of National Planning and Treasury Department which will consolidate and incorporate all major climate agendas such as National and County Environment Policy, SDGs, NDC goals, Kenya Vision 2030 and the national adaptation plan. The framework will provide guidelines on enhancing 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 taxations and economic incentives such as **carbon trading mechanism 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.

On the national level, a **Climate Change Fund (CCF)** has been already established in Kenya by the National Treasury as a financing mechanism for the priority climate change actions and interventions under the Public Finance Management Regulations 2018. **However, the fund is not yet operational.** Once fully operational, CCF could effectively manage both national and international climate finance sources, monitor and support implementation of climate financing activities in the priority areas in a holistic manner. **Within the CCF, a dedicated Green Hydrogen Finance Desk can be established** that will support implementation of priority projects and programs on green hydrogen economy. The existing **County Climate Change Fund (CCCF) can be also integrated in managing financing for green hydrogen projects or programs.** Notably, the CCCF is a county-controlled fund enacted by Kenya's 47 county governments and it has successfully financed climate projects, mainly in the resilience and climate adaptation sectors, identified and prioritised by local communities. CCCF could also play an important role in strengthening proposals for green hydrogen economy development resulting from participatory local planning, identify synergies across different counties, and align county-level opportunities with national level green hydrogen strategy.

Kenya has a well-functioning financial sector. **Participation from local public/private banks, financial institutions is necessary** in implementing green hydrogen agenda of the government. Local financial actors can play a crucial role in blending national funds and international support together (technical assistance fund, grants, debt finance, investment) and developing new financial products and services that will be beneficial for the green hydrogen industry. For instance, **Kenya Commercial Bank Group (KCB)**[36] has become the country's first bank accredited by the Green Climate Fund (GCF), one of the key financial instruments in mobilizing climate finance globally, to support climate mitigation and adaptation projects through green financing. Kenya has also planned to establish **Kenya Green Investment Bank** to allow easier access to finance for government and private projects in renewable energy, energy efficiency, green transport and waste-water treatment projects. The finance ministry has plan to issue its first sovereign green bond.[37] Being first movers, these banks can extend their climate finance portfolio in green hydrogen and encourage other banks to tap into this new market.

The key objective of mobilizing public funding in green finance is to reduce the funding gaps through increasing the flow of private capital and leverage private investments through various policy and financial de-risking measures. Private sectors such as banks, project developers will step forward into this new green hydrogen market once the risk-return profile would match to their investment decision criteria. The proposed economy support framework on green hydrogen will thereby give a positive signal to private sector participants towards an enabling environment for investment in green hydrogen economy.

36 https://kcbgroup.com/kcb-green-climate-fund/

37 https://www.reuters.com/world/africa/kenya-plans-set-up-emissions-trading-system-2021-05-11/

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8.3.1 Types of Funding Instruments

The following list gives possible funding mechanisms for green hydrogen projects. As green hydrogen projects' economics are still directly or indirectly highly dependent on public support, the list also contains a number of incentive measures. These can be used to help make a project financially feasible.

Type of financing	Main characteristics
Equity	■ At highest risk ■ May be provided in the form of grants or "quasi-equity"
Debt	■ Available at different levels of risk ■ May be in form of corporate or project finance, i.e. with recourse to the project's assets only (ring fencing)
PPP	■ Concessional financing of a public good/service ■ Mostly done in the form of no-recourse financing ■ Risk sharing with the public authority
Incentive measures:	
Investment grants	■ On electrolysis or other relevant assets ■ Reduces the financing burden and thus the risk
Tax incentives/exemption	■ Reduce the OPEX by beneficial tax rates or partial/full exemption
Accelerated depreciation	■ May reduce the fiscal profits of the investor and thus provide opportunity profits, which reduce the financing burden ■ Reduce tax payments
Carbon tax	■ Internalize societal cost of carbon emissions in relevant economic activities (e.g. transport sector, grey hydrogen and its derivatives) ■ Yielded revenues can be used e.g. to provide investment grants to promote new hydrogen projects
Carbon pricing mechanism	■ Establishment of a price for carbon emission allowance to be paid to the state ■ Makes carbon emitting technologies less competitive (and green H2 products thus more competitive) ■ Can be supplemented with contract-for-difference approach to further promote green H2 products
Price premium for green H2 production	■ Operational grant (compared to investment grant) depending upon per avoided ton of CO2 in green hydrogen projects
Public procurement of PtX products	■ State agencies purchasing products made using green hydrogen (=offtake guarantee)
Quotas of green H2 in end use cases	■ Direction of quotas of green H2/PtX based products in a certain end-use application ■ Reduces the offtake risk by kick-starting the demand
Guarantee of origin for green H2	■ Certificates the greenness of H2/PtX product ■ Enables higher price compared the corresponding gray H2 based products

In the following sub-sections the describe financing sources and mechanisms in more detail.

8.3.1.1 Equity Products

Natixis considers that "in the private sector, projects involving green hydrogen in the energy and industrial sectors (chemicals manufacturing and refining activities) are still at the pilot phase, initiated by energy producers and industrial concerns keen to develop a learning curve in this promising, but still nascent activity. These private sector sponsors (generally international groups that are leaders in their field and enjoy privileged access to the capital markets) raise their own financial resources, hoping that at a later development stage they will benefit from the recently announced aids at national level and at European level (EU Green Deal)."[38]

In its "Guide to Policy Making on Green Hydrogen", IRENA assesses that policymakers can provide direct dedicated funding from public state budgets or assist access to private capital by establishing guidelines or new facilitating mechanisms. For the first investment projects public support may be needed in order to attract private capital. Based on the versatility of hydrogen, multiple ways can be taken to expand existing funding programmes to cover its development.[39]

At the end of 2019 the European Investment Bank (EIB) announced that it will offer companies financing options including corporate loans, project finance, or venture capital debt. Together with the Hydrogen Council and InnovFin, EIB aims to identify funding gaps for hydrogen projects and to introduce new financial instruments.

For example, EIB has supported the downstream projects close to the finish line Elcogen in Estonia and the EverFuel project in Denmark in the areas of alternative mobility solutions or in fuel-cell technology, which had a higher-risk component (project costs in the range of few tens of millions of euros).

Elcogen secured a 12 million EUR quasi-equity facility for further research and development, supported by the European Commission under the InnovFin programme. With this support, Elcogen has been enabled to bring its fuel-cell technology to the market. The company plans to manufacture approximately 2 million cells per year (~50 MW electric capacity). The innovation about Elcogen's fuel cell technology is that it can convert a range of fuels, mainly hydrogen and biogas, into electrical energy with a higher electrical efficiency compared to conventional fuel cells.

The company Everfuel has been given a 20.7 million EUR quasi-equity facility to support development of hydrogen production and distribution infrastructure for Danish public transport. The company will make use of hydrogen from existing and new sources to deliver refuelling stations for busses and heavy-duty vehicles first in Denmark but later throughout Europe.[40]

8.3.1.2 Debt Products

Green hydrogen is far from forming a homogeneous sector. Green hydrogen rather represents an extended value chain at the intersection between three sectors (energy, industry, mobility) which also brings together three business lines (upstream/downstream equipment manufacturing, hydrogen production and infrastructure required for its end-uses). Each one brings in its own challenges and specific risk profile.

38 https: Natixis 2021: Financing Green Hydrogen's development – Clearing the hurdles

39 IRENA 2020: Green Hydrogen, A Guide to Policy Making

40 Gordon, Oliver 2021: How the EIB aims to power Europe's green hydrogen revolution.

If the financial sector is to participate in the hydrogen sector's lift-off, the stated characteristics constitute two challenges:

1 Develop instruments with features suitable for the challenges and level of the risk underlying each of the assets/entities financed across the value chain.

2 Replicate wherever possible across this chain the least costly financing arrangements already widely deployed in other sectors, drawing on the business models and nascent public support mechanisms.[41]

The table below offers a simplified overview of the main equity and debt instruments available for financing economic assets or companies.

Asset class	Instrument	Key source of risk for capital proviers	Instrument's maturity	Seniority in claim in the event of a liqudation	Overall risk level
Debt	Senior secured debt	Credit quality of the financed asset	Usually in line with that of the financed asset	Very high	1
	Senior unsecured debt	Credit quality of the borrowing company	Up to 100 years	High	2-4
	Hybrid debt	Credit quality of the borrowing company + legal clauses specific to the instrument	≥60 years or even perpetual	Average to low	3-8
	Subordinated debt (2)		≤ 10 years	Average to low	4-8
Equity	Preferred shares	Ability of the company to ensure its continuity of operations and to remunerate its shareholders	Non applicable	Very low	9
	Ordinary shares			Very low	10

Typology of main debt and equity instruments and assessment of risk for capital provider ranging from 1 (very low risk) to 10 (very high risk) (Source: Natixis 2021)

Figure 8-5: Typology of main debt and equity instruments

The above table visualises the variety of risk exposure levels underlying each instrument, influencing the returns required by creditors (debt instruments) or shareholders (equity instruments). From the standpoint of the development of the hydrogen sector this calls for the following observations:

(i) The most efficient way of minimising the cost of the financial resources mobilised for the sector's lift-off is to privilege as much as possible ***financings based on the cash flow profile of the assets****/equipment rather than the credit quality of the companies that will operate them.*

These financings generally take the form of ***secured senior debt instruments****. The servicing of these instruments (interest payments and repayment of principal) is thus based on the cash flows generated solely by the assets being financed. In return, in the event of the liquidation of the legal entity carrying these assets, holders of secured senior debt instruments have priority over other funding providers (holders of unsecured senior debt instruments, shareholders).*

The use of these instruments does suppose, however, that ***cash flows*** *for the engineering works/equipment being financed are both* ***of a sufficient amount and also stable/predictable over time*** *to ensure there are no*

41 Source: Natixis 2021: Financing Green Hydrogen's development – Clearing the hurdles

interruptions in the debt servicing. Meeting these conditions appears ***conceivable for hydrogen production and for the infrastructure activities*** *of the value chain (fuelling stations, hydrogen-powered collective equipment).*

For the deployment of ***equipment*** *entering into the* ***production of hydrogen or its end-uses*** *(commercial vehicles, collective transport), an alternative approach would be for financing to be provided directly by the supplier of the equipment (or by commercial banks), in the form of* ***leasing agreements*** *(with a flat annual payment) or pay-per-use arrangements (where the annual payment would be linked to the extent to which the assets being financed are used).*

Nascent amongst car and truck manufacturers selling vehicles equipped with fuel cells, ***pay-per-use models*** *can be expected to play a crucial role in the development of territorial hubs structured around the production of green hydrogen and its end-uses. The main benefit for the equipment operators is to* ***avoid making an upfront payment*** *corresponding to their entire cost. For the development of collective transport fleets (busses) or commercial vehicle fleets (taxis, waste collection trucks, etc.), the interest presented by this model is to base payments on the effective use of the equipment concerned, with the cost being passed on in a transparent manner to the end-user.*

(ii) Apart from senior secured debt instruments used to finance engineering works/equipment, the other instruments available, mainly ***unsecured senior debt instruments*** *and common equity, address* ***conventional corporate financing requirements****. In the hydrogen sector, companies present in the industrial sector (i.e. manufacturers of electrolysers and downstream equipment) can be expected to depend chiefly on these sources of financing in addition to eventual subsidies received from the authorities at national and/or supranational level (i.e. EU).*

Furthermore, to speed the development of their industrial base and to build their experience curve, these ***companies*** *will probably go to the capital markets, staging* ***initial public offerings (IPOs)*** *or rights issues. Note in this respect that, last autumn, McPhy raised 180 million EUR by opening its capital to new shareholders (Chart International Holdings and Technip Energies), its existing shareholders (EDF Pulse Croissance Holding and Fonds Ecotechnologies, managed by BPI France Investissement under the French State's Investment for the Future Programme) taking up their entitlement. This fundraiser was intended to enable McPhy to invest in R&D, but especially upscale its industrial activities, notably through the construction of its electrolyser giga-factory.*

From a broader perspective, within the industrial segments of the value chain, one would expect ***the equity financing requirements*** *to be* ***met by*** *a multitude of different players: leading* ***international industrial groups*** *entertaining ambitions in the hydrogen sector and forging strategic partnerships with specialist players, but also* ***para-public financial institutions*** *(such as BPI in France) serving the general interest as well as* ***venture capital providers****, this last category being more likely to be involved at an early stage in the development of the equipment (R&D and production phases before starting up real assembly lines).*

Another way of providing capital to these segments could come from the development of debt instruments ***blending the characteristics of debt*** *instruments* ***and equity*** *instruments. One example is the venture debt developed at the level of the European Union by the European Investment Bank as part of a blended finance approach. In practice, for borrowers,* ***venture debt constitutes quasi equity and is remunerated as such****. Broadly speaking, venture debt provides a cushion against the combined effects of the investment cycle and the build-up of the experience curve in equipment manufacturing through contractual arrangements that adjust debt servicing to the cash flows being generated by the borrower.*

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For the industrial segments of the value chain, the ***benefit of venture debt*** *is that provides* ***loss-absorbing capital if need be, without*** *a* ***dilutive effect for the existing shareholders*** *of the companies concerned. Despite facilitating the funding of companies at the start-up phase in the hydrogen sector, supplementing proceeds raised through the issuance of capital instruments and/or senior debt instruments, the provision of venture debt will remain very targeted, since intended in priority to finance SMEs positioned in as yet niche activities during the growth stage.*[42]

The presented aspects suggest that the **main challenge** in funding the sector in the next decade relies in the development of mechanisms to **mobilise private capital on the assets themselves.** This will help to bring down deployment costs for engineering works as well as equipment within the entire value chain.

In the Consultant's point of view, in the Kenyan context, in the initial phase of ramping up the market, the financing should preferably come from equity supplemented by public support instruments to allow for commercial operation. If debt funding is required, then corporate loans appear reasonable. If those cannot be raised, then cash flow/asset-based financing instruments appear suitable, as they may limit the risk profile for potential financiers. However, as those latter will come at higher costs, whenever possible corporate debt financing should be privileged.

8.3.1.3 PPP – Public Private Partnerships

IRENA states that "*Public-private partnerships may serve as a platform to exchange information to advance technological progress, create consensus, align views, develop incentives and co-ordinate activities. Public-private partnerships can reduce the risks during early deployment, facilitating the transition from demonstration to commercialisation.*

They allow companies to build experience while providing the benefits of first-mover advantage in case of success. The objective should be to reach a point where no further public support is needed. This model has already been successful in mobility and in the European Union (through the Fuel Cells and Hydrogen Joint Undertaking) to demonstrate hydrogen technologies for multiple pathway."[43]

Public-private partnerships may generally be seen as any kind of public support for contributing to make a project financially profitable (more information on general public incentive measures are given within section 8.3.3). However, in its original, more narrow sense, a public-private partnership (PPP) is rather defined as a "long-term contract between a private party and a government entity, for providing a public asset or service, in which the private party bears significant risk and management responsibility."[44] At the core of the contractual PPP setup, there is mostly an offtake guarantee from the public authority. On the other side, the private party commits to provide a certain availability of its service/delivery. The PPP setup can be further complemented with grants or soft loans.

Green hydrogen as well as its derivative PtX products are rather private not public goods or services. From today's point of view, a public good/asset/service in the field of green H2 or PtX products may be predominantly seen in the mobility sector for the domains of public transport and waste collection. Here, the green hydrogen is used for fuelling busses and/or trains as well as waste collection trucks to enable an emission free public transport or waste collection.

42 Source: Natixis 2021: Financing Green Hydrogen's development – Clearing the hurdles

43 Source: IRENA 2020: Green Hydrogen, A Guide to Policy Making.

44 Source: World Bank 2021: About PPPLRC and PPPs: Are you financing or structuring public-private partnerships in infrastructure?

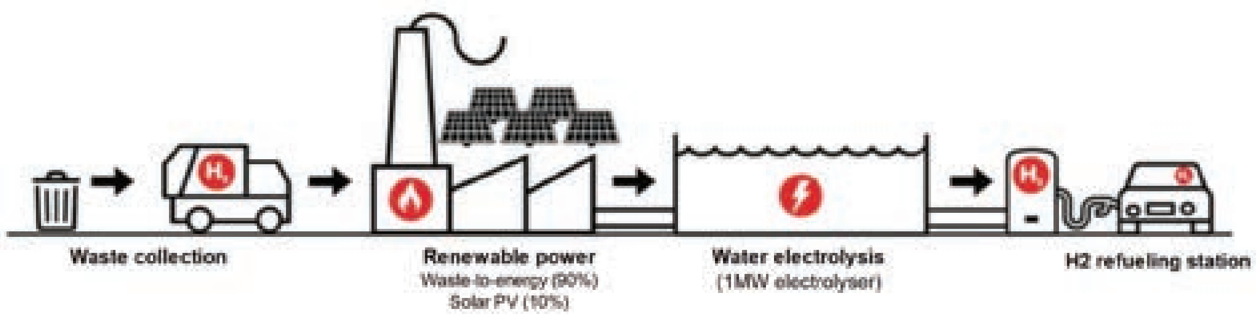
Such PPP scheme has already been applied in one sample project in Dijon/France which is highlighted in the following box.

The Dijon Métropole (France) Smart EnergGy project

A local green H2-centric mobility ecosystem

The recently (July 2020) launched Smart EnergHy project in Dijon Métropole (France) offers an interesting example of **value chain built at local level** around the application of hydrogen in different means of transport, with **an autonomous ecosystem involving**:

- **Renewable power generation** (waste-to-energy / solar PV)
- **Water electrolysis** (1MW electrolyser to be supplied by McPhy)
- **A captive fleet of FCEVs** (set of 22 buses, 9 waste collection trucks, 15 light-duty vehicles upon project completion, to be later expanded)
- **One Hydrogen refueling station** (HRS)



In its structuring & financing, **the €6.5m phase 1 of the project relies a great deal on public support/intervention**, with:

- **For the electrolysis part, the creation of an ad hoc company jointly owned by Dijon Metropole** (Greater Dijon municipality) **and Rougeot Energy** (McPhy's contractor for the deployment of the electrolyser)
- **The setting of a take-or-pay contract with local authorities / public transport company Keolis** (70% owned by the SNCF, France's State-owned railways operator) for the local green hydrogen production
- **Direct public financing from the French government in the form of grants totaling €3.4m** from ADEME (France's environment agency):
  - €1.8m for the hydrogen production and distribution infrastructure
  - €1.6m for the captive fleet of vehicles to be purchased by Dijon Metropole

(Source: Natixis 2020)

Figure 8-6: The Dijon Métropole (France) Smart EnergGy project

8.3.2 Potential International Funding Partners

8.3.2.1 Global Climate Funds

The following table lists a sampling global climate funds as potential funding partners of green hydrogen projects. Notably, MDBs and DFIs including EBRD, IBRD, IFC, AFD, JICA, EIB, KfW, IDB, may also directly provide funds to low carbon energy projects through their public/private sector lending facilities in the energy sector and might not always channel financing to low carbon projects through these specific climate funds cited below.

Table 8-1: Global Climate Funds

Climate Funds	Description	Financing instruments
Green Climate Fund GREEN CLIMATE FUND	The Green Climate Fund headquartered in Songdo, Incheon City, Republic of Korea, established within the framework of the UNFCCC as an operating entity of the Financial Mechanism to assist developing countries in adaptation and mitigation financing under the Paris Agreement www.greenclimate.fund	Both public and private sector financing in the form of low-interest and long-tenor project loans, lines of credit to banks and financial institutions, equity investments and risk mitigators, such as guarantees, first-loss protection, and grant-based capacity-building programmes
Zero Gap Fund The ROCKEFELLER FOUNDATION MacArthur Foundation	The Zero Gap Fund is an impact investing collaboration between The Rockefeller Foundation and the John D. and Catherine T. MacArthur Foundation. It provides innovative financial solutions that demonstrate the potential for large-scale private investment towards the Sustainable Development Goals (SDGs). www.rockefellerfoundation.org	Financial mechanisms such as securitizations, insurance products, risk-sharing instruments and grants to unlock additional private capital for impact across the full project development cycle
Global Environment Facility (GEF) Trust Fund gef	The GEF is the largest multilateral trust fund focused on enabling developing countries to invest in nature and supports the implementation of international environmental conventions including on biodiversity loss, chemicals and waste, climate change, international waters, and land degradation. www.thegef.org	Mainly grants as well as mobilization of co-financing
NAMA Facility NAMA Facility	The NAMA (Nationally Appropriate Mitigation Actions) Facility supports developing countries and emerging economies in implementing their NDCs under the Paris Agreement. The facility provides funding to NAMA Support Projects (NSP) that has the potential to catalyse transformational change towards low carbon development in all sectors. The facility is a multi-donor fund by Germany (BMU), UK(BEIS), Denmark (KEFM, MFA) and European Commission, being implemented by KfW and GIZ. www.nama-facility.org	Each NSP is eligible to receive grant funding between 5-20 million EUR, which can be used to mobilize additional funds and setup a range of financial mechanisms (concessional loans, partial credit guarantee, results-based finance etc.) as needed in the project level.
Multilateral Investment Guarantee Agency (MIGA) MIGA Multilateral Investment Guarantee Agency WORLD BANK GROUP	The MIGA, a member of the World Bank Group, promotes cross-border investment in developing countries by providing guarantees to investors and lenders across all economic sectors, including industry, financial, renewable energy etc. www.miga.org	Political risk insurance and credit enhancement guarantees to private sector investors and lenders

The Climate Pledge Fund	The Climate Pledge Fund is a corporate venture capital fund of Amazon that invests in companies for the development of sustainable and decarbonizing technologies. The fund invests in companies across multiple industry sectors, including transportation and logistics, energy generation, storage, and utilization, buildings, manufacturing and materials, circular economy, food and agriculture www.theclimatepledge.com	Venture capital investments in companies
Microsoft Climate Innovation Fund	Microsoft investment initiative to accelerate technology development and deployment of new climate innovations on areas such as direct carbon removal, digital optimization, advanced energy systems, industrial materials, circular economy, water technologies, sustainable agriculture, and business strategies for nature-based markets. The fund invests in emerging climate technology solutions that have early commercial traction and need capital to scale in the market www.microsoft.com	Debt and equity capital, project finance
Breakthrough Energy Ventures (BEV)	Breakthrough Energy Ventures is a fund of around 20 global investors that aim to accelerate innovation in sustainable energy and in other technologies to reduce greenhouse gas emissions. It invests in a variety of start-up companies that are attempting to commercialize early-stage technologies across several sectors including electricity generation and storage, transportation, industrial system use, agriculture, energy efficiency www.breakthroughenergy.org	Long term capital investments (Patient capital) and flexible capital in start-up companies
The French Global Environment Fund (FFEM)	The French Global Environment Fund (FFEM), created by the French government, supports innovative projects with significant scale up potential in the areas of environmental protection and sustainable socio-economic development in developing countries. Historically, the focus of the fund has been to interventions in the areas of energy transition, biodiversity, water, land degradation, pollution and waste management www.ffem.fr/en	Project specific grants
Clean Investment Funds	The Clean Technology Fund (CTF), one of two multi-donor trust funds under the Climate Investment Funds (CIF) framework, promotes scaled-up financing for demonstration, deployment and transfer of low-carbon technologies with significant potential for long-term greenhouse gas emissions savings implementation in renewable energy, energy efficiency, and clean transport in emerging market middle-income and developing economies. www.climateinvestmentfunds.org	Grants, contingent grants, concessional loans, equity and guarantees in low carbon technologies to both public and private sector investors in developing countries

8.3.2.2 International Cooperation on Green Hydrogen

The following table lists a sampling of institutional partners who provide technical assistance funding support, policy and research advisory, as well as market incentives for the development of green hydrogen market.

Table 8-2: Potential Institutional Partners

Institution	Description
The German Federal Ministry for Economic Affairs and Climate Action (BMWK)/ GIZ Bilateral Energy Partnerships[45]	■ Energy partnerships and energy dialogues with more than 20 partner countries ■ The **German H2 Strategy 2020 targets a funding of €2 billion for international cooperation on green H2 deployment, establishing pilot projects, and building up a hydrogen alliance in cooperation with other EU initiatives** ■ Energy Partnerships support high-level political dialogue and civil society activities, facilitate business environments, enhance exchange of best practices and energy transition ideas in the field of hydrogen strategies, RE roll out, EE, RE integration, energy infrastructure, electricity and energy market regulations, coal phase-out, grid expansion, energy audits etc.
IRENA Collaborative Framework on Green Hydrogen	■ Exchange dialogues, co-operation and coordinated action to accelerate development and deployment of green hydrogen and its derivatives for the global renewable energy transformation for member countries ■ Kenya is also a member country of IRENA ■ Participation is also open to the private sector and international organizations ■ Co-facilitators: European Commission and Morocco
International Partnership for Hydrogen and Fuel Cells in the Economy[46]	■ Facilitate multinational research, development, and deployment initiatives that advance the introduction of hydrogen and fuel cell technologies on a global scale ■ Currently 22 partner countries including European Commission and other countries ■ Kenya is not yet a member of IPHE. ■ Founder: U.S. Department of Energy and the U.S. Department of Transportation, Current chair: Netherlands

45 https://www.bmwi.de/Redaktion/EN/Artikel/Energy/international-energy-policy-2.html

46 https://www.iphe.net/

Hydrogen Council[47]	■ A global CEO-led initiative of leading companies to foster hydrogen as clean energy. ■ promote collaboration between governments, industry and investors, provides guidance on accelerating the deployment of hydrogen solutions around the world ■ a diverse group of 123 companies based in 20+ countries and across the entire hydrogen value chain, including large multinationals, SMEs, and investors ■ Membership is open to all global companies ■ **International investor groups in green H2: Antin Infrastructure Partners, Barclays, BNP Paribas, Crédit Agricole, FiveT Hydrogen, GIC, John Laing, Mubadala Investment Company, Natixis, Providence Asset Group, Société Générale and Sumitomo Mitsui Financial Group (SMFG).**
German Export Initiative Environmental Tech (EXI)	■ The Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) supports German green technology companies with its funding programme Export Initiative for Green Technologies (EX).[48] ■ Projects in the field of "green hydrogen and fuel cell technologies" for off-grid and decentralized power supply can be explicitly funded via the initiative ■ The funding is aimed specifically at German technology companies in the field of hydrogen and fuel cell technology that want to establish themselves on an international level and create sales markets worldwide ■ Priority will be given to international pilot/demonstration projects in which German technology companies in collaboration with research institutions. Eligible for funding are also preparatory measures such as feasibility and conceptual design studies.
H2 Global Initiative[49]	■ Hydrogen Energy Partnerships with countries for climate protection and industrial growth ■ The aim of H2Global is to create an efficient funding program for a timely market ramp-up and import of green hydrogen and Power-to-X products (PtX) to Germany. ■ The funding program offers the necessary investment security for the market participants involved in the market introduction phase. ■ **The funding mechanism provides for supply and demand to be brought together with a double auction mechanism via long-term purchase agreements on the supply side and short-term resale agreements on the demand side.** ■ The existing difference between offer and demand prices will be compensated using **a funding mechanism based on the "Contracts for Difference" (CfD) approach.** This will incentivize investment in green hydrogen generation capacities abroad and optionally in Germany, boost up domestic demand in Germany as well as global value chain for green hydrogen. ■ The H2Global funding program was designed within the framework of the federal government's national hydrogen strategy. The funding program is based on the H2Global concept, which was developed by GIZ GmbH

47 https://hydrogencouncil.com/

48 www.exportinitiative-umweltschutz.de

49 www.h2-global.de

Europe Initiative Green Deal[50]	■ The EU Green Deal underlines cooperation between EU and the African Union to explore a mutually beneficial green hydrogen ecosystem ■ The European Green Deal has created the post COVID-19 economic recovery fund and shows potential to assist Africa in the short term and to enable both Africa and Europe to complete their respective clean energy transitions in the long term. ■ Through a joint EU-Africa hydrogen partnership strategy, EU will cooperate with Africa on research & innovation, technology scale-up, create a market for local use and trade, set international standards, facilitate investment, meet the needs in both exporting and importing countries through green hydrogen certificate system and guarantees of origin scheme, and build the capacity to help execute the strategy. ■ African Union will get the benefits of clean energy transitions through direct and indirect (taxation, permits) revenue from H2 exports, new investments in electricity, gas and hydrogen infrastructure, develop Africa's blue economy, reduce dependence on fossil fuels as well as create social transitions through new jobs. ■ The European Investment Bank will set up an investment pipeline of generation projects and support the demand for hydrogen
African Hydrogen Partnership[51]	■ The African Hydrogen Partnership Trade Association (AHP) is incorporated as a non-profit private company dedicated to the development of green and natural (native) hydrogen, hydrogen-based chemicals, fuel cell technology and related business opportunities in Africa. ■ Platform for knowledge sharing, business intelligence, exchange and networking across various segments of the industry as well as for interacting with decision-makers and stakeholders in Africa and other continents. ■ Focus on economically and commercially feasible Green Hydrogen programs in close cooperation with industry, financial institutions, governmental organizations as well as large end consumers

8.3.3 Incentive Measures

Globally, investments in green hydrogen projects are in early stage. In an early-stage market, the financing cost is presumably high for private investors especially in the developing countries reflecting the investment risks that exist in early-stage markets. Green hydrogen projects are capital intensive. If we assume required capital machinery and equipment cost will be identical in all countries following the international price trends, the total capital cost differences in each country would account for country specific risk factors such as market risk, regulatory risk up-take risk, technology risk etc. Investors can be compensated for these risks if public measures are introduced.

The following graph presents a set of policy and financial de-risking measures which could be applicable for green H2 projects.

50 https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

51 www.afr-h2-p.com

Figure 8-7: Policy and Financial Incentive Measures

The following section describes these incentive measures in detail.

8.3.3.1 Investment Grants

Globally, there is a common expectation green hydrogen sector will need to be developed to a pre-commercialisation stage until 2030 through several market enabling measures and demonstration projects. This stage can be labelled as market creation and early market growth. Between 2030-2050 the sector is expected to witness rapid scale up. In this current early stage of green H2 sector development, government funding supports are deemed to be instrumental in R&D, technology innovation and green H2 demonstration projects. In the national level H2 strategies across the countries, investment grants play an important role to develop the green H2 sector- let it be for CAPEX reduction for green H2 production or adoption of green H2 applications for different segments.

The production cost of green hydrogen largely depends on the investment cost of the electrolyser and its capacity factor. According to IRENA (2020),[52] given today's relatively high electrolyser costs, low-cost electricity is needed (in the order of USD 20/MWh) to produce green hydrogen at prices comparable with grey hydrogen, which is about is about USD 1-2/kg of hydrogen. IRENA projects that due to scale of economy the cost of electrolyser will be reduced to between USD 130 to USD 307 per kW by 2050 compared to the current price between USD 650

52 IRENA (2020), *Green Hydrogen: A guide to policy making,* International Renewable Energy Agency, Abu Dhabi

and USD 1000 per kW (IRENA 2020).[53] In today's contexts, public funding - grants or CAPEX subsidies - is key to enable the green hydrogen market to realize demonstration projects. Apart from regulatory supports, the need for such funding supports is also echoed in the national level hydrogen strategies that are in place globally.

Example of public support instruments including grants and fiscal incentives include:

Country	Support type	Actions
Germany	Investment grants in green H2 applications (BMWI 2020)	■ Germany's Energy and Climate Fund (ECF) to provide €2.1 billion in purchase grants for electric vehicles; €0.9 billion in purchase grants for utility vehicles, €0.6 billion for the purchase of busses powered by alternative, climate-friendly driveline technology; ■ ECF's €3.4 billion in grants for the construction of a refuelling and charging infrastructure targeting alternative technologies including hydrogen applications ■ The Energy and Climate Fund in Germany has allocated EUR 45 million to help decarbonise the steel, cement and chemical industries, and Germany's 2020 budget includes EUR 445 million specifically to support larger industrial use of green hydrogen by 2024
Australia	Investment grants and loans for hydrogen projects	■ The South Australian Government has committed more than $40 million in grants and loans for the development of hydrogen projects.[54]
France	Investment grants and operational grants for production of green H2	■ Operating incentives either as PPA with a maximum 20-year term or in the form of a contract for difference where a premium will be granted to the producer of low-carbon and renewable hydrogen in €/kg ■ A combination of operating incentives and investment grants[55]
Netherlands	Investment and operational grants for production of green H2 as well as for blue H2 projects	■ Two lines of supports: the DEI+ (Energy Innovation Demonstration Scheme) and the carbon emission reduction or SDE++ scheme.[56] ■ Within the DEI+, R&D, pilot green H2 demonstration projects to receive a subsidy for 25%-45% of the eligible costs, up to a maximum of € 15 million per project.
	Off-take security (blending obligations)	■ Within the existing Climate Budget fund, SDE++ will provide temporary operating cost supports of € 35 million per year for scaling up and cost reduction of green hydrogen projects. On the project level, that would mean a subsidy up to € 1064 per avoided tonne of CO2, given electrolysis runs for 2000 full load hours with significant production of RE electricity. In case of blue hydrogen project (with CCS), a subsidy amounts up to € 300 per avoided tonne of CO2 will be provided. ■ As off-take security to the green hydrogen producers, a blending option up to 10-20% of green hydrogen into the gas grid is proposed ■ Subsidy schemes for zero emissions urban logistics and heavy-duty transport are being developed under the framework of the National Climate Agreement ■ In aviation industry, under the sustainable aviation policy, up to 14% blending of sustainable fuels (e.g. synthetic kerosene) by 2030 and 100% by 2050.

53 IRENA (2020), *Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5ºC Climate Goal*, International Renewable Energy Agency, Abu Dhabi.

54 Commonwealth of Australia (2019), *Australia's National Hydrogen Strategy,* COAG Energy Council Hydrogen Working Group, ISBN: 978-1-922125-62-0

55 https://www.wfw.com/articles/the-french-hydrogen-strategy/

56 Government Strategy on Hydrogen, Government of The Netherlands, https://www.government.nl/documents/publications/2020/04/06/government-strategy-on-hydrogen

8.3.3.2 Tax Incentives

Corporate/sales tax reductions in green hydrogen projects will result in improved revenues and rate of return of the projects. In addition, import duty/VAT can be reduced/eliminated, in particular for the electrolyser, to bring down the CAPEX of green hydrogen projects. The purpose of the tax reductions is to increase competitive advantages of greener production facilities that have higher carbon avoidance costs than business as usual industrial facilities.

Especially in energy and transport sectors, Kenya is already providing indirect fiscal incentives:

Sector	Fiscal incentives
Energy	■ The exemption from VAT for specialized equipment for the development and generation of solar and wind energy, including deep cycle batteries which use or store solar power. ■ Direct financial support through feed-in tariff policies and concessional loans
Transport	■ Reduced import duty for electric powered motor vehicles is 10%, compared to 25% for petrol and diesel cars. ■ There are ongoing discussions about increasing subsidies for green vehicles.

Source: CPI (2021)

8.3.3.3 Carbon Tax

Carbon tax refers to imposing tax on carbon emissions to companies, industries in order to internalize societal cost of carbon emissions into their economic activities. Carbon tax is widely applied in the transport sector. The yielded revenues through the carbon tax can on the other side then be used e.g. to provide investment grants for electrolysers or other equipment to promote new hydrogen-based projects.

8.3.3.4 Carbon Pricing Mechanism

Carbon price can be an important public instrument to make green hydrogen and PtX products competitive with the conventional technology. Kenya is currently preparing the National Green Fiscal Incentives Policy Framework. It is understood that Kenya has planned to set up carbon tax as well as an emissions trading system by imposing caps on emissions, and applying charges on companies that exceed emissions, or requiring them to purchase additional emission allowances from the market. However, necessary legal framework needs to be created in order to implement the carbon pricing mechanism in Kenya.

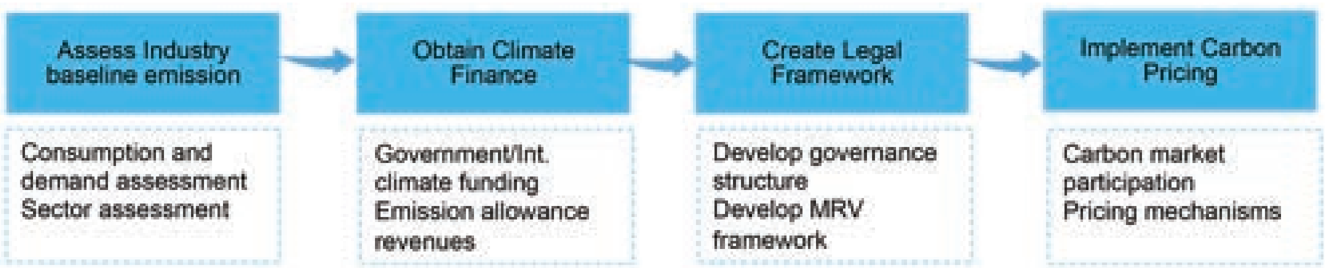
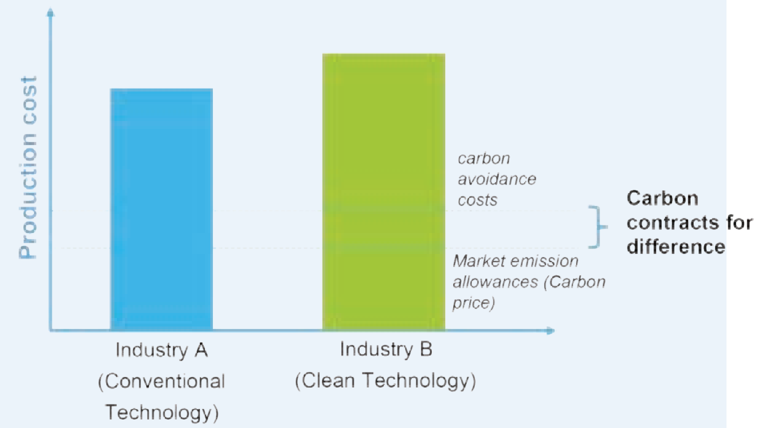


Figure 8-8: Simplified steps to implement carbon pricing mechanism

Example: Carbon contracts for difference (CfD) in Germany[57]

As part of the national hydrogen strategy to promote climate-friendly industrial procedures, the Federal Government of Germany intends to launch a pilot CfD programme targeting the energy-intensive steel and chemical industries with their process-related emissions. The mechanism is similar to price hedging where the Federal Government will guarantee funding amounting to the difference between the market price for emission allowances (carbon price) and the carbon avoidance costs due to using more expensive, greenhouse-gas-neutral technology. This will ensure production cost competitiveness of the industry owner opting for clean/carbon neutral process with an industrial owner using conventional technology and paying only for the emission allowances or carbon price for the carbon emissions generated in the production process.



As illustrated above in the figure, if the market price for emission allowances is lower than the carbon avoidance costs, the state pays the difference to Industry B using clean technology. If it is higher, Industry B must pay the difference to the state.

8.3.3.5 Demand Side Incentives

Price premium for green hydrogen production: Apart from investment subsidies, price premium refers to operational grants depending upon per avoided tonne of CO2 in green hydrogen projects. As mentioned above, The SDE++ programme in the Netherlands aims to increase profitability of green hydrogen projects by supporting them with operational grants based on per avoided tonne of CO2.

The German government's H2Global initiative is introducing the CfD scheme that will enable temporary compensation for the difference between the purchase price (production and transport costs) and the sales price (currently the market price for fossil hydrogen) of renewable hydrogen and derived products

Public procurement of PtX products: As part of green public procurement policy, state agencies can take a leading role to enable the market by purchasing steel or other products made using green hydrogen. They may also require a certain threshold of those products in the overall material mix of public buildings. This will encourage industries to shift to green materials production when certain market up-take risk can be directly eliminated by the state agencies through public procurements.

8.3.3.6 Green Hydrogen Quotas of End Uses

A technology- and origin-neutral quota for green hydrogen would help reduce grey hydrogen share in the market. The quota system will oblige users to increase usage or consumption of end-products produced from green

57 BMWI (2020) *The National Hydrogen Strategy*, Federal Ministry for Economic Affairs and Energy, Germany

58 H2 Global, https://h2-global.de/

hydrogen and help green hydrogen producers to match their generations with a better forecast of market demands across different sectors. For instance, the quota system can be applied to promote the carbon-free/ green steel sector. However, the green quota system for different industrial commodities must be carefully scrutinised for its effects on global competitiveness with other traditional producers (e.g. traditional steel production).

8.3.3.7 Green Hydrogen Guarantee of Origin

The Guarantee of Origin (GO) scheme is a certification system that is being applied to green or low carbon hydrogen, among other energy commodities, to certify the origin and the "green" labelling of hydrogen. The scheme can be used to track life cycle GHG emissions from the production, transportation to end-use of hydrogen and help users and governments identify carbon footprints of hydrogen compared to alternative interventions (e.g. bioenergy, direct electronification etc.). The GO scheme is expected to boost up particularly the export market and create demands for green hydrogen through certification.

As an example of GO scheme, the pilot CertifHy[59] project in the European Union has already issued over 76,000 GO certificates within EU for green or low carbon hydrogen where the emission intensity must be 60% lower than the baseline emission (hydrogen from natural gas).

8.4 Potential Investment Risks and Mitigation Measures

EIB has conducted a survey among 50 players in the hydrogen investors space to understand their outlooks and issues to gather feedback from the market. Apparently, the following aspects are considered most risky for future investments into hydrogen:

- the economics of the market,
- forthcoming regulation,
- offtake and
- operational and technology scale-up risks.

EIB countered that it will look to support them with a suite of blended finance tools in order to de-risk the market for these players, at least until the market matures.

Suitable financing instruments could for example be to use blended finance tools to come in at a junior level of the financing structure of a green hydrogen project, taking on an elevated risk profile, in order to make it possible for other lenders to come in at a more senior level with lower risk.

Norton Rose Fulbright see that the "gold standard for project financing is a long-term, fixed-price offtake contract with a utility or other public or quasi-public purchaser". The power and public transportation sectors would provide the best early opportunities for hydrogen project developers to sign such contracts. However, many offtake structures would depend on corporate off-takers. Corporate counterparty credit risk would be the most important aspect and where the electrolyser is located on-site or adjacent to the customer that the hydrogen project is designed to serve.

59 www.certifhy.eu

Financiers would also be focused on technology risk. Although electrolysis technology has existed for some time, given the limited track records in electrolyser deployment, financiers are expected to carefully examine manufacturer and EPC warranties.

While some very large companies have entered the sector and partnerships are announced at an accelerating pace, several of the most relevant technology suppliers in the market do not have very large balance sheets. Major maintenance reserves will be required by lenders, and manufacturer warranties may need to be backed by insurance or other financial instruments to provide credit support. Such security would likely be expensive for first-mover projects.[60]

The following table lists risks in hydrogen projects as a function of type of activity in the hydrogen value chain. Herein, the following three types of activities are distinguished:

- **Industrial activities** in the upstream (manufacture and electrolysers) as well as in the downstream segment (manufacture of equipment for hydrogen end-use applications
- **Production activities**, i.e. operating an electrolyser to produce green hydrogen
- **Infrastructure activities** catering for bridging the hydrogen production to the end-use markets and its distribution to collective equipment used for public transport (busses) or municipal waste collection (trucks)

Business profile	Segments / assets concerned	Addressable market	Associated risks / challenges
Industry	• **Manufacture of electrolysers** (components, assembly) • Manufacture of downstream equipment allowing final use of H2 (industry, mobility, industry)	• **Global market** given the multiplicity of potential green H2 production areas	• **Inadequacy of the products offered with the demand** (cost, specifications) • **Overcapacity** • **Competition within the segment** (price, technical specifications) • **Competition** from established or alternative equipment and technologies
Commodity production	• **Green electrolysis** (electrolysers + low-carbon electricity sources)	• **Market today local** through the conclusion of hydrogen purchase contracts under private law (HPA) • **At some point in the future, market partly national** with the expected introduction of public support systems (additional remuneration following calls for tenders) • **Potentially global market** depending on the development of global demand and transport infrastructure	• Save for very specific instances, **lack of cost competitiveness compared to the gray hydrogen sector** • **Technical risk** (construction and operation of electrolysers) • **Double counterparty risk**: seller of low-carbon electricity and buyer of green H2 • **"Merchant" risk** in the event of a mismatch between the duration of the contract for the purchase of green H2 and the lifespan of the
Infrastructure	• **Compressor stations and transport trucks** • **H2 charging stations** (HRS) • **H2-fueled collective equipment** (buses, dumpsters, taxis) • **Eventually**, depending on demand, **dedicated infrastructures for the delivery of H2** (transport and distribution networks)	• **Market for the moment local** (near the electrolysers) for recharging stations and collective equipment • **At some point in the future, national and international market** in the event of changes in demand justifying the development of transport infrastructure dedicated to H2 (land and submarine networks, logistics chain for maritime transport)	• **Economic "value" dependent on the end use** of the molecule it supports: • **Oversized**, the infrastructure induces an **additional cost** for the end user / community (when the development cost is shared) • **Undersized**, it constitutes a **bottleneck** for the development of the sector • For charging stations, **potential competition from various deployment methods**, putting de facto assets in competition

(Source: Natixis 2021)

Figure 8-9: Risks & Challenges of hydrogen projects for different business profiles

60 Source: Norton Rose Fulbright 2021: Financing hydrogen projects brings unique challenges.

From the standpoint of the arranging banks, when providing financing through secured debt instruments the three main sources of risk for the asset concerned are:[61]

- the **technical risk** during the construction and operational phase
- the **credit risk**: incapacity of the asset financed to generate cash flows needed for the servicing of the debt,
- the **counterparty risk:** a default in the obligations of the buyer, of the equipment supplier or the electricity supplier, in instances where the power plant supplying the low-carbon electricity and the electrolyser are operated by distinct entities.

General risks and possible mitigation measures are given in the following table.

Table 8-3: Type of Risk

Risk	Potential mitigation measure
Construction risk	Guarantees provided by the subcontractor Collaboration between a government agency and a private-sector company that can be used to finance, build, and operate projects: Balance sheet support tools, such as debt guarantees and equity
Operational cost risk	Securing return on investment for developers by passing costs down to consumers. This increases revenue certainty.
Off-take risk	Minimum revenue guarantee Future purchase commitment Regulated Asset Base Model (RABM)
Counterparty risk	Credit quality of the H2 buying counterparty (financial strength, experience in the execution of similar contracts) Existence of other potential counterparties
Technology risk	Guarantees provided by the manufacturer Availability payments
Credit risk	Soundness of the underlying contractual, regulatory and economic scheme (price, volume) for guaranteeing the stability of cash flows Equivalence between the duration of the scheme and the life of the asset DSCR > 1.x in order to create a safety cushion for unforeseen events
Risk of policy uncertainty	Political risk insurance
Currency devaluation risk	Foreign currency liquidity facility or hedging

61 Source: Natixis 2021: Financing Green Hydrogen's development – Clearing the hurdles.

8.5 Green Hydrogen Economy Support Framework

For green hydrogen market to develop at scale in Kenya policies and support frameworks must be in place to encourage and support private investment in the sector. These support frameworks vary in scope and cover a range of aspects including Financial, Institutional, Legal/Regulatory, Political, Environment and Infrastructure. While Kenya has already put in place many policies that can nurture the hydrogen economy, multiple barriers still exist to scale up green hydrogen.

Key enablers relate to **sourcing green electricity** (green electricity source with a long term secured tariff (range), *this strongly relates continuous and reliable expansion of RE capacity for h2 and beyond*)**, water** (rights as well as sustainable supply), **demand for hydrogen and its products** (lack of clear targets and strategies at the sector level), **frameworks for applications and infrastructure** (missing hydrogen transport, storage and application regulation for use of existing infrastructure and potentially new infrastructure) and **electrolyser scale up** (high initial costs) among others.

Figure 8-10: Barriers to Green Hydrogen Implementation

The following section describes the existing support frameworks as well as barriers to green hydrogen deployment at scale, followed by recommendations on overcoming these barriers. The Consultant interviewed several commercial/industrial stakeholders as well as stakeholders from industry groups, financing institutions and governmental stakeholders. The following chapter is a consolidation of the responses from the various stakeholder groups as well as based the Consultants' experience in developing hydrogen projects world-wide.

8.5.1 Existing Green Hydrogen Policies and Frameworks

Although there is currently no policy and framework established exclusively on green hydrogen in Kenya, Kenya's long-term low emission development strategy highlights the significance of hydrogen contributing to decarbonise its electricity sector and introducing cleaner consumption practises in transport, industries. Specific green H2 projects can take the benefits of following existing policies:

Table 8-4: Existing Policies and Frameworks Relevant for Green Hydrogen

Policy	Relevant authority	Relevance for Green H2 projects
Green Incentive Policy Framework (draft)	National Planning and Treasury Department	■ Carbon taxations ■ Economic incentives (carbon trading mechanism)
Nationally Determined Contribution (NDC) Strategy	Ministry of Environment and Forestry	■ Abate GHG emissions by 32% by 2030 relative to the BAU scenario of 143 MtCO2eq. ■ Total cost for implementing mitigation and adaptation actions is estimated at USD 62 billion (˜EUR 55 billion), of which 13% of the costs is expected to be mobilized through local resources and 87% through international supports.
Long Term Low Emission Development Strategy (LTS) 2050	Ministry of Environment and Forestry	■ Decarbonization of electricity sector ■ Clean fuel for transport (hydrogen fuel) ■ Cleaner production process for industries (hydrogen fuel)
National Climate Change Fund (CCF)	National Planning and Treasury Department	■ Manage both national and international climate finance sources ■ Provide funding supports to strategically important green H2 projects
Kenya Vision 2030[62]	Ministries, Vision 2030 Delivery Secretariat	■ Clean and environment-friendly modern industrialization ensuring social and economic developments: ■ Agriculture sector: fertilizer cost reduction strategy ■ Infrastructure sector: Construction industry development policy for enhanced industry performance ■ Oil and gas sector: Establish requisite infrastructure and production in the oil, gas and other minerals sector ■ Manufacturing sector: ■ Development of integrated iron and mini steel mills ■ Development of industrial clusters, SME and industrial parks, ■ Establishment of Special Economic Zones (operational) in Mombasa (including Dongo Kundu Free Port), Lamu and Kisumu to attract more local and foreign investments, diversify products for export market, promote value addition and technology development ■ Establishment of industrial and manufacturing zones through Special Economic Clusters (SEC) in Mombasa targeting export market for agro-industrial products and in Kisumu targeting promotion of regional market for cement, chemicals, metals, agro-processing industries. ■ Trading sector: ■ Establish and operationalize a Credit Guarantee Scheme and Export Development Fund, establishment of distribution infrastructure in Democratic Republic of Congo, South Sudan and United Arab Emirates ■ Establish international trade flagship projects through one free trade port in Mombasa, create business linkages through Public Private Partnerships (PPP)

62 http://vision2030.go.ke/

Technical Frameworks

The strategies listed above are policy frameworks. What is completely lacking in Kenya are specific (technical) policies which allow hydrogen and hydrogen applications, such as hydrogen fuel cells. As well as policies and regulatory frameworks related to the safe usage storage and transport of hydrogen. There is, as of yet, no regulatory framework which allows the installation of hydrogen fuel cells and which lists the requirements which must be met for their safe operation. There are no national guidelines for the safe transport or storage of hydrogen or hydrogen related products. The technical frameworks describing the safe production and use of hydrogen are a critical first step to enabling a green hydrogen market.

Please see chapter 4.4.2 International norms and standards for more information on international standards and frameworks which could be applied in Kenya.

Regional Collaboration

Kenya has been collaborating in jointly developing a climate finance strategy with Eastern African countries (ESE) where there are opportunities in terms of market and technology transfer.

Government Funds

There are currently no government funds set aside specifically for green Hydrogen. On-going climate change incentives and subsidies are paid through budget re-allocation as week as some donor funding for climate change agenda. A vehicle was defined in Climate fund regulation 2018, however, the regulations have not been approved by the cabinet.

Incentives /Policy

The Treasury Department is actively working on ways to incentivize investment in the green space which also includes green hydrogen investments.

The sectors to be incentivized have been identified using the National Action Plan and Green Strategy Plan. These focus areas include Manufacturing, Energy and Transport. For example, in the energy sector, shifting to renewable energy and accelerated growth of geothermal, expand the off-grid connection, development of alternative fuels for transport sector.

The policy does not specify the type of incentive, but the Treasury department is working on developing the appropriate incentives.

One key method currently being investigated a Carbon Tax which is currently being drafted with the assistance of a Task Force including a number of industries and government stakeholders. Although the Carbon Tax which would likely be proposed as a tax on fossil fuel is delayed, the Treasury is working on developing the mechanism design by end of Q1 2022. The elements to be included, for example should it only include taxation and/or a carbon trading mechanism, will form the basis for the policy discussion.

The policy is designed to drive green technology, but there is not any which is hydrogen technology specific.

There are several interventions for RE, for example electric vehicles which currently have and import tax of 10%, are proposed to be exempt from import tax. However, there is nothing specific on hydrogen, these discussions are starting now.

Subsidies

In terms of subsidies for specific sectors or industries, policy discussions are still required. For example, there are a number of subsidies for fertilizers which could overlap with a green fertilizer subsidy. In terms of trying to shift policy to low carbon it would be beneficial to cut those non-green subsidies, at the same time, the policy needs to be developed in such a way as to ensure no unintended consequences which would hurt the agricultural sector.

Guarantees

The Green Investment Bank is intended to provide a range of funding instruments and guarantees to overcome barriers to investment. Some financial instruments could include credit guarantees and de-risking facilities. None are specifically for renewable energy.

8.5.2 Green Hydrogen Investment Bottlenecks

The Consultant has carried out a number of interviews with multiply industrial, ministerial and IFI stakeholders to learn their views on scale-up of green hydrogen bottlenecks as well as potential alleviation measures. The following section presents the viewpoints (consolidated and edited) learned during these interviews, expanded based on the Consultant's experience in hydrogen and renewable energy world-wide. The issues have been grouped under the categories of Financing Challenges, Approval Process and Sourcing Green Electricity, however there is significant overlap, and these categorizations should be considered as high-level groupings only.

8.5.2.1 Financing Challenges in Kenya

8.5.2.1.1 Loan Tenor

The cost of financing plays a significant role. Financing from local institutions tends to be very short term and costly. For green hydrogen projects to be financially viable it needs the longer tenors available with international financings in combination with other applicable facilities such as guarantees.

Issue*: Local Loan Tenors too short*

Potential solution: *IFI could facilitate the availability if international funding sources in country and offer longer loan tenors in combination with other applicable facilities such as guarantees.*

8.5.2.1.2 Compliance and Reporting

Interviewees described significant challenges with compliance and reporting both for the financing agencies as well as government process which required them to received multiple approvals being referred back and forth between national and regional agencies.

Issue: *Complex Compliance and Reporting Process*

Potential solution: *Create a Green Hydrogen "One-Stop-Shop" assisting with all aspects of project implementation and approvals for green hydrogen investments including the full range of requirements and how to meet them as well as having a single coordination office for all required government approvals. (please see section 8.6.1 for more information)*

8.5.2.1.3 Environmental and Social Requirements

Meeting IFI environmental and social requirements can often be a challenge for project developers in Kenya. Most specifically for safeguarding requirements which project developers are often not fully prepared, which has caused financier(s) to pullout late in project development in the past.

Issue: *developers and industrial partners unfamiliar with meeting environmental and social requirements*

Potential solution*: "One-Stop-Shop" for green hydrogen investment which can assist in advising on the full range of requirements and how to meet them as well as having a single coordination office for all required government approvals. Additionally, technical assistance to help companies carry out the required environmental and social studies.*

8.5.2.1.4 Project Implementation Timelines

There is a passive risk in terms of timing. It is a simple fact that project development takes longer in Kenya then elsewhere. The extended development timelines need to be anticipated and factored into the pricing to ensure the project does need to secure late round financing which is expensive or does not fit the projects true needs in order to complete development.

Issue: *Extended development timelines lead to higher risk and higher project costs.*

Potential solution: *"One-Stop-Shop" for green hydrogen investment which can assist in advising on the full range of requirements and how to meet them as well as having a single coordination office for all required government approvals. The experience of the various stakeholders working together in the same office will assist in reducing approval and thus development time.*

8.5.2.1.5 Price Discovery

The biggest challenge in reaching financial close for green hydrogen projects is that the product markets don't exist yet and therefore it is unknown if the LCOH is low enough with regards to what the market will pay.

The risk is that grey hydrogen is available very cheaply as the social and economic costs of the carbon are currently not properly included. If the LCOH for green Hydrogen will have to meet the market at 2 EUR/kg then it will be hard to match and this challenge cannot be met with the current technology. However, if buyers are willing to pay a premium for green production, for example if purchasers are willing to pay a premium for green production equivalent to the current diesel equivalent[63] price point for steel or transportation, then markets could develop much more rapidly. Until the markets develop, and the accepted market price is understood, reaching financial close without significant incentives will be difficult. Adding to the complexity, is that some key potential markets, such as shipping, have very long (20 year) life cycles, meaning that the markets will take time to develop.

8.5.2.2 Approval Process

8.5.2.2.1 Technical Frameworks and Standards

There currently not regulatory frameworks in Kenya which all the use of hydrogen and derivative products, nor are there established requirements for the production, transport and storage of hydrogen.

63 If is it assumed that 6kg of hydrogen is required for 600 km, then the diesel equivalent price point would be ~10EUR/kg (depending on diesel cost and fuel efficiency)

Issue: *Lack of regulatory frameworks allowing the use of hydrogen and hydrogen-based applications.*

Potential solution*: Develop technical regulatory frameworks for the use, transport and storage of hydrogen based on international guidelines, along with safety requirements to enable project implementation.*

8.5.2.2.2 Land Rights Access

Country government approval is required for industrial land use, however commercial scale production will likely cross boundaries and will need multiple approvals leading to additional time delays and overhead costs.

Issue: *Multiple County (regional) approvals with multiple stakeholders with differing requirements required for land use*

Potential solution*: Large scale projects could be granted strategic status allowing a "fast track" through approvals. Create a Green Hydrogen "one-stop-shop" assisting with all aspects of project implementation and approvals for green hydrogen investments. (please see section 8.6.1 for more information)*

8.5.2.2.3 Transparency on Project Agencies to be contacted

Within the National Treasury there is the Public Private Partnership Directorate which has the responsibility to facilitate PPP projects in Kenya. However, the industry stakeholders interviewed felt that it was not relevant to what they are trying to do. Green hydrogen does not fit the standard PPP model as there is no classic "public good" for green hydrogen and derivative products as there might be for electricity or roads. Although it is felt the PPP unit is not relevant to their project, commercial/industrial partners are increasingly being told by government agencies to involve the PPP unit. This is causing additional delays as the process is being broken when told to contact additional agencies.

Issue*: Lack of understanding of green hydrogen products business models and being requested to contact additional agencies such as the PPP unit which don't apply in this context.*

Potential solution: *Enable the PPP unit to be more flexible with the types of models they use to be applicable to green hydrogen and green hydrogen products. Create a Green Hydrogen "one-stop-shop" assisting with all aspects of project implementation and approvals for green hydrogen investments. (see section 8.6.1 for more information)*

8.5.2.3 Sourcing Green Electricity

Many of the bottlenecks to ramping up green hydrogen investment focused on securing the value chain most specifically the sourcing green electricity. The key issues as described by stakeholders are presented below. It is noted that depending on the business model of the stakeholder the importance of these topics can vary. For example, some points below apply only to stakeholders whose business models depend on large scale geothermal energy. However, in all cases a long term stable and secure supply of green electricity at a predicable price (which does not vary by an unpredictable amount on an annual basis) is required for a bankable business plan.

8.5.2.3.1 Value Chain - Geothermal

The present interest in developing green hydrogen is often compared with the development of renewable energy at scale 10-15 years ago. While many of these comparisons hold true, particularly with regards to financial aspects,

it is important to remember that for electricity there is a simple and clear-cut market demand for the end product. This is not necessarily the case for green hydrogen where the price which can be earned on the end product is independent of its cost of production.

For example, if you are a power producer (geothermal) you know what you pay GDC for steam and you know what price you can sell electricity at, therefore you know your margin. However, for captive power being used to produce ammonia or hydrogen no one knows what the price will be and the market does not exist yet. There is an unpredictable margin and there is concern that is will not be enough to cover GDC profit as well as that of the investor. There is a risk in how the market will develop, and in this case GDC profits from a positive development but does not share in this risk. Therefore, there is significant interest from developers to control their entire value chain, including that of the RE used to produce green hydrogen, carrying the risk as well as the profit.

Furthermore, for hydrogen production from other sources, for example solar energy, long term price stability is still key to a feasible business plan. An electricity tariff which could vary dramatically year by year depending on the foreign exchange market (to cover foreign currency CAPEX) does not lend itself to a financially feasible business model.

Issue*: Currently GDC is responsible for developing the geothermal assets and selling the steam. They hold the production license and sell the steam with a profit model built in. However, for industrial scale green hydrogen investments many investors will want full ownership over the value chain managing the risk as well as benefiting from the profit so that they can fully manage their processes. It is felt that the hydrogen production investment is too high to risk having no control over the primary input, green electricity.*

Possible solution: *Allow the private development of captive geothermal energy as utility scale for the production of green hydrogen. Develop a risk sharing mechanize where GDC shares in the market risk of green hydrogen.*

8.5.2.3.2 Time Scale of Investment (Length of Geothermal Licence)

One concern for large scale investment in green H2 production using geothermal energy is the time frame of the investment. Geothermal is a complex and expensive technology (compared to for example solar PV), which requires a significant running time to recoup the investment.

The license period for Geothermal power is 30 years with a possible 5-year renewal, however given the high upfront cost of geothermal plant and industrial scale green hydrogen production, it is felt that a limit of 35 years is not sufficient to justify the investment.

Issue: *geothermal license is not long enough to allow for positive investment decision*

Potential solution*: a longer lease, or right of first refusal to be offered after renewal period.*

8.5.2.3.3 Exclusivity of exploration/feasibility licenses

Currently the exclusivity of exploration licenses are an assumption, however it is not clearly stated.

Issue: *unclear exclusivity of Geothermal exploration licenses*

Potential solution: *Clearly state period of exploration exclusivity in regulation*

Issue: *no exclusivity during feasibility stage for wind and solar locations (at the mercy of the landowner)*

***Potential solution:** can apply for a period of exclusivity during feasibility stage for renewable energy projects with Ministry of Energy (similar model as Mozambique)*

8.5.2.3.4 Licenses for Captive Power

An electricity generation licence is required for captive power, if larger than 1 MW. This limit is too small for industrial applications.

***Issue:** Electricity generation license is required even for captive power, above 1 MW adding unnecessary costs*

***Potential solution:** wave electricity license requirements, or raise the limit to 10 GW for self-consumed captive power*

8.5.2.3.5 Net Power

While some industries plan to match their captive power production to their demand, other business models use variable renewable energy sources, which will result in troughs and surplus peaks and a method to flatten curve. On site storage is prohibitively expensive at this scale. One option would be to sue the grid for balance power whereby the net power would be zero. However, an enabling regulatory framework would first need to be developed. Legal and commercial guidelines around power exchange, will help unlock solar and wind potential.

***Issue:** Enabling Net Power when using variable renewable energy as captive power.*

***Potential solution**: Implement regulatory framework with legal and commercial guidelines enabling an "energy bank" for balancing power*, however limiting any negative effect on the non-green H2 demand (e.g. in the worst case always banking during off-peak and consuming for green H2 during peak)

8.5.2.3.6 Electricity Royalties

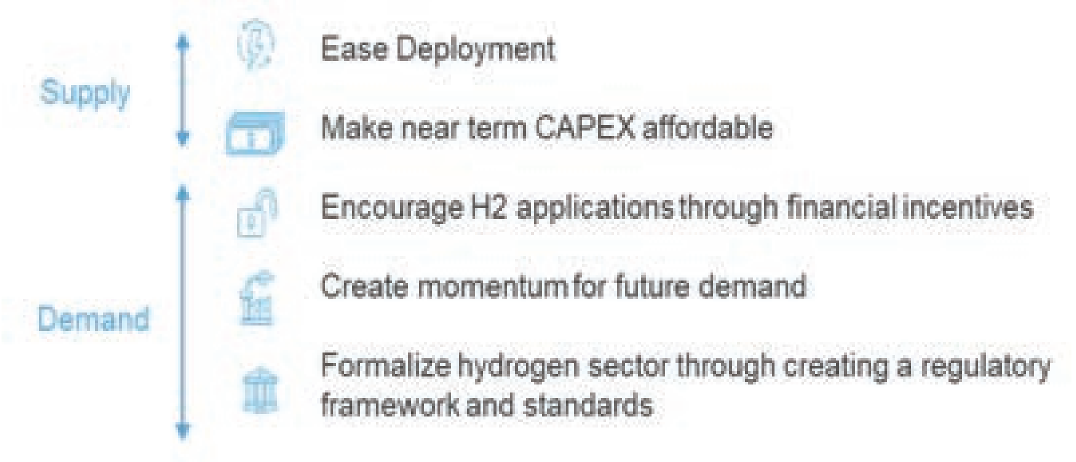
Under the Energy Act royalties are to be paid to local communities during the first 10 years. For industrial scale green hydrogen, the concern from investors is that this royalty would be required to be paid at the front end of the project, before it is profitable, which hinders the projects' ability to be "bankable".

***Issue:** payment of royalties on revenue prior to project being profitable*

***Potential solution:** shift royalty to later time period or implement a sharing of profits not revenue*

8.6 Investment Enablers

As described in the beginning of the chapter, the key enablers for the ramp up of green hydrogen and derivative products is the support of the development of supply and the encouragement of the development of the market for demand.



Policy and regulatory enablers should ease deployment of RES and electroysers, make near-term capex affordable, encourage H2 applications, create momentum for future demand. It should also formalize the hydrogen sector through standards and defined requirements for the production, storage, transport and implementation of green hydrogen and its applications, such as fuel cells. Supporting policies around RES deployment, land and water use must also be coherent with creating a hydrogen economy and sustainable future. The following actions would help enable this.

- Ease Deployment by creating a Green Hydrogen "One-Stop-Shop" assisting with all aspects of project implementation and approvals for green hydrogen investments as well as having a single coordination office for all required government agencies for approvals.
- Make near term CAPEX more affordable and encourage H2 applications through incentives such as direct funding, tax incentives, investment subsidies and innovative (leasing) financing products
- Create momentum for future demand through policy incentives for manufactures for cleaner production and transport, removal of subsidy for fossil fuels, carbon tax, sector integration planning which includes green hydrogen and capacity development for industry leaders to demonstrate the opportunities green hydrogen provides.
- Establish standards and requirements to make transparent technology specifications and guarantee safety of hydrogen production, storage and transport and of applications.

The following section describes some of these recommendations in more detail, particularly the recommendation of a "Green Hydrogen One-Stop-Shop" to assist in project development, as well as descriptions for products IFI's could offer to ease the financial constraints. Specific incentive measures cannot be recommended without further study and a modeling of the costs and benefits of the various options. Section 8.3.3 contains a detailed review of potential fiscal and non-fiscal incentive measures. This is followed by a summarized table of the bottleneck issues and potential mediation measures described in detail in section 8.5.2.

8.6.1 "Green Hydrogen One-Stop-Shop"

A key recommendation for assisting the deployment of green H2 an attracting private investment to the sector is to assist the implementation for green projects through the create of a "Green Hydrogen One-Stop-Shop", where a representative from all required government agencies work together in one office to assist developers in the process of implementing green H2.

The concept is not a new one. Ken-invest have a one-stop-shop for foreign investors establishing a presence in Kenya, consisting of a member from the various government agencies in one office. The opinion from industrial stakeholders is that this office works quite well enabling a simplified and transparent process. This is also similar to the Pubic-Private Partnership Directorate.

The Green Hydrogen "One-Stop-Shop" would assist with all aspects of the project approval process including the full range of requirements (environments, social, technical, financial) and how to meet them as well as having a single coordination office for all required government approvals.

One major hindrance to project implementation, reiterated by nearly all stakeholders, was the current non-transparent and lengthy approval process, where it often seemed that the various agencies were providing conflicting information and having conflicting requirements. An honest evaluation of the past handling of RE projects under the Feed in Tariff (FIT) will provide hands on lessons learnt in terms of good and bad practices for the administrative procedures for similar projects including green H2. There has been a FIT working group with representatives from most relevant agencies which from the Consultant perspective was functioning with a suitable composition of capable officers which handled the process in an efficient way. However, the outcome was mostly not satisfactory (with few projects approved) until today. This could be due to insufficient (e.g. inflexible and incomplete with regard to source of funding) policy and regulatory framework and due to contradicting interests among the involved agencies which likely more influence by the "stronger" agencies. A clear mandate to the leading agency (Ministry of Energy) and a mechanism to adapt the policy framework and to solve potential cost / risk burdens from such projects for some agencies may solve these problems.

It is expected that the experience of the various stakeholders working together in the same office will improve understanding of the overall requirements by the stakeholders, create a sense of ownership and accountability among the stakeholders and well as in assist creating a transparent process reducing approval time and thus project development time. The "one office" concept has the advantage of creating transparency with everyone in the same room, there is less opportunity for side conversations which makes the entire process more transparent.

Furthermore, it is suggested that in addition to the concerned national government agencies, regulatory agencies (NEMA, EPRA, water authority), energy sector agencies (KETRACO, GDC, KenGen), local/regional representatives and community representation also be invited on an as needed basis. This could help prevent and facilitate the resolution of potential issues, particularly as related to land and water rights aspects before then become problems.

As there are currently so many levels of negotiation required to implement a project that a cross functional steering committee should be established with a focus on members from industry, the various government stakeholders, community representatives, but also with members from the financing community to create a forum for the negotiation. The overall object is to create a spirit of cooperation as opposed to each stakeholder focusing on just their very narrow piece of the puzzle.

8.6.2 Potential Opportunities for DFIs

A key opportunity for DFIs is to reduce or mitigate the risks attached to green hydrogen projects and technologies to leverage the private finance needed for investment. Over time, as policy and framework conditions for green hydrogen market would become more certain, technologies are proven and investors become more familiar with the green hydrogen field, perceived or actual risks should be reduced, resulting in more capital flows from the private sector besides DFI financing.

As per Kenya's revised NDC pledge of 32% emission reduction by 2030 with a corresponding cost of USD 62 billion (~EUR 55 billion) by 2030, government has announced to bear 13% of the costs (~EUR 7 billion) through its own budgetary allocations, leaving a gap of ~EUR 48 billion funding requirements by 2030 in climate finance sector which would potentially include green hydrogen. DFIs can play a major role in bridging this funding gap by extending their financing portfolio for potential green hydrogen projects in Kenya.

The most relevant DFI tools and mechanisms to overcome risk for hydrogen projects include:

DFI tools and mechanisms	Description
Technical assistance (TA) fund	i TA fund to specific green hydrogen projects in carrying out technical and financial feasibility studies as well as project due diligence supports ii TA and associated funding support to government to establish required policy frameworks pertaining to green hydrogen sector. Examples: ■ Develop green transport strategy to streamline use of hydrogen fuel in transport sector ■ Prepare industrial policy action plan which would provide financial incentives/direct manufactures from targeted sectors for opting cleaner production practices using green hydrogen. ■ Technical assistance to setup standards and certifications of green hydrogen that will boost up the domestic and export market.
Loan guarantee	DFIs can underwrite loans to green hydrogen projects to protect the private investor against defaults. This tool transfers part or all the risks from the lender onto the DFI as loan guarantor, thus encouraging local financial institutions to finance green hydrogen projects. Often, when a partial or full risk guarantee is extended by a DFI, an as impact, lender is then better positioned to charge a lower interest rate on the loan than their usual local market rate. These DFI loan guarantees are de facto a subordinated (rank) position as partial first loss provision making the overall risk sharing measures attractive for the local banks to extend financing for green hydrogen projects.
Concession Loan	Besides lack of capital (debt and equity) from the private sector for investing into green hydrogen projects, investors would require concessional funding with low upfront payments. It is expected that, most of the pilot green hydrogen projects in the private sector will be based on off-balance project finance rather than on-balance sheet corporate finance mechanisms. For green hydrogen projects to be financially viable, concessional loans shall be available at low cost as well as for longer tenor which is currently not available from local financial institutions in Kenya. DFI concessional financing can be structured through differences in rate, tenor, security and rank as first-risk takers for pilot H2 projects, such as subordinated debt (financing with a lower repayment priority than other loans).

DFI tools and mechanisms	Description
Grants for CAPEX	Green hydrogen projects are at early market stage globally. For Kenya, to implement pilot green hydrogen projects will involve high capital costs, mostly due to the high cost of electrolyser. DFIs may consider providing a portion of their funding supports as grants to bring down the overall CAPEX of green hydrogen project. Required grants amount can be estimated project-by-project basis with an objective to support commercialization of green hydrogen production and at the same time not to distort the present hydrogen market.
Lease-financing mechanism	As part of end-user financing, it is expected that industrial clusters opting for green hydrogen as fuel for their production practises would prefer fee-for-service and leasing options due to the lack of upfront costs. Likewise, privately owned utilities provide fee-for-service and leasing of RE systems, similar leasing mechanism can be adopted for green hydrogen project enabling a third-party operator to obtain lease finance and sell generated energy to industrial clusters. For obtaining lease finance[64] from commercial bank, it will be important to have hydrogen purchase agreements (HPA) between the operator and end-user (industrial cluster) based on a take-or-pay model or a fee-for-service (annual payment would be linked to usage of green hydrogen) The leasing-based finance mechanism can achieve critical mass and better financial sustainability due to typically larger scale of the project. However, often private operators might face difficulty accessing local bank financing required to bear large upfront capital costs for machinery and equipment. Particularly for green hydrogen project, there could be mismatch between the leasing and HPA periods resulting in merchant risk (price and volume) for the operator/commercial bank. There is also greater uncertainty about pricing strategy of green hydrogen-based products/services To mitigate this merchant risk, DFIs may facilitate finance lease by commercial banks backed by lease guarantee[65] up to a certain percentage of finance lease amounts granted for implementing green hydrogen business activities by the private operator. DFI finance lease/business guarantee can increase local bank involvement offering finance lease as an innovative financing mechanism for green hydrogen projects.

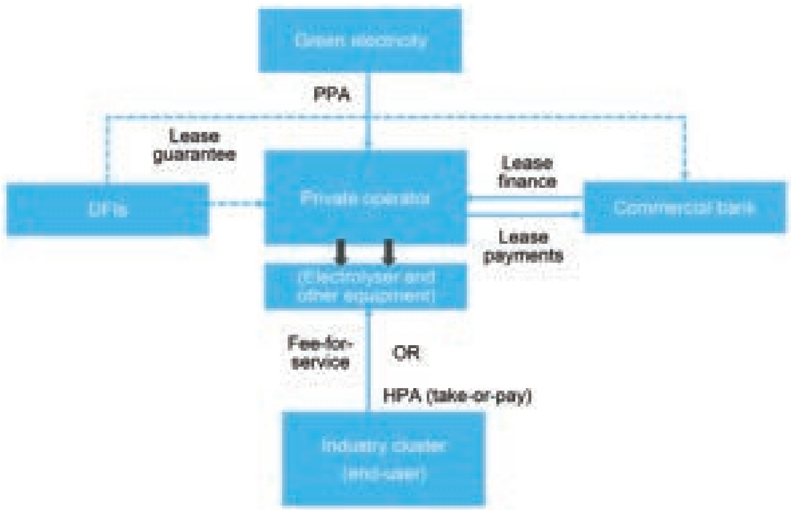


Figure 8-11: Lease Finance Backed by DFI guarantee

64 Refers to finance lease in which a commercial bank is the legal owner of the asset for the duration of the lease, while the private operator (lessee) possesses operating control over the asset as well as economic risks and benefits of the leased asset.

65 A lease guarantee refers to a guarantee to be issued by the DFI to the commercial bank (lessor) to guarantee on-time payment of rent by the private operator (lessee).

Ministry of Energy, Kenya, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH Complete Study Report

DFI tools and mechanisms	Description
Incremental cost incentives	DFIs can contribute directly to the incremental cost of green hydrogen projects. Examples include: a top-up or results-based finance for the incremental operational costs until RE market develops and price parity is achieved with alternative fuel options. Incremental costs can be estimated project-by-project basis against carbon avoidance costs of the underlying green hydrogen project, thus directly improving project's revenues and financial viability.

8.6.3 Green Hydrogen and Derivative Products Capacity Building

There is a strong need for briefing financial institutions on green hydrogen and derivative investments. Many have some understanding of green hydrogen, but not enough to be able to assess risk levels and make an investment decision. Therefore, capacity building on risk and risk mitigation as well as valuation of green hydrogen and derivative products could help facilitate private financing.

The most important factor in engaging private finance is the development of a market for green hydrogen and its derivative products. A key step in developing this market is to develop and industrial appetite for them. Therefore, is it vital to engage with industry to help them understand the opportunity that green hydrogen presents for improving their operations. This could be done for example through a series of workshops which present not only case studies showing the opportunities and cost vs. benefit of modernizing to green operations but which also provide a networking forum for industry, suppliers, and financing institutions to share experiences.

8.6.4 Summary of Bottlenecks

The following table is a high-level summary of the stakeholders' responses to the hindrances in the development of green hydrogen at scale in Kenya described in detail in section.

Issue	Potential Solution
Financing Challenges	
Local Loan Tenors too short	IFI could facilitate the availability if international funding sources in country and offer longer loan tenors in combination with other applicable facilities such as guarantees.
Complex compliance and reporting process	Create a Green Hydrogen "One-Stop-Shop" assisting with all aspects of project implementation and approvals for green hydrogen investments including the full range of requirements and how to meet them as well as having a single coordination office for all required government approvals.
Complex environmental and social requirements. Developers and industrial partners are often unfamiliar with meeting the environmental and social requirements required by IFI's	Create a Green Hydrogen "One-Stop-Shop" Provide technical assistance to help companies carry out the required environmental and social studies.
Project Implementation Timelines: Extended development timelines lead to higher risk and higher project costs.	Create a Green Hydrogen "One-Stop-Shop". The experience of the various stakeholders working together in the same office will assist in reducing approval and thus development time.

Issue	Potential Solution
Approval Process	
Technical Frameworks and Standards: Lack of regulatory frameworks allowing the use of hydrogen and hydrogen-based applications.	Develop technical regulatory frameworks for the use, transport and storage of hydrogen based on international guidelines, along with safety requirements to enable project implementation.
Land Rights: Multiple county approvals required for land use	Large scale projects could be granted strategic status allowing a "fast track" through approvals. Green Hydrogen "one-stop-shop"
PPP referrals: Lack of understanding of green hydrogen products business models and being requested to contact additional agencies such as the PPP unit which don't apply in this context.	Enable the PPP unit to be more flexible with the types of models they use to be applicable to green hydrogen and green hydrogen products. Green Hydrogen "one-stop-shop"
Sourcing Green Electricity	
Fully control value chain, including geothermal production is not currently possible	Allow the private development of captive geothermal energy as utility scale for the production of green hydrogen. (or develop a risk sharing agreement where GDC shares in the market risk of green hydrogen)
geothermal license is not long enough to allow for positive investment decision	A longer lease, or right of first refusal to be offered after renewal period
Exclusivity of exploration/feasibility study licenses: unclear exclusivity of Geothermal exploration licenses	Clearly state period of exploration exclusivity in regulation
Exclusivity of exploration/feasibility study licenses: no exclusivity during feasibility stage for wind and solar locations (at the mercy of the land owner)	Allow developers to apply for a period of exclusivity during feasibility stage for renewable energy projects with Ministry of Energy
Licenses for Captive Power: Electricity generation license is required even for captive power, above 1 MW adding unnecessary costs	Waive electricity license requirements or raise the limit for self-consumed captive power
Net Power/Power Balancing: Enabling Net Power when using variable renewable energy as captive power.	Implement regulatory framework with legal and commercial guidelines enabling an "energy bank" for balancing power, however limiting any negative effect on the non-green H2 demand (e.g. in the worst case always banking during off-peak and consuming for green H2 during peak)
Electricity Royalties: payment of royalties on revenue prior to project being profitable	Shift royalty to later time period or implement a sharing of profits not revenue

9 ACTION PLAN TOWARDS A GREEN HYDROGEN ROAD MAP AND STRATEGY

Upon defining the current state of the country in regard to green H2 generation potential and respective PtX opportunities as well as a short list of focus sites and potential pilot projects, this chapter outlines a series of actions – the action plan – to illustrate and schedule necessary stages across the short, medium and long-term in order to facilitate a successful and efficient development of a green H2 economy in Kenya.

The action plan is structured into 6 overall actions (as strands for implementation), each consisting suggestions for the following dimensions:

- Tasks (elements),
- Time frame,
  - Short-term (now-2025),
  - Medium-term (2025 – 2030)
  - Long-term (2030 – 2050).
- Required resources (i.e. funding, oversight responsibilities).
- Key performance indicators (KPIs)

It is aligned with typical instruments and actions suited to set off sector developments and inspire investor's confidence. The actions are organised to develop along the maturity of the green H2 economy in Kenya. It may be broken down to specific sectors in certain cases (e.g. for pilot projects) and further adapted as overall efforts proceed (e.g. strategy is developed and decisions are made) and the market evolves.

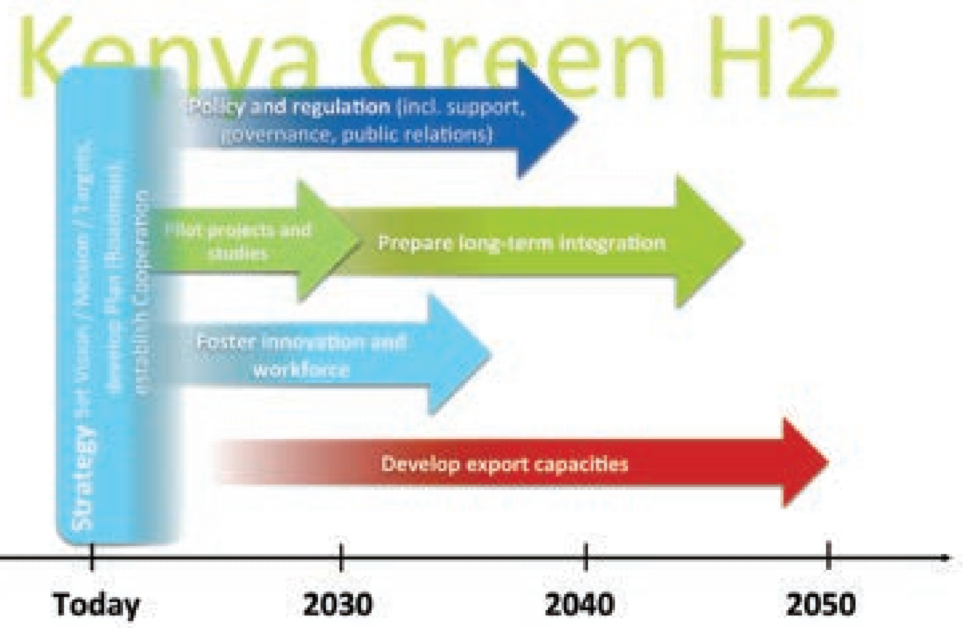


Figure 9-1: Proposed series of actions for a green H2 economy in Kenya

Proposed periods are indicative only and will require preparatory actions. For example, the setting up of pilot projects will require initial studies on siting, layouts, etc. Developing export capacities will require advance discussions and negotiations with potential trade partners and the engagement within dedicated forums of trade and development. These advance actions are expressed by the shading of arrows in the previous figure.

9.1 Key Performance Indicators (KPIs)

Measuring progress of a proposed action plan is key to allow for adjustment along the way and communicate success to a wider audience to garner additional support and investors' confidence. Among the proposed KPI are general KPI which may be monitored continuously as well as KPI that will only apply for certain actions.

Based on international benchmarks and H2 action plans from other parts of the world, general indicators can be derived. These should be evaluated e.g. on a monthly or quarterly basis by the responsible statistical organisation and published along energy / economic statistics. General KPI may include:

1 Volume of green H2 produced / measured in tons per year

2 Volume of green H2 exported

3 Foreign direct investment in H2 infrastructure

4 Cumulative capital investment in H2 infrastructure

Propositions for action specific KPIs will be introduced in the specific actions described below.

9.2 Action 1: Strategy

Time frame	Short-term (now, 2022), to be continuously evaluated and updated
Elements (tasks)	Vision, Mission, Targets, KPIs, Road map/Plan, Working Group(s) – derived / adapted from the Green Hydrogen Working Group (GHWG) and other modes of cooperation
Responsibility and support	Ministry of Energy Dedicated ministries (e.g. Ministry of Transport, Ministry of Agriculture, Livestock, Fisheries and Co-operatives) and other official organisations (EPRA) Dedicated public, parastatal, private stakeholders (e.g. Kenya ports authority, KPLC, National Oil Corporation of Kenya, Universities, etc.) Development partners
Funding	Public funding (Government of Kenya, development partners for support measures, e.g. technical assistance to fund studies or continuous back-up with international expertise for ad hoc needs for planning and policy development)
Action-specific KPIs	See general KPIs in section 9.1. Further KPIs could be defined, if considered useful and measurable, e.g. on cooperation

Setting up a sustainable H2 economy in Kenya and ultimately generating associated environmental, social and economic benefits, requires a clear commitment by the government of Kenya. It has been shown that Kenya possesses both the generation potential as well as the demand opportunities to develop a green H2 economy. Under this pre-text it will be the first objective of the government of Kenya to develop and openly communicate its vision and mission for green H2 in Kenya.

Given Kenya's unique composition of the energy sector, as well as its unique geographical and economic position within the region, a reasonable working proposition would be to "establish a viable and sustainable PtX industry in Kenya over the next decades in order to become a regional hub and leader for green hydrogen applications and trade."

A second step would be to clearly define its mission in respect to certain sectors, product and targets as well the other strands of the action plan, actions 2 to 6 in close collaboration with key industrial players and international stakeholders.

This has to be based on a road map: a plan which has to be a workable compromise between being detailed and realistic on the one hand but also open and flexible considering the uncertainties of H2 on the other. In part, a clear outline on the regular update of the strategy and road map will deal with the high technical and economic uncertainties of green H2.

Further, a collaboration framework with clear commitments and participation of the relevant stakeholders from public and private sphere has to be established during this phase as a precondition that this plan can be implemented. A clear mandate for the overall topic to the Ministry of Energy, potentially with further facilitation e.g. from presidential level, should allow for solving potentially contradicting targets of different government departments (e.g. due to limited resources or different focus) towards suitable compromises.

9.3 Action 2: Policy and Regulation

Time frame	Short-term to medium-term (Now – 2030) and beyond
Elements	Overall governance and monitoring structure, public relations Specific certificates and standards incl. specific safety, health and environmental regulations, Market regulation, (fiscal) support and other incentives
Responsibility and support	Ministry of Energy Kenya Bureau of Standards, Energy Regulatory Commission of Kenya Dedicated ministries (e.g. Ministry of Energy, Ministry of Transport, Ministry of Agriculture, Livestock, Fisheries and Co-operatives) Treasury, Government of Kenya (overall)
Funding	Public funding (Government of Kenya, development partners for support measures, e.g. technical assistance to fund studies or continuous back-up with international expertise for ad hoc needs for planning and policy development), potential funding from levies on carbon intensive products / imports (e.g. CO_2 tax)
Action-specific KPI	None recommended, but KPIs could be defined, if considered useful and measurable.

There needs to be a clear governance structure for the topic of green H2 / PtX, as already mentioned under Action 1 Strategy with regard to cooperation. This structure is not only a precondition for an efficient and effective collaboration in this multi stakeholder environment but also for a consistent policy and regulatory frame with continuous monitoring and adaption. Lessons learnt from similar policies should be used, in particular, the RE policy with FIT where the structure and processes were not effective and fully efficient.

To avoid additional interfaces, it is not advisable to create a new entity but rather to enlarge competences of the Energy Regulatory Commission of Kenya and Ministry of Energy in respect to H2 regulation and policy.

At the same time a clear commitment from the Government of Kenya should be expressed to allow for quick actions and adjustments periodically. For example, incentives need to be put in place and adjusted in a transparent manner to avoid over subsidization or delays / hindrance of projects (as it has been the case for the PV FIT), technical standards need to be sufficiently clear and detailed to allow for their compliance, etc. An important field with regard to overall support of the Government of Kenya would need to be the required budgets of support and incentives to achieve national green H2 targets. The green H2 policy have to be an integral part of the overall energy policy (respective policies / acts to be adapted, in particular RE policy) and energy and power system planning and economic policy. This should address major concerns of potential investors such as sourcing of sufficient amounts of green electricity at secured tariff (ranges) and enabling demand for hydrogen and its products. With regard to this, a continuous and reliable expansion of RE generation is essential to allow for overall ramping up the green H2 market and necessary trust of private investors to invest into PtX technologies. This expansion has to be beyond organic demand development, i.e. with very likely oversupply which has to be kept in manageable ranges my means of proper planning of demand and supply (e.g. including more flexible operation of electrolysers). Further, the policy has to be aligned with overall environmental / climate change policies and commitments, e.g. with regard to any CO2 prices.

A Green Hydrogen "One-stop-Shop" which places members from all required government agencies in one office, to assist investors and developers in attaining the approvals and working through the development process would help make the approval process clear and transparent and shorten green hydrogen development times.

Some technical regulations for the industrial use and handling of hydrogen are in place but require a thorough review, refinement and filling of gaps to allow for a roll-out across different sectors and matching international developments. Obstacles to the import and implementation of H2 technologies are known today, e.g. non-existence of regulations to import and run H2 equipment such as fuel cells and storage units, which may in the worst case be stopped from import or operation due to unsolved safety and environmental concerns. Therefore, this needs to be addressed one the one hand in structured and comprehensive way but on the other also immediately (e.g. with project accompanying approvals with international expertise) to back up pilot project development as well as ongoing private sector initiative.

Another large facet of the introduction of suitable green H2 regulations should be the alignment within the regional and the international markets, particularly in terms of internationally harmonised technical standards, certificates, quotas and competitive prices (e.g. within East African Community).

Major components need further research and may comprise, but not be limited to:

- Combining RE policy / regulation and overall energy policy with policy regulation for green hydrogen and its derivatives (including wheeling, tariff schemes for green H2 production, captive development of RE sources for green H2, etc.),

- PtX off-taker arrangements including regulations for markets / subsidies for green H2 products, in particular fertilizer
- Regulation and standards for generation, transmission, distribution and storage of green H2 and its derivatives,
- Standards and certification for operators, suppliers, vendors, infrastructure, etc.
- Admission quotas,
- Non-discriminatory access to market and infrastructure,
- Health and safety regulations,
- GHG accounting options,
- Environmental impact regulation,
- Financial incentives and support mechanisms (on a country as well as per sector and/or product level).

Pilot projects, i.e. smaller scale projects as proof of concepts and beyond, should be implemented (with all necessary studies) as soon as possible. However, premature decisions on large scale projects and overall technologies, should be avoided to maintain momentum and confidence in the new national strategy and avoid any lock-in effect (e.g. with regard to technology or allocation of limited resources such as available (surplus) electricity). This involves sufficient and clear-cut public participation, maintaining flexible processes in response to market demand and allowing for timely decisions to allow investors to reap low-hanging fruits. For transparency's sake it will be advisable to involve a standing stakeholder committee being composed of industry and association representatives in the discussion of regulatory monitoring results and needed amendments.

9.4 Action 3: Facilitate Studies and Pilot Projects

Time frame	Short-term (now – 2025/30)
Elements	Confined pilot projects across several sectors, pool to develop domestic hubs, Studies
Responsibility and support	Ministry of Energy Dedicated ministries (e.g. Ministry of Transport, Ministry of Agriculture, Livestock, Fisheries and Co-operatives) Dedicated stakeholders (e.g. Kenya ports authority, Kenya Power and Lighting Company, National Oil Corporation of Kenya, Universities, etc.)
Funding	Public funding (Government of Kenya, development partners for support measures , e.g. technical assistance to fund studies or continuous back-up with international expertise for ad hoc needs for planning and policy development), DFI and IFI Technical Assistance
Action-specific KPI	Price of green H2 in kg, Conversion efficiency per kg green H2 (e.g. kWh/kg, l water /kg), Pilot project aggregated capacity / production volume, CO_2 reduction per H2 production capacity or USD invested

Pilot projects are a proven tool to learn about the technical as well as economic feasibility, risks and implications and needed regulatory environment within a well observed and limited scale. Pilot projects offer options for dedicated research and public campaigning before going all-in with regulation and investments. In that sense, they constitute a necessary first action to avoid costly mistakes and gather public as well as political support. If implemented and running (even in small scale), they are a proof of concept in the particular area / country and for a particular design / technology. Even if detailed studies are done and international experience exist, proof of concept is often necessary or at least strongly enabling e.g. for larger scale developments and respective funding, securities, insurances, etc. Pilot projects should be developed in close cooperation with the private sector, universities and covered by government guarantees.

Pilot projects will require advance studies and research to be able to decide a suitable layout, supply and configuration against the background of the national H2 strategy. Pilot projects should be also seen as a potential foundation for the development of green H2 hubs in the country (e.g. in coastal and central areas) where the further expansion benefits from a common infrastructure etc.

In parallel, various studies have to be conducted to fill the gaps of information identified in this study for particular PtX opportunities and overall subjects such as water availability:

1 **Site selection study for matrix of use / site candidates -** answering the question which areas and sites are most suitable to put certain capacities of electrolysis plants and infrastructure (i.e. near network, RE supply, near demand, depending on logistics, etc.) - with preliminary design (optimization exercise, e.g. with TE Prosumer), also for proof-of-concept project (Mombasa, Nairobi, Olkaria…);

2 **Market studies** (incl. regulatory needs) (fertilizers as well as other products), Kenya and region (oversea), industrial readiness for green H2 economy, market study looking at linkages between industry, manufacturing and market, including capability and capacity for in country production of equipment. Strategic road map planning to establish demand certainty across sectors. For fertilizer, downstream analysis on actual need for fertilizer product range, considering specific requirements such as regional soil and crops, food security objectives, farmer capabilities, habits and needs as well as climate change protection requirements (to mitigate adverse effects of nitrogen-based fertilization.

3 **Water resource study / concept.** This should contain environmental studies considering competitive use, direct as well as indirect social and environmental impacts in particular areas, exploitation of additional water resources,

4 **Power generation / network system studies** (e.g. overall expansion with H2 as energy carrier scenario, H2 vs. BESS, peaking/back-up plant Mombasa etc., integrated in overall energy / power system planning / LCPDP applying LIPS, PSSE, Plexos etc.)

5 **Technical process engineering studies** e.g. geothermal exhaust gases (additional environmental benefit H_2S, CH_4, CO_2,..) and other CO_2 sources (bagasse, cement…) or on green / environmental friendly fertilizer production (e.g. Nitric Acid)

6 **Infrastructure and logistics studies**, analysing suitable means of supply and transport and storage of hydrogen and derivatives (mainly ammonia) but also water and other input such as CO_2.

7 **Financial and Economic Studies,** modelling the impact of green hydrogen on the Kenya economy, Cost-benefit modelling of potential incentive programs such as Carbon Tax to ensure no undesired consequences to the policy. Cost-benefit of a top-up program similar to H2 Global

8 **(Pre-)Feasibility studies for specific or set of site / use candidates**

9 **Specific study on green transport (mobility) options for Kenya** comparing green H2 and alternatives (battery electric and others) for different transport sub-sectors (public transport, heavy duty transport, short/long distances, railway/road/ maritime/aviation) with surveillance and projections of technological developments and costs (to be updated regularly); including (pre-)feasibility or concept studies for selected cases (e.g. railway techno-economic comparison of electrification and green H2 based operation, green maritime bunker fuel, public transport case Nairobi)

Note: Studies which focus on the development of entire sectors and their possible interactions will be subject to research required at the levels of individual actions (e.g. regulatory gap analysis, long-term system integration, export market analysis, etc.) and need to be headed by the governing authorities. Even if multiple studies are and will be conducted by private entities, the development of a publicly available common set of assumptions and data (e.g. with regard to costs of input resources, average tax/duty, water availability) would allow for conducting these studies more efficiently and less costly, more potential market players being able to conduct or contract such studies and will allow for a better comparability and use of the results.

Based on the PtX demand opportunities ranked in Section 6, particularly the opportunities with little obstacles and high enablers constitute “no regret options” and should, hence, be chosen as pilots and/or proof of concept for selected sectors. Prime candidates could be the use of the domestic production of green H2 in agriculture, manufacturing, transport and the electricity sector. This means green H2 and ammonia (fertilizer) products are chosen to be of strategic value. Under this pretext the following sector are suggested for strategic pilot projects.

- **Transport Sector:** On-site transport / logistics vehicles at Mombasa port, public transport vehicles in Nairobi and (potentially) heavy duty vehicles in mining areas around Mombasa offer prime implementation options for pilot projects.
- **Research / standards**: smaller scale electrolyser and fuel cell at (former) refinery site in Mombasa to complement laboratory work, research sites at a university in Nairobi or other academic / research institutions, including private company production / research sites with support from government / academic. Due to size and purpose (and respective available technologies) this would be likely the quickest project to implement facilitating all other projects with building up know how in ten country.
- **Light manufacturing industry:** Existing demand of hydrogen and ammonia in the chemical industries could be partially or fully be substituted by green H2. Seamless integration expected as handling of green H2 does not differ from standard H2, effects on economies and supply chain logistic could be researched. Green H2 may serve as a higher quality product, replacing e.g. LPG. If domestically supplied green H2 and derivatives is available in the country volume may increase due to potentially lower prices and more reliable supply compared to imports.
- **Agriculture / manufacture:** Due to the high demand in H2 and ammonia for fertilizer production also the setting up of a local fertilizer production facility based on green H2, could be among the list of pilot projects. Also, fertilizer products could be among the first export opportunity for green H2 products. Due to the required size, the high environmental precautions and wider value-chain to be taken and wider economic implications to farmers, suppliers, it may not be among the first pilots to be launched, however planning for implementation should start immediately. Depending on the political and economic vision, such a project should be envisioned with a very high political commitment only.

- **Electricity Sector:** as a solution for off-grid / captive power supply the integration of electrolysis and fuel cells into remote hybrid grids or isolated consumers such as base stations or large scale consumers with a need for captive / uninterrupted power supply will certainly constitute a near-term application of green hydrogen where suitable products are already available. Such a solution would need to withstand though competition from also innovating battery technologies and technological challenges in terms of a safe and reliable long-term operation. This could be immediately tested in a pilot project. Also, being closed loops, such applications will offer opportunities for a proof of various concepts on a small scale. Further, it may be the starting point to analyse the benefits and challenges to use this technology as a grid connected capacity for back-up/peaking power also to support regional grids as in the coastal area / Mombasa port area.
- A more ambitious pilot for the medium to long term would be a plant for **raw steel production by DRI.** Due to size and current ongoing implementation of similar projects at established steel mills in Europe (to be operation around 2025) such a pilot may be introduced rather in the period 2025 to 2030.

On that basis a pilot programme could comprise: An electrolyser unit at / near Mombasa port supplying on-site transport, selected public transport vehicles and charges of demands of the light industry as well as an option for a dedicated production line for green ammonia and green fertilizers. Scales and dedicated logistics would need to be studied as part of a distinct feasibility study. Another pilot with similar purpose may be implemented in Nairobi as the commercial and industrial centre of Kenya. As third pilot is proposed to be focussing rather on large-scale applications should yield surplus energy around in the Olkaria region putting dedicated research focus on logistics as well as applications in the fertilizer industry. For areas with sustainable CO2 available (Mombasa, Olkaria) this could be extended to e-methanol and beyond. For Olkaria a pilot may already cover the use and treatment of geothermal exhaust gases as additional benefits.

Across all pilot projects a clear political commitment needs to be in place securing the balancing of adverse economic effects. Hence, each project will require a dedicated **project and monitoring team** being composed of representatives from the respective companies as well as the concerned ministries (e.g. Ministry of Transport) and the Ministry of Energy. The project and monitoring team should also have a clear mandate and budget for sustainably running the project(s) for the envisaged operation period.

It is further advisable, to bundle a number of pilot projects across sectors or value chain element (i.e. electrolysis, storage, use) in a certain area. This will offer the advantage of being able to consider cross-sector exchange of green H2, balance H2 surplus or deficiencies and develop a domestic and even regional **H2 knowledge hub**. The latter may constitute a go-to-place where visitors, decision makers and investors could be informed about different green H2 applications and their pros and cons. Another very big advantage of pooling green H2 pilot projects would be that questions regarding the locations and distances between electrolysis, storage and use as well as the specific means of transport will not decide over the general viability. In that sense the level of complexity may be reduced during the initial stages.

9.5 Action 4: Foster Innovation and Work Force

Time frame	Short to medium-term and long term (Now – 2030/35)
Elements	RD&I hubs including laboratories / institutes for standards, certification, vocational trainings / further education with specific or extended curricula, knowledge sharing networks (national across sectors and spheres and international)
Responsibility and support	Ministry of Education, Ministry of Labour Universities, Large corporations, NGOs
Funding	Public funding (Government of Kenya, development partners for support measures, e.g. technical assistance), International Associations / Research Institutes
Action-specific KPI	Number of students and apprentices in green H2 subjects, Employment rate in green H2 economy

As stated in the context of Action 2, the creation of a domestic or even regional knowledge hub for green H2 should be among the key priorities of the early actions. In cooperation with national and international universities, pilot projects will offer a great resource for research and innovation. This will touch a variety of disciplines from engineering to law, conduct on-site research on the specific of generating, storing and transporting green H2. Again, the organisation in a green H2 hub offers better access for research and innovation practises. This will offer the opportunity to immediately start of building up expertise in the country.

Clear R&D targets will need to be set along the realisation and operation of pilot projects. At the same time public financial support to these R&D activities should be available either as direct funding or the creation of suitable incentives for private companies (e.g. tax exemptions, subsidies, etc.).

Another pillar of work force development will be putting a strategic focus on further education and vocational trainings for specific topics related to green H2 economy (e.g. logistics, etc.). This includes defining and communicating job opportunities and marketing as well as focussing vocational training schemes. Educational schemes involving dual education models (combination of university study and vocational training), industry scholarships and practical work and internships may also play a major role for aligning education to the industries' needs.

Strategic focus also implies the provision of a framework for workshops and educational public-private collaborations or worker exchange programs. Also the newly created jobs should be promoted via job fairs and employment databases.

This should be developed upon a successful proof of sector concepts and dedicated commitment to develop green H2 economy. Hence, while the design of training courses and vocational trainings may be starting with a small delay to the implementation of pilot projects only, their inception should take place once a clear regulation is in place in the medium-term only.

All the above should build on the one hand on the existing structure for research and education (as stated in section 4.5) as well as on lessons learnt gathered during building up research and education for RE subjects, introduced in numerous projects and organisations in the past 10 years.

9.6 Action 5: Prepare Long-Term Integration

Time frame	Medium-term (2030 – 2045)
Elements	Sector coupling studies and infrastructure, transparent and public information
Responsibility and support	Ministry of Energy; Ministry of Industrialization, Trade and Enterprise Development, Ministry of Transport, Infrastructure
Funding	Private corporations as main source, public funding for supporting infrastructure / schemes; potential funding from levies on carbon intensive products / imports (e.g. CO_2 tax)
Action-specific KPI	Green H2 consumed per sector in tons, Green H2 share of energy consumed per sector in GJ (or as %), CO_2 reduction, Price of green H2 (products) in USD/kg,

Long-term integration requires a solid framework and market demand for green H2. This would constitute the logical next step after having learnt the lessons from pilot projects in Kenya and worldwide. Striking a fine balance between strict regulation and an open market is key as some pathways are already close to cost competitiveness but market risks for new entrants may remain high. Investor's and costumers' confidence will be the key driver to promote a long-term integration of green H2 as a standard commodity across different sectors.

Integration is to be understood twofold:

1 Green hydrogen will increasingly be a means of coupling sectors and processes

2 Green hydrogen should become an integral part of Kenya's list of commodities

A prerequisite is a strong link to strategy and regulation by setting standards and quotas, e.g. for the permissible admission of green H2 or green methane to the gas network and other natural gas applications. This, however, needs to be closely aligned with a systematic integration of hydrogen and excess RE generation in the long-term expansion planning to be able to build up a clear pipeline of viable investment projects. At the same time this serves as a guarantee to investor's for sufficient generation potential and network availability.

Even beyond this, long-term integration still requires an active part by the Ministry of Energy, to equip investor's with sufficient information and access to required processes. Considerable investment in infrastructure may be required. For this a viable vehicle could be PPP projects, sharing risks and responsibilities among public and private investors. A good vehicle to promote H2 investments would also be the above mentioned "Green Hydrogen One-Stop-Shop" potentially under the auspices of the MoE. The office would function as a point of contact for investors providing information, access to market information, helping with applications and regulation as well as gathering constant feedback for the regulatory monitoring of the government's green H2 strategy.

In that context, the development and updating of a green hydrogen map, similar to a solar atlas, showing areas of potential demand and generation potential could proof a useful tool.

9.7 Action 6: Identify Export Capacities

Time frame	Medium- to Long-term (2030 – 2050)
Elements	Extension / preparation of Mombasa port (preparation of Lamu port, to be assessed), development of long-distance logistics concept (in collaboration with importing countries and trading companies) and feasibility study, study on export markets and continuous market surveillance, negotiations with potential trade partners and engagement within dedicated forums of trade (private and public)
Responsibility and support	Ministry of Industrialization, Trade and Enterprise Development, Ministry of Energy, Ministry of Transport, Infrastructure; Ministry of Agriculture, Livestock, and Fisheries, Dedicated authorities and corporations (e.g. Kenya ports authority, National Oil Corporation of Kenya, etc.)
Funding	Public funding (Government of Kenya, development partners including support schemes to ramp up green H2 trade e.g. H2Global), Public-private partnerships
Action-specific KPI	Volume of green H2 (products) exported in tons Green H2 exports as a share of total green H2 produced

Exporting green PtX products is in direct support to the proposed vision of becoming a regional and international hub for green PtX products mainly in terms of physical goods but potentially also for know-how. Large scale export opportunities, however, are only realistic when domestic supply is stable and competitive, regulation meets international standards and international demand is well established. Hence, in order to be able to capitalise on Kenya's export potential, all the previous actions need to have led to a sustainable green PtX economy which may sustainably generate surplus green PtX products dedicated for the international market.

Due the already high demand as well as the potential cost competitive green production, fertilizers may be among the first export products, in particular in the EAC region with similar demand patterns and established transport routes allowing for economies of scale on top of domestic demand. High competition on the worldwide market – in particular from countries with established fertilizer industry and available natural gas resources - necessitates a close monitoring of foreign markets, e.g. establishment of long term agreements e.g. within EAC (against price dumping) and technical alignment in terms of standards to unlock export opportunities. Another area is green H2 and its derivatives (mainly ammonia) as a higher priced commodity for various industrial processes. As for Kenya, it may likely be already cost competitive in the region compared to international import, which already goes physically through Kenya for most countries in the region. This export potential could be further expanded for more sophisticated products such as methanol or e-fuels (e.g. e-kerosene) if technical innovation (and learning curves) and building up sufficient production capacity in Kenya provides the basis for cost competitiveness compared to international fossil fuel based imports or local production in neighbouring countries themselves. However, self-sustaining and export-ready green H2 markets in neighbouring countries may only be expected beyond 2030. Concluding, fertilizer and green H2 and derivatives and fuel exports may offer medium term export opportunities at increasing scales. In the long term, this may be expanded product wise, e.g. for green steel (if this proves to be feasible for the local market) and export destination wise competing on a worldwide market.

With export from Kenya's seaports, Kenya will have to compete with several potential green H2 hubs for the European and Asian market.

- Particularly countries in the MENA (Middle East Northern Africa) region are exploring export opportunities and may become the main competitors in the medium- to-long-term, with considerable strategic advantages with regard to established industries and trade routes and geographical vicinity to main markets (e.g. Europe).
- Others are countries in Northern Europe with huge and diversified RE potential (e.g. hydropower, off-and onshore wind) and fully established industries also benefitting in terms of transport costs from the geographical vicinity to the demand centres in Europe.
- As well as Australia and countries in South America as established export countries for energy and other commodities and with a huge, diversified and low cost RE potential.

Hence, a close market surveillance based on an initial market study for exports, discussion with potential international stakeholders/secure off-takers and export potential analysis may need to be an ongoing task already now. During these discussions, a strong argument for potential large volume off-takers to source green H2 (products) also from countries like Kenya is to diversify the supply. This will be much easier than for the petroleum and gas market today where not only prices and availability but also politics are directly influenced by the main suppliers. Among these "second tier" suppliers Kenya likely ranks high due to various reasons, e.g. its strategic location, availability of diversified RE resources and relative stable political and investment environment.

However, green H2 trade will need to be considered as a flexible option or scenario within the future infrastructure and RE expansion planning and any direction of green H2 policies. That being said, not only port infrastructure and market surveillance but also infrastructure and RE capacity planning will play a pivotal role. Both handling of green H2 as well as building a (parallel) chain of transport logistics for green H2 (products) exports would need to be considered on feasibility level. This should also consider impact on the domestic market in order not to disadvantage domestic market and environment (too much) e.g. with regard to availability of resources such as RE capacity and water for the sake of foreign exchange income.

The different potential production locations will have an impact on the costs and technical requirements for transport and storage of export products. This very much depends on the kind of product starting from the – from today's point of view – rather difficult to store and transport raw green H2 via liquid derivatives (starting from the potentially harmful ammonia to the relatively easy to store and transport methanol) to solid products such as fertilizers and steel which can be transported and stored as bulk. It is entirely open which products could be cost competitive and in demand on the international market in the medium to long term. Therefore, any such assumption on export potential cannot be robust to be the main reason to decide for or against sites or areas today. In other words: other parameters such as availability of resources (e.g. water or RE capacity / network) and (existing) domestic demand have to be ranked higher; in particular considering that export capability will be more likely if built on expertise and capacity for a (more reliable and regulable) local market. However, in the above-mentioned site selection study, potential expansion for export capacities should be considered as a scenario (to identify expansion thresholds for e.g. land availability, power transmission capacity or water as well as the cost reduction potential from economies of scale). Mombasa as the main hub for the country and the entire region and with other technical, regulatory and economic advantages may be the no / lowest regret location for potential regional and international export combined with supply for local demand. Other preferred locations such as Olkaria or Nairobi area are not per se excluded as potential production areas for exports due to the established transport corridors to neighbouring countries and to Mombasa.

9.8 Summary on Action Plan and Next Steps

Kenya's interconnected power system with already today mostly green electricity, its position within the EAPP and EAC as a hub for trade and know-how and its abundant RE resources and integration rate form an excellent point of departure for creating a green H2 economy.

Little restrictions of transport capacities within its power network and RE penetration rates above 90% offer sufficient flexibility for high utilisation rates of electrolysis plants which may convert excess and new RE generation to green H2. Implemented and planned large scale enhancement of nearly all network backbones and surplus capacity offer a unique advantage compared to other countries.

Given the current development of electricity demand and the planned power system expansion, a window of opportunity of about 10 to 15 years will allow for exceptionally low generation costs (due to excess energy) of green H2 at any location with sufficient transmission capacity. This may provide a suitable testing ground for initial pilot projects and developing early supply chains requiring relatively low regulatory incentives.

At the same time, there is already sufficient potential local and regional demand for green H2 (products) in various industrial pathways to ramp up a green H2 economy in the country.

With these preferential frame conditions on the one hand and amid the very high technical and economic uncertainty of green H2 on the other the following can be summarized with regard to actions towards a green H2 strategy and road map and implementation:

Kenya neither needs to "rush" into green H2 - with the risk for to early and unsustainable commitments or lock-in decisions - nor to wait - as plenty of preparatory and no-regret work and projects can be started immediately:

- A strategy and plan leading to a reliable and comprehensive policy and regulatory framework including governance and monitoring of the topic is a prerequisite. It should be flexible enough to adopt to the uncertainty and maturing market and learn from first pilot projects
- In parallel, pilot projects and research projects of different sizes (from laboratory size to actual production for the market) should be kicked off immediately. They will proof different concepts of green H2 to be viable in Kenya. They will be the potential starting points for green H2 hubs within the country to allow for the long-term ramp up and integration of the green H2 market. There are various no regret projects to be kicked-of immediately which may also help to inform strategy and policy making process.
- Further, immediate start of building up expertise in the country (RD&I and education) will be no-regret actions as they could and should benefit from the above mentioned pilots and proof of concepts and build on existing structures (public/academic and private) as Kenya to some extent is already a hub for selected technologies and industrial processes.

With its geographical position both the domestic as well as the regional market offer attractive offsetting potential for green H2 in the medium and long-term. Whether Kenya will be able to compete on a worldwide market with the potential future green H2 hubs cannot be said today. The development of a stable local and regional market is a strong enabler for this.

Annex A PESTEL criteria

Categories (PESTEL forces)			Weighting PESTEL force	Importance of assessment criteria (country view /objectives study)
1		**Political**	**10%**	
1.1		Ensure security of supply / diversification		1.1
	1.11	Diversify country energy mix in general		1.0
	1.12	Provide additional reliability (back-up) to power system		1.0
	1.13	Provide additional reliability to overall supply (energy and other commodities)		1.2
	1.14	Reduce uncertainties and strengthen planning		1.2
1.2		Use of domestic resources		1.2
	1.21	Reduce dependencies which cannot be influenced		1.0
	1.22	Reduce impact of foreign exchange rate / currency / trade balance		1.3
1.3		Obligations international policy		1.2
	1.31	Contribution to NDC		1.5
	1.32	Reduction of GHG emissions (globally)		1.5
	1.33	Other environmental int. policies / obligations (e.g. harmful substances)		0.8
	1.34	Other international policies / obligations (trade,...)		1.0
	1.35	RE additionality (additional RE capacity for green H2 production)		1.5
2		**Economic**	**25%**	
2.1		Project economics (feasibility) in terms of competetive levelized costs (i.e. vs. alternatives, fossil fuel		1.1
	2.11	Today / near future (2025)		1.5
	2.12	Medium to long term (2030)		1.2
	2.13	Long term (2040)		1.0
	2.14	Very long term (2050)		0.8
2.2		Financing opportunities and challenges		1.3
	2.21	Commercial financing (domestic and international)		1.5
	2.22	Preferential financing (IFI, DFI) possible		1.5
	2.23	Funding of GHG reduction technologies supported internationally		1.5
	2.24	Total CAPEX volume (e.g. finance/euqity/debt requ.)		0.8
	2.25	Cost-benefit relation: CO2 reduction cost efficiency		1.0
2.3		Frame / external conditions: location / infrastructure and size effects on specific economics		1.4
	2.31	Site close to supply (of RE and other input) and demand for output		1.5
	2.32	Infrastructure exists		1.5
	2.33	Scaling up / down costs potential / restrictions		1.0
	2.34	Savings of national / international transport costs		1.5
	2.35	Is there a national / regional market / demand for the product incl. possibility to expand to other prod		1.0
3		**Social**	**15%**	
3.1		Socio-economic losses /benefits		1.2
	3.11	Enhanced/reduced vulnerability to climate change		0.8
	3.12	Enhanced/reduced vulnerability to job creation/income		1.5
	3.13	Other benefits / costs to community		1.2
	3.14	Social issues, conflicts vs. supportive social structure in planning area		1.2
3.2		Workers / population safety		1.3
	3.21	Harmful substances		1.5
	3.22	Technical Standards / regulation exists / enforced		1.0

4		**Technical**	**25%**	
4.1		Technology readiness		1.2
	4.11	Global level: proven and available (off the shelf) vs. pilot or research		1.5
	4.12	Regional/national level: as above, in country, region		1.2
	4.13	Innovation potential / learning curve		1.0
4.2		Project design		1.0
	4.21	Suitable project / unit size		1.0
	4.22	Flexibility of technology (in terms of operation, adaption to supply/demand)		1.0
	4.23	Construction/implementation schedule (short/long, easy/complicated)		1.0
	4.24	Safety standards easy to fulfil		1.0
	4.25	Project already pre-developed (in Kenya) / documents, prel. design etc. (in part) available		1.0
4.3		Frame / external conditions: location / infrastructure		1.0
	4.31	Supply / evacuation of input/output (e.g. infrastructure exists, easy to be build)		1.0
	4.32	Knowhow (O&M, R&D) available (research organisations, service companies, experts)		1.0
5		**Environmental**	**15%**	
5.1		Local environmental impact (immission few km) to wider environmental impact / national		1.3
	5.11	Environmental impact: soil, air, water		1.5
	5.12	Mitigation measures available / possible (at certain costs/regulatory requirements)		1.0
	5.13	Water availability and needs		1.5
6		**Legal**	**10%**	
6.1		Land use		1.5
	6.11	Land availability (also for international investors)		1.5
6.2		Legal / regulatory processes		1.2
	6.21	Legal / regulatory frame exists (incl. safety standards etc.)		1.0
	6.22	Similar processes / projects in the past / present		1.2
	6.23	Doing business / bureaucracy / corruption		1.0
	6.24	Project already pre-developed (in Kenya) / documents etc. (in part) available		1.5

Score Card - evaluating and ranking candidate uses and sites along PESTEL criteria DRAFT

Date 10/21/21
Status In Progress / Draft

Notes/legend Blue fonts entry fields
Red text and yellow fileds indicate clarification needs
Grey font is for comments / explanation

- 2 = -- = insufficient
- 1 = - = sufficient (but rather negative)
0 = o = satifactory (neutral)
+ 1 = + = good
+ 2 = ++ = very g ood

Categories		Candidate (site/use)	Weighting PESTEL force	Importance of assessment criteria (country view /objectives study)								
				Use	Agriculture / fertilizer only	Agriculture / fertilizer+ (H2/ammonia and other derivatives to industry)	Agriculture / fertilizer+ additional benefits (H2/ammonia and other derivatives to industry)	Agriculture / fertilizer+ (H2/ammonia and other derivatives to industry)	Agriculture / fertilizer+ (H2/ammonia and other derivatives to industry)	Agriculture / fertilizer+ (H2/ammonia and other derivatives to industry)	Agriculture / fertilizer+ (H2/ammonia and other derivatives to industry)	Agriculture / fertilizer+ (H2/ammonia and other derivatives to industry)
				Site	Olkaria	Olkaria	Olkaria	Mombasa	Lamu / LAPPSET	7-Forks dam area / Thika with lower hydropower costs	Nairobi	Western Kenya (Kisumu/Eldoret)
				ID								
				Name	Olkaria fertilizer only	Olkaria fertilizer+	Olkaria fertilizer+ "add benefits"	Mombasa fertilizer+	Lamu fertilizer+	7-Forks fertilizer+	Nairobi fertilizer+	Western Kenya fertilizer+
				Result	0.46	0.43	0.49	0.74	0.14	0.40	0.37	0.10
				Rank	14	17	11	6	38	20	21	41
				Gaps: Obstacles / Knock-out criteria	High	High	Very High	Some	Very High	High	Some	High
				count - 2 = -- = insufficient	4	4	8	2	9	4	3	5
				Enablers, niches, low hanging fruits	Some	Very High	Very High	Very High	High	Very High	Very High	High
1		Political	10%		1.6	1.6	1.7	1.6	1.6	1.6	1.6	1.5
1.1		Ensure security of supply / diversification		1.1	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95
	1.11	Diversify country energy mix in general		1.0	2	2	2	2	2	2	2	2
	1.12	Provide additional reliability (back-up) to power system		1.0	1	1	1	1	1	1	1	1
	1.13	Provide additional reliability to overall supply (energy and other commodities)		1.2	2	2	2	2	2	2	2	2
	1.14	Reduce uncertainties and strengthen planning		1.2	2	2	2	2	2	2	2	2
1.2		Use of domestic resources		1.2	1.80	1.80	1.15	1.80	1.80	1.80	1.80	1.80
	1.21	Reduce dependencies which cannot be influenced		1.0	1	1	1	1	1	1	1	1
	1.22	Reduce impact of foreign exchange rate / currency / trade balance		1.3	2	2	1	2	2	2	2	2
1.3		Obligations international policy		1.2	1.00	1.00	1.96	1.00	1.00	1.00	1.00	0.70
	1.31	Contribution to NDC		1.5	1	1	2	1	1	1	1	0
	1.32	Reduction of GHG emissions (globally)		1.5	2	2	2	2	2	2	2	2
	1.33	Other environmental int. policies / obligations (e.g. harmful substances)		0.8	0	0	1	0	0	0	0	0
	1.34	Other international policies / obligations (trade,...)		1.0	-1	-1	0	-1	-1	-1	-1	-1
	1.35	RE additionality (additional RE capacity for green H2 production)		1.5	1	1	2	1	1	1	1	1
2		Economic	25%		1.2	1.5	1.5	1.3	0.1	1.2	1.4	1.0
2.1		Project economics (feasibility) in terms of competetive levelized costs (i.e. vs. alternatives, fossil fuel or electrification)		1.1	1.13	2.25	1.88	2.25	1.13	2.25	2.25	1.58
	2.11	Today / near future (2025)		1.5	1	2	1	2	1	2	2	1
	2.12	Medium to long term (2030)		1.2	1	2	2	2	1	2	2	1
	2.13	Long term (2040)		1.0	1	2	2	2	1	2	2	2
	2.14	Very long term (2050)		0.8	1	2	2	2	1	2	2	2
2.2		Financing opportunities and challenges		1.3	0.84	0.68	0.98	0.68	-0.22	0.68	0.68	0.68
	2.21	Commercial financing (domestic and international)		1.5	0	0	-1	0	-1	0	0	0
	2.22	Preferential financing (IFI, DFI) possible		1.5	1	1	2	1	-1	1	1	1
	2.23	Funding of GHG reduction technologies supported internationally		1.5	1	1	2	1	1	1	1	1
	2.24	Total CAPEX volume (e.g. finance/euqity/debt requ.)		0.8	-1	-2	-2	-2	-2	-2	-2	-2
	2.25	Cost-benefit relation: CO2 reduction cost efficiency		1.0	2	2	2	2	2	2	2	2
2.3		Frame / external conditions: location / infrastructure and size effects on specific economics		1.4	1.50	1.50	1.50	0.90	-0.60	0.60	1.20	0.60
	2.31	Site close to supply (of RE and other input) and demand for output		1.5	2	2	2	0	-2	0	1	0
	2.32	Infrastructure exists		1.5	1	1	1	1	-2	0	1	0
	2.33	Scaling up / down costs potential / restrictions		1.0	-2	-2	-2	-2	-2	-2	-2	-2
	2.34	Savings of national / international transport costs		1.5	2	2	2	2	2	2	2	2
	2.35	Is there a national / regional market / demand for the product incl. possibility to expand to other products / markets (div		1.0	2	2	2	2	2	2	2	2
3		Social	15%		-0.5	-0.5	0.5	-0.3	-0.5	-0.5	-0.3	-0.5
3.1		Socio-economic losses /benefits		1.2	0.28	0.28	0.58	0.58	0.28	0.28	0.58	0.28
	3.11	Enhanced/reduced vulnerability to climate change		0.8	1	1	1	1	1	1	1	1
	3.12	Enhanced/reduced vulnerability to job creation/income		1.5	1	1	1	1	1	1	1	1
	3.13	Other benefits / costs to community		1.2	1	1	2	1	1	1	1	1
	3.14	Social issues, conflicts vs. supportive social structure in planning area		1.2	-2	-2	-2	-1	-2	-2	-1	-2

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Candidate (site/use)

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+ 1 = + = good
+ 2 = ++ = very g ood

Categories		Criterion	Weighting PESTEL force	Importance of assessment criteria (country view /objectives study)							
				Use	Manufact. - light ind. / commodities (for regional ind. consumers)	Manufact. - light ind. / commodities (for regional ind. consumers)	Manufact. - light ind. / commodities (for regional ind. consumers)	Manufact. - light ind. / commodities (for regional ind. consumers)	Manufact. - light ind. / commodities (for regional ind. consumers)	Manufact. - light ind. / commodities (for regional ind. consumers)	Manufact. - light ind. / commodities (methanol, for regional ind. consumers)
				Site	Olkaria	Mombasa	Nairobi	Lamu / LAPPSET	7-Forks dam area / Thika with lower hydropower costs	Western Kenya (Kisumu/Eldoret)	Olkaria / Rift V. (CO2 geothermal or CO2 wells)
				ID							
				Name	Olkaria Manufact. - light ind. / commodities (for regional ind. consumers)	Mombasa Manufact. - light ind. / commodities (for regional ind. consumers)	Nairobi Manufact. - light ind. / commodities (for regional ind. consumers)	Lamu / LAPPSET Manufact. - light ind. / commodities (for regional ind. consumers)	7-Forks fertilizer+ (regional industry)	Western Kenya fertilizer+ (regional industry, export)	Olkaria / Rift V. (CO2 geothermal or CO2 wells) Manufact. - light ind. / commodities
				Result	0.63	1.01	0.83	0.34	0.67	0.29	0.17
				Rank	8	1	3	24	7	28	37
				Gaps: Obstacles / Knock-out criteria	Low	Low	Low	High	Low	Low	Some
				count - 2 = -- = insufficient	1	0	0	5	0	1	2
				Enablers, niches, low hanging fruits	Some	High	High	Some	Some	Some	Low
1		Political	10%		0.9	0.9	0.9	0.7	0.7	0.7	0.8
1.1		Ensure security of supply / diversification		1.1	1.20	1.20	1.20	1.20	1.20	1.20	1.15
	1.11	Diversify country energy mix in general		1.0	0	0	0	0	0	0	1
	1.12	Provide additional reliability (back-up) to power system		1.0	0	0	0	0	0	0	0
	1.13	Provide additional reliability to overall supply (energy and other commodities)		1.2	2	2	2	2	2	2	1
	1.14	Reduce uncertainties and strengthen planning		1.2	2	2	2	2	2	2	2
1.2		Use of domestic resources		1.2	1.15	1.15	1.15	1.15	1.15	1.15	0.65
	1.21	Reduce dependencies which cannot be influenced		1.0	1	1	1	1	1	1	0
	1.22	Reduce impact of foreign exchange rate / currency / trade balance		1.3	1	1	1	1	1	1	1
1.3		Obligations international policy		1.2	0.30	0.30	0.30	-0.30	-0.30	-0.30	0.60
	1.31	Contribution to NDC		1.5	0	0	0	-1	-1	-1	1
	1.32	Reduction of GHG emissions (globally)		1.5	1	1	1	0	0	0	1
	1.33	Other environmental int. policies / obligations (e.g. harmful substances)		0.8	0	0	0	0	0	0	0
	1.34	Other international policies / obligations (trade,...)		1.0	0	0	0	0	0	0	0
	1.35	RE additionality (additional RE capacity for green H2 production)		1.5	0	0	0	0	0	0	0
2		Economic	25%		1.3	1.3	1.5	0.3	1.2	0.8	0.2
2.1		Project economics (feasibility) in terms of competetive levelized costs (i.e. vs. alternatives, fossil fuel or electrification)		1.1	2.25	2.25	2.25	1.13	2.25	1.58	-1.05
	2.11	Today / near future (2025)		1.5	2	2	2	1	2	1	-2
	2.12	Medium to long term (2030)		1.2	2	2	2	1	2	1	-1
	2.13	Long term (2040)		1.0	2	2	2	1	2	2	0
	2.14	Very long term (2050)		0.8	2	2	2	1	2	2	0
2.2		Financing opportunities and challenges		1.3	0.66	0.66	0.66	0.36	0.66	0.36	0.80
	2.21	Commercial financing (domestic and international)		1.5	1	1	1	0	1	0	1
	2.22	Preferential financing (IFI, DFI) possible		1.5	0	0	0	0	0	0	1
	2.23	Funding of GHG reduction technologies supported internationally		1.5	0	0	0	0	0	0	0
	2.24	Total CAPEX volume (e.g. finance/euqity/debt requ.)		0.8	1	1	1	1	1	1	0
	2.25	Cost-benefit relation: CO2 reduction cost efficiency		1.0	1	1	1	1	1	1	1
2.3		Frame / external conditions: location / infrastructure and size effects on specific economics		1.4	1.10	1.10	1.70	-0.70	0.80	0.50	0.90
	2.31	Site close to supply (of RE and other input) and demand for output		1.5	1	1	2	-2	0	0	2
	2.32	Infrastructure exists		1.5	1	1	2	-2	1	0	1
	2.33	Scaling up / down costs potential / restrictions		1.0	0	0	0	0	0	0	0
	2.34	Savings of national / international transport costs		1.5	1	1	1	1	1	1	0
	2.35	Is there a national / regional market / demand for the product incl. possibility to expand to other products / markets (div		1.0	1	1	1	1	1	1	0
3		Social	15%		0.2	0.2	0.2	0.2	0.2	0.2	-0.3
3.1		Socio-economic losses /benefits		1.2	0.38	0.38	0.38	0.38	0.38	0.38	0.08
	3.11	Enhanced/reduced vulnerability to climate change		0.8	0	0	0	0	0	0	0
	3.12	Enhanced/reduced vulnerability to job creation/income		1.5	1	1	1	1	1	1	1
	3.13	Other benefits / costs to community		1.2	0	0	0	0	0	0	-1
	3.14	Social issues, conflicts vs. supportive social structure in planning area		1.2	0	0	0	0	0	0	0

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+ 2 = ++ = very g ood

Categories		Candidate (site/use)	Weighting PESTEL force	Importance of assessment criteria (country view /objectives study)							
		Use			Manufact. - light ind. / commodities (methanol, for regional ind. consumers)	Manufact. - light ind. / commodities (methanol, for regional ind. consumers)	Manufact. - heavy ind. (steel)	Manufact. - heavy ind. (steel)	Manufact. - heavy ind. (steel)	Manufact. - heavy ind. (petroleum/refining , heavy chemistry)	Manufact. - heavy ind. (cement)
		Site			Western Kenya (CO2 bagasse)	Mombasa (CO2 bagasse)	Olkaria	Mombasa/Coast	Nairobi	Mombasa	Mombasa/Coast
		ID									
		Name			Western Kenya (CO2 bagasse) Manufact. - light ind. / commodities (methanol, for	Mombasa (CO2 bagasse) Manufact. - light ind. / commodities (methanol, for	Olkaria Manufact. - heavy ind. (steel)	Mombasa/Coast Manufact. - heavy ind. (steel)	Nairobi Manufact. - heavy ind. (steel)	Mombasa Manufact. - heavy ind. (petroleum/refinin g, heavy chemistry)	Mombasa/Coast Manufact. - heavy ind. (cement)
		Result			0.03	0.27	0.12	0.46	0.37	0.20	0.29
		Rank			42	29	39	16	22	34	26
		Gaps: Obstacles / Knock-out criteria			Some	Low	Some	Low	Low	Very High	Some
		count - 2 = -- = insufficient			2	1	2	1	1	7	2
		Enablers, niches, low hanging fruits			Low	Low	Some	High	High	Some	Low
1		Political	10%		0.8	0.8	1.8	1.8	1.8	1.8	1.0
1.1		Ensure security of supply / diversification		1.1	1.15	1.15	1.95	1.95	1.95	1.95	1.65
	1.11	Diversify country energy mix in general		1.0	1	1	2	2	2	2	2
	1.12	Provide additional reliability (back-up) to power system		1.0	0	0	1	1	1	1	1
	1.13	Provide additional reliability to overall supply (energy and other commodities)		1.2	1	1	2	2	2	2	1
	1.14	Reduce uncertainties and strengthen planning		1.2	2	2	2	2	2	2	2
1.2		Use of domestic resources		1.2	0.65	0.65	2.30	2.30	2.30	2.30	0.00
	1.21	Reduce dependencies which cannot be influenced		1.0	0	0	2	2	2	2	0
	1.22	Reduce impact of foreign exchange rate / currency / trade balance		1.3	1	1	2	2	2	2	0
1.3		Obligations international policy		1.2	0.60	0.60	1.00	1.00	1.00	1.20	1.20
	1.31	Contribution to NDC		1.5	1	1	1	1	1	1	2
	1.32	Reduction of GHG emissions (globally)		1.5	1	1	2	2	2	2	2
	1.33	Other environmental int. policies / obligations (e.g. harmful substances)		0.8	0	0	0	0	0	0	0
	1.34	Other international policies / obligations (trade,...)		1.0	0	0	-1	-1	-1	0	0
	1.35	RE additionality (additional RE capacity for green H2 production)		1.5	0	0	1	1	1	1	0
2		Economic	25%		-0.2	-0.1	0.6	0.7	0.9	-0.4	-0.1
2.1		Project economics (feasibility) in terms of competetive levelized costs (i.e. vs. alternatives, fossil fuel or electrification)		1.1	-1.05	-1.05	0.28	0.28	0.28	-1.60	-1.60
	2.11	Today / near future (2025)		1.5	-2	-2	-1	-1	-1	-2	-2
	2.12	Medium to long term (2030)		1.2	-1	-1	0	0	0	-2	-2
	2.13	Long term (2040)		1.0	0	0	1	1	1	-1	-1
	2.14	Very long term (2050)		0.8	0	0	2	2	2	0	0
2.2		Financing opportunities and challenges		1.3	0.50	0.80	0.84	0.84	0.84	-0.52	0.50
	2.21	Commercial financing (domestic and international)		1.5	0	1	1	1	1	-1	1
	2.22	Preferential financing (IFI, DFI) possible		1.5	1	1	0	0	0	-1	-1
	2.23	Funding of GHG reduction technologies supported internationally		1.5	0	0	1	1	1	0	1
	2.24	Total CAPEX volume (e.g. finance/euqity/debt requ.)		0.8	0	0	-1	-1	-1	-2	0
	2.25	Cost-benefit relation: CO2 reduction cost efficiency		1.0	1	1	2	2	2	2	1
2.3		Frame / external conditions: location / infrastructure and size effects on specific economics		1.4	0.00	0.00	0.80	1.10	1.70	0.90	0.80
	2.31	Site close to supply (of RE and other input) and demand for output		1.5	0	-1	1	1	2	1	1
	2.32	Infrastructure exists		1.5	0	1	0	1	2	1	1
	2.33	Scaling up / down costs potential / restrictions		1.0	0	0	-1	-1	-1	-1	0
	2.34	Savings of national / international transport costs		1.5	0	0	1	1	1	1	0
	2.35	Is there a national / regional market / demand for the product incl. possibility to expand to other products / markets (div		1.0	0	0	2	2	2	1	1
3		Social	15%		-0.3	-0.3	-0.15	0.00	0.00	-0.19	-0.38
3.1		Socio-economic losses /benefits		1.2	0.08	0.08	0.45	0.75	0.75	0.38	0.00
	3.11	Enhanced/reduced vulnerability to climate change		0.8	0	0	0	0	0	0	0
	3.12	Enhanced/reduced vulnerability to job creation/income		1.5	1	1	2	2	2	1	0
	3.13	Other benefits / costs to community		1.2	-1	-1	0	0	0	0	0
	3.14	Social issues, conflicts vs. supportive social structure in planning area		1.2	0	0	-1	0	0	0	0

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Categories			Weighting PESTEL force	Importance of assessment criteria (country view /objectives study)							
				Use	Manufact. - heavy ind. (cement)	Mining (on and off grid)	Mining (on and off grid)	Mining (on and off grid)	Electricity - peaking / storage / back-up	Electricity - peaking / storage / back-up	Electricity - peaking / storage / back-up
				Site	Nairobi	Western Kenya / Rift Valley	Lamu / LAPPSET	Mombasa/Coast	Olkaria	Nairobi	Mombasa
				ID							
				Name	Nairobi Manufact. - heavy ind. (cement)	Western Kenya / Rift Valley Mining (on and off grid)	Lamu / LAPPSET Mining (on and off grid)	Mombasa/Coast Mining (on and off grid)	Olkaria Electricity - peaking / storage / back-up	Nairobi Electricity - peaking / storage / back-up	Mombasa Electricity - peaking / storage / back-up
				Result	0.18	0.25	0.36	0.51	0.43	0.46	0.80
				Rank	36	32	23	10	18	15	4
				Gaps: Obstacles / Knock-out criteria	Some	Low	Low	Low	Some	Some	Low
				count - 2 = -- = insufficient	2	0	1	0	2	2	0
				Enablers, niches, low hanging fruits	Low	Low	Low	Low	Some	Some	Some
1		Political	10%		1.0	0.4	0.4	0.4	0.7	0.7	0.9
1.1		Ensure security of supply / diversification		1.1	1.65	0.00	0.00	0.00	1.60	1.60	1.60
	1.11	Diversify country energy mix in general		1.0	2	0	0	0	2	2	2
	1.12	Provide additional reliability (back-up) to power system		1.0	1	0	0	0	2	2	2
	1.13	Provide additional reliability to overall supply (energy and other commodities)		1.2	1	0	0	0	0	0	0
	1.14	Reduce uncertainties and strengthen planning		1.2	2	0	0	0	2	2	2
1.2		Use of domestic resources		1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1.21	Reduce dependencies which cannot be influenced		1.0	0	0	0	0	0	0	0
	1.22	Reduce impact of foreign exchange rate / currency / trade balance		1.3	0	0	0	0	0	0	0
1.3		Obligations international policy		1.2	1.20	1.20	1.20	1.20	0.60	0.60	1.20
	1.31	Contribution to NDC		1.5	2	1	1	1	0	0	1
	1.32	Reduction of GHG emissions (globally)		1.5	2	2	2	2	0	0	1
	1.33	Other environmental int. policies / obligations (e.g. harmful substances)		0.8	0	0	0	0	0	0	0
	1.34	Other international policies / obligations (trade,...)		1.0	0	0	0	0	0	0	0
	1.35	RE additionality (additional RE capacity for green H2 production)		1.5	0	1	1	1	2	2	2
2		Economic	25%		0.0	0.1	0.0	0.1	0.0	0.0	0.6
2.1		Project economics (feasibility) in terms of competetive levelized costs (i.e. vs. alternatives, fossil fuel or electrification)		1.1	-1.60	0.08	0.08	0.08	-1.60	-1.60	-0.48
	2.11	Today / near future (2025)		1.5	-2	-1	-1	-1	-2	-2	-1
	2.12	Medium to long term (2030)		1.2	-2	0	0	0	-2	-2	-1
	2.13	Long term (2040)		1.0	-1	1	1	1	-1	-1	0
	2.14	Very long term (2050)		0.8	0	1	1	1	0	0	1
2.2		Financing opportunities and challenges		1.3	0.50	0.20	0.20	0.20	0.72	0.72	0.92
	2.21	Commercial financing (domestic and international)		1.5	1	1	1	1	1	1	1
	2.22	Preferential financing (IFI, DFI) possible		1.5	-1	-1	-1	-1	1	1	1
	2.23	Funding of GHG reduction technologies supported internationally		1.5	1	0	0	0	0	0	0
	2.24	Total CAPEX volume (e.g. finance/euqity/debt requ.)		0.8	0	0	0	0	2	2	2
	2.25	Cost-benefit relation: CO2 reduction cost efficiency		1.0	1	1	1	1	-1	-1	0
2.3		Frame / external conditions: location / infrastructure and size effects on specific economics		1.4	1.10	0.00	-0.30	0.00	0.80	0.80	1.30
	2.31	Site close to supply (of RE and other input) and demand for output		1.5	2	0	-1	0	1	1	2
	2.32	Infrastructure exists		1.5	1	0	0	0	1	1	1
	2.33	Scaling up / down costs potential / restrictions		1.0	0	1	1	1	1	1	1
	2.34	Savings of national / international transport costs		1.5	0	0	0	0	0	0	0
	2.35	Is there a national / regional market / demand for the product incl. possibility to expand to other products / markets (div		1.0	1	-1	-1	-1	0	0	1
3		Social	15%		-0.38	0.0	0.0	0.0	0.0	0.0	0.0
3.1		Socio-economic losses /benefits		1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3.11	Enhanced/reduced vulnerability to climate change		0.8	0	0	0	0	0	0	0
	3.12	Enhanced/reduced vulnerability to job creation/income		1.5	0	0	0	0	0	0	0
	3.13	Other benefits / costs to community		1.2	0	0	0	0	0	0	0
	3.14	Social issues, conflicts vs. supportive social structure in planning area		1.2	0	0	0	0	0	0	0

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0 = o = satifactory (neutral)
+ 1 = + = good
+ 2 = ++ = very g ood

				Lake Turkana	Lamu / LAPPSET	7-Forks	Western Kenya	All Kenya	Nairobi	Mombasa
			Use	Electricity - peaking / storage / back-up	Electricity - peaking / storage / back-up	Electricity - peaking / storage / back-up	Electricity - peaking / storage / back-up	Electricity - Off-grid supply	Transport - H2 for railway, road transport, urban mobility (public transport)	Transport - H2 for railway, road transport, urban mobility (public transport)
			Site	Lake Turkana (wind)	Lamu / LAPPSET	7-Forks dam area / Thika with lower hydropower costs	Western Kenya (Kisumu/Eldoret)	All Kenya	Nairobi	Mombasa
			ID							
			Name	Lake Turkana (wind) Electricity - peaking / storage / back-up	Lamu / LAPPSET Electricity - peaking / storage / back-up	7-Forks dam area / Thika with lower hydropower costs Electricity - peaking / storage / back-up	Western Kenya (Kisumu/Eldoret) Electricity - peaking / storage / back-up	All Kenya Electricity - Off-grid supply	Nairobi Transport - H2 for railway, road transport, urban mobility (public transport)	Mombasa Transport - H2 for railway, road transport, urban mobility (public
			Result	0.26	0.20	0.47	0.32	0.76	-0.03	0.19
			Rank	30	33	13	25	5	43	35
Categories		**Weighting PESTEL force**	**Importance of assessment criteria** (country view /objectives study) / **Gaps: Obstacles / Knock-out criteria**	Some	Very High	Some	Some	Low	High	High
			count - 2 = -- = insufficient	3	7	2	2	0	5	5
			Enablers, niches, low hanging fruits	Some	Some	Some	Some	High	Some	Some
1	Political	10%		0.7	0.7	0.7	0.7	0.83	1.7	1.7
1.1	Ensure security of supply / diversification		1.1	1.35	1.35	1.60	1.60	0.80	1.95	1.95
1.11	Diversify country energy mix in general		1.0	2	2	2	2	2	2	2
1.12	Provide additional reliability (back-up) to power system		1.0	1	1	2	2	0	1	1
1.13	Provide additional reliability to overall supply (energy and other commodities)		1.2	0	0	0	0	0	2	2
1.14	Reduce uncertainties and strengthen planning		1.2	2	2	2	2	1	2	2
1.2	Use of domestic resources		1.2	0.00	0.00	0.00	0.00	0.50	1.80	1.80
1.21	Reduce dependencies which cannot be influenced		1.0	0	0	0	0	1	1	1
1.22	Reduce impact of foreign exchange rate / currency / trade balance		1.3	0	0	0	0	0	2	2
1.3	Obligations international policy		1.2	0.60	0.60	0.60	0.60	1.20	1.20	1.20
1.31	Contribution to NDC		1.5	0	0	0	0	1	2	2
1.32	Reduction of GHG emissions (globally)		1.5	0	0	0	0	1	2	2
1.33	Other environmental int. policies / obligations (e.g. harmful substances)		0.8	0	0	0	0	0	0	0
1.34	Other international policies / obligations (trade,...)		1.0	0	0	0	0	0	0	0
1.35	RE additionality (additional RE capacity for green H2 production)		1.5	2	2	2	2	2	0	0
2	Economic	25%		-0.4	-0.6	-0.2	0.0	1.32	0.2	0.2
2.1	Project economics (feasibility) in terms of competetive levelized costs (i.e. vs. alternatives, fossil fuel or electrification)		1.1	-1.85	-2.05	-1.60	-1.60	1.20	0.08	0.08
2.11	Today / near future (2025)		1.5	-2	-2	-2	-2	0	-1	-1
2.12	Medium to long term (2030)		1.2	-2	-2	-2	-2	1	0	0
2.13	Long term (2040)		1.0	-2	-2	-1	-1	2	1	1
2.14	Very long term (2050)		0.8	0	-1	0	0	2	1	1
2.2	Financing opportunities and challenges		1.3	0.72	0.92	0.72	0.72	1.06	0.24	0.24
2.21	Commercial financing (domestic and international)		1.5	1	1	1	1	-1	-1	-1
2.22	Preferential financing (IFI, DFI) possible		1.5	1	1	1	1	2	1	1
2.23	Funding of GHG reduction technologies supported internationally		1.5	0	0	0	0	2	2	2
2.24	Total CAPEX volume (e.g. finance/euqity/debt requ.)		0.8	2	2	2	2	1	-1	-1
2.25	Cost-benefit relation: CO2 reduction cost efficiency		1.0	-1	0	-1	-1	0	-1	-1
2.3	Frame / external conditions: location / infrastructure and size effects on specific economics		1.4	-0.10	-0.70	0.20	0.80	1.70	0.20	0.20
2.31	Site close to supply (of RE and other input) and demand for output		1.5	-1	-2	0	1	2	2	2
2.32	Infrastructure exists		1.5	0	-1	0	1	0	-2	-2
2.33	Scaling up / down costs potential / restrictions		1.0	1	1	1	1	2	-1	-1
2.34	Savings of national / international transport costs		1.5	0	0	0	0	1	0	0
2.35	Is there a national / regional market / demand for the product incl. possibility to expand to other products / markets (div		1.0	0	0	0	0	2	2	2
3	Social	15%		0.0	0.0	0.0	0.0	0.21	-0.2	-0.2
3.1	Socio-economic losses /benefits		1.2	0.00	0.00	0.00	0.00	1.18	0.30	0.30
3.11	Enhanced/reduced vulnerability to climate change		0.8	0	0	0	0	1	0	0
3.12	Enhanced/reduced vulnerability to job creation/income		1.5	0	0	0	0	1	0	0
3.13	Other benefits / costs to community		1.2	0	0	0	0	1	1	1
3.14	Social issues, conflicts vs. supportive social structure in planning area		1.2	0	0	0	0	1	0	0

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Candidate (site/use)

- 2 = -- = insufficient
- 1 = - = sufficient (but rather negative)
0 = o = satifactory (neutral)
+ 1 = + = good
+ 2 = ++ = very g ood

			Use	**Transport** - H2 for railway, road transport, urban mobility (public transport)	**Transport** - H2 for port logistics etc.	**Transport** - H2 for railway	**Transport** - H2 for public transport, local utility	**Transport** - ammonia for ships, export	**Transport** - ammonia for ships, export	**Transport** - ammonia for ships, export
			Site	Olkaria	Mombasa	Mombasa	Nairobi	Nairobi	Mombasa	Olkaria
			ID							
			Name	Olkaria Transport - H2 for railway, road transport, urban mobility (public transport)	Mombasa Transport - H2 for port logistics etc.	Mombasa Transport - H2 for railway	Nairobi Transport - H2 for public transport, local utility	Nairobi Transport - ammonia for ships, export	Mombasa Transport - ammonia for ships, export	Olkaria Transport - ammonia for ships, export
			Result	-0.23	0.99	0.47	0.58	-0.21	0.25	-0.25
			Rank	45	2	12	9	44	31	46
Categories		**Weighting PESTEL force**	**Importance of assessment criteria** (country view /objectives study) **Gaps: Obstacles / Knock-out criteria**	Very High	Low	Some	Low	Some	Some	High
			count - 2 = -- = insufficient	8	0	2	1	3	2	4
			Enablers, niches, low hanging fruits	Some	Very High	High	High	Low	Low	Low
1	Political	10%		1.7	1.7	1.7	1.7	0.9	1.0	0.9
1.1	Ensure security of supply / diversification		1.1	1.95	1.95	1.95	1.95	1.10	1.10	1.10
1.11	Diversify country energy mix in general		1.0	2	2	2	2	1	1	1
1.12	Provide additional reliability (back-up) to power system		1.0	1	1	1	1	1	1	1
1.13	Provide additional reliability to overall supply (energy and other commodities)		1.2	2	2	2	2	1	1	1
1.14	Reduce uncertainties and strengthen planning		1.2	2	2	2	2	1	1	1
1.2	Use of domestic resources		1.2	1.80	1.80	1.80	1.80	1.30	1.30	1.30
1.21	Reduce dependencies which cannot be influenced		1.0	1	1	1	1	0	0	0
1.22	Reduce impact of foreign exchange rate / currency / trade balance		1.3	2	2	2	2	2	2	2
1.3	Obligations international policy		1.2	1.20	1.20	1.20	1.20	0.44	0.74	0.44
1.31	Contribution to NDC		1.5	2	2	2	2	0	1	0
1.32	Reduction of GHG emissions (globally)		1.5	2	2	2	2	2	2	2
1.33	Other environmental int. policies / obligations (e.g. harmful substances)		0.8	0	0	0	0	-1	-1	-1
1.34	Other international policies / obligations (trade,...)		1.0	0	0	0	0	0	0	0
1.35	RE additionality (additional RE capacity for green H2 production)		1.5	0	0	0	0	0	0	0
2	Economic	25%		-0.3	0.9	0.5	0.7	-0.4	-0.1	-0.3
2.1	Project economics (feasibility) in terms of competetive levelized costs (i.e. vs. alternatives, fossil fuel or electrification)		1.1	-0.85	0.08	0.08	0.08	-1.05	-0.68	-1.05
2.11	Today / near future (2025)		1.5	-2	-1	-1	-1	-2	-1	-2
2.12	Medium to long term (2030)		1.2	-1	0	0	0	-1	-1	-1
2.13	Long term (2040)		1.0	0	1	1	1	0	0	0
2.14	Very long term (2050)		0.8	1	1	1	1	0	0	0
2.2	Financing opportunities and challenges		1.3	0.08	1.16	0.40	0.86	0.40	0.60	0.40
2.21	Commercial financing (domestic and international)		1.5	-1	0	-1	-1	0	0	0
2.22	Preferential financing (IFI, DFI) possible		1.5	1	2	1	2	1	1	1
2.23	Funding of GHG reduction technologies supported internationally		1.5	2	2	2	2	1	1	1
2.24	Total CAPEX volume (e.g. finance/euqity/debt requ.)		0.8	-2	1	0	1	0	0	0
2.25	Cost-benefit relation: CO2 reduction cost efficiency		1.0	-1	-1	-1	-1	-1	0	-1
2.3	Frame / external conditions: location / infrastructure and size effects on specific economics		1.4	-0.10	1.50	1.10	1.30	-0.50	-0.20	-0.20
2.31	Site close to supply (of RE and other input) and demand for output		1.5	1	2	2	2	0	1	1
2.32	Infrastructure exists		1.5	-2	1	1	1	-1	-1	-1
2.33	Scaling up / down costs potential / restrictions		1.0	-1	1	-1	0	-1	-1	-1
2.34	Savings of national / international transport costs		1.5	0	0	0	0	0	0	0
2.35	Is there a national / regional market / demand for the product incl. possibility to expand to other products / markets (div		1.0	2	2	2	2	0	0	0
3	Social	15%		-0.2	0.5	-0.2	0.3	-0.2	0.2	-0.2
3.1	Socio-economic losses /benefits		1.2	0.30	0.30	0.30	0.50	0.38	0.38	0.38
3.11	Enhanced/reduced vulnerability to climate change		0.8	0	0	0	1	0	0	0
3.12	Enhanced/reduced vulnerability to job creation/income		1.5	0	0	0	0	1	1	1
3.13	Other benefits / costs to community		1.2	1	1	1	1	0	0	0
3.14	Social issues, conflicts vs. supportive social structure in planning area		1.2	0	0	0	0	0	0	0

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Candidate (site/use)

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0 = o = satifactory (neutral)
+ 1 = + = good
+ 2 = ++ = very g ood

Categories	Criterion	Weighting PESTEL force	Importance of assessment criteria (country view /objectives study)							
				Use	Transport - e-fuels (H2 for regional only) for aviation		Transport - e-fuels (H2 for regional only) for aviation		Transport - e-fuels (H2 for regional only) for aviation	
				Site	Nairobi		Olkaria		Mombasa	
				ID						
				Name	Nairobi Transport - e-fuels (H2 for regional only) for aviation		Olkaria Transport - e-fuels (H2 for regional only) for aviation		Mombasa Transport - e-fuels (H2 for regional only) for aviation	
				Result	0.29		0.11		0.40	
				Rank	27		40		19	
				Gaps: Obstacles / Knock-out criteria	Some		Some		High	
				count - 2 = -- = insufficient	2		3		4	
				Enablers, niches, low hanging fruits	Some		Some		Some	
1	Political	10%			1.1		1.1		1.1	
1.1	Ensure security of supply / diversification		1.1		0.75		0.75		0.75	
1.11	Diversify country energy mix in general		1.0			2		2		2
1.12	Provide additional reliability (back-up) to power system		1.0			1		1		1
1.13	Provide additional reliability to overall supply (energy and other commodities)		1.2			0		0		0
1.14	Reduce uncertainties and strengthen planning		1.2			0		0		0
1.2	Use of domestic resources		1.2		0.65		0.65		0.65	
1.21	Reduce dependencies which cannot be influenced		1.0			0		0		0
1.22	Reduce impact of foreign exchange rate / currency / trade balance		1.3			1		1		1
1.3	Obligations international policy		1.2		2.00		2.00		2.00	
1.31	Contribution to NDC		1.5			2		2		2
1.32	Reduction of GHG emissions (globally)		1.5			2		2		2
1.33	Other environmental int. policies / obligations (e.g. harmful substances)		0.8			0		0		0
1.34	Other international policies / obligations (trade,...)		1.0			1		1		1
1.35	RE additionality (additional RE capacity for green H2 production)		1.5			2		2		2
2	Economic	25%			0.1		-0.2		-0.5	
2.1	Project economics (feasibility) in terms of competetive levelized costs (i.e. vs. alternatives, fossil fuel or electrification)		1.1		-1.30		-1.30		-2.05	
2.11	Today / near future (2025)		1.5			-2		-2		-2
2.12	Medium to long term (2030)		1.2			-1		-1		-2
2.13	Long term (2040)		1.0			-1		-1		-2
2.14	Very long term (2050)		0.8			0		0		-1
2.2	Financing opportunities and challenges		1.3		0.80		0.80		0.80	
2.21	Commercial financing (domestic and international)		1.5			0		0		0
2.22	Preferential financing (IFI, DFI) possible		1.5			2		2		2
2.23	Funding of GHG reduction technologies supported internationally		1.5			2		2		2
2.24	Total CAPEX volume (e.g. finance/euqity/debt requ.)		0.8			0		0		0
2.25	Cost-benefit relation: CO2 reduction cost efficiency		1.0			-2		-2		-2
2.3	Frame / external conditions: location / infrastructure and size effects on specific economics		1.4		0.90		0.00		-0.30	
2.31	Site close to supply (of RE and other input) and demand for output		1.5			2		1		-1
2.32	Infrastructure exists		1.5			1		-1		0
2.33	Scaling up / down costs potential / restrictions		1.0			-1		-1		-1
2.34	Savings of national / international transport costs		1.5			0		0		0
2.35	Is there a national / regional market / demand for the product incl. possibility to expand to other products / markets (di		1.0			1		1		1
3	Social	15%			-0.3		-0.3		-0.3	
3.1	Socio-economic losses /benefits		1.2		0.00		0.00		0.00	
3.11	Enhanced/reduced vulnerability to climate change		0.8			0		0		0
3.12	Enhanced/reduced vulnerability to job creation/income		1.5			0		0		0
3.13	Other benefits / costs to community		1.2			0		0		0
3.14	Social issues, conflicts vs. supportive social structure in planning area		1.2			0		0		0

- 2 = -- = insufficient
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0 = o = satifactory (neutral)
+ 1 = + = good
+ 2 = ++ = very g ood

Categories		Candidate (site/use)	Weighting PESTEL force	Importance of assessment criteria (country view /objectives study)								
		Use			Agriculture / fertilizer only	Agriculture / fertilizer+ (H2/ammonia and other derivatives to industry)	Agriculture / fertilizer+; additional benefits (H2/ammonia and other derivatives to industry)	Agriculture / fertilizer+ (H2/ammonia and other derivatives to industry)	Agriculture / fertilizer+ (H2/ammonia and other derivatives to industry)	Agriculture / fertilizer+ (H2/ammonia and other derivatives to industry)	Agriculture / fertilizer+ (H2/ammonia and other derivatives to industry)	Agriculture / fertilizer+ (H2/ammonia and other derivatives to industry)
		Site			Olkaria	Olkaria	Olkaria	Mombasa	Lamu / LAPPSET	7-Forks dam area / Thika with lower hydropower costs	Nairobi	Western Kenya (Kisumu/Eldoret)
		ID										
		Name			Olkaria fertilizer only	Olkaria fertilizer+	Olkaria fertilizer+ "add benefits"	Mombasa fertilizer+	Lamu fertilizer+	7-Forks fertilizer+	Nairobi fertilizer+	Western Kenya fertilizer+
		Result			0.46	0.43	0.49	0.74	0.14	0.40	0.37	0.10
		Rank			14	17	11	6	38	20	21	41
		Gaps: Obstacles / Knock-out criteria			High	High	Very High	Some	Very High	High	Some	High
		count - 2 = -- = insufficient			4	4	8	2	9	4	3	5
		Enablers, niches, low hanging fruits			Some	Very High	Very High	Very High	High	Very High	Very High	High
3.2		Workers / population safety		1.3	-1.25	-1.25	0.50	-1.25	-1.25	-1.25	-1.25	-1.25
	3.21	Harmful substances		1.5	-1	-1	2	-1	-1	-1	-1	-1
	3.22	Technical Standards / regulation exists / enforced		1.0	-1	-1	-2	-1	-1	-1	-1	-1
	0.01											
	0.02											
	0.03											
	0.04											
	0.05											
4		Technical	25%		0.9	0.5	-0.4	0.5	-0.2	0.5	0.5	0.2
4.1		Technology readiness		1.2	2.07	1.67	1.17	1.67	1.67	1.67	1.67	1.67
	4.11	Global level: proven and available (off the shelf) vs. pilot or research		1.5	2	2	1	2	2	2	2	2
	4.12	Regional/national level: as above, in country, region		1.2	1	0	0	0	0	0	0	0
	4.13	Innovation potential / learning curve		1.0	2	2	2	2	2	2	2	2
4.2		Project design		1.0	0.00	-0.20	-0.80	-0.20	-0.20	-0.20	-0.20	-0.20
	4.21	Suitable project / unit size		1.0	0	-1	-1	-1	-1	-1	-1	-1
	4.22	Flexibility of technology (in terms of operation, adaption to supply/demand)		1.0	-1	1	1	1	1	1	1	1
	4.23	Construction/implementation schedule (short/long, easy/complicated)		1.0	1	0	-1	0	0	0	0	0
	4.24	Safety standards easy to fulfil		1.0	-1	-1	-2	-1	-1	-1	-1	-1
	4.25	Project already pre-developed (in Kenya) / documents, prel. design etc. (in part) available		1.0	1	0	-1	0	0	0	0	0
4.3		Frame / external conditions: location / infrastructure		1.0	0.50	0.00	-1.50	0.00	-2.00	0.00	0.00	-1.00
	4.31	Supply / evacuation of input/output (e.g. infrastructure exists, easy to be build)		1.0	1	1	-1	1	-2	1	1	0
	4.32	Knowhow (O&M, R&D) available (research organisations, service companies, experts)		1.0	0	-1	-2	-1	-2	-1	-1	-2
5		Environmental	15%		-1.2	-1.2	-0.2	0.8	0.0	-0.5	-1.2	-1.5
5.1		Local environmental impact (immission few km) to wider environmental impact / national		1.3	-1.17	-1.17	-0.17	0.83	0.00	-0.50	-1.17	-1.50
	5.11	Environmental impact: soil, air, water		1.5	-1	-1	1	-1	-2	-2	-2	-2
	5.12	Mitigation measures available / possible (at certain costs/regulatory requirements)		1.0	1	1	1	1	0	0	1	0
	5.13	Water availability and needs		1.5	-2	-2	-2	2	2	1	-1	-1
6		Legal	10%		0.5	0.3	0.0	0.7	0.7	-0.3	-0.3	-0.3
6.1		Land use		1.5	1.50	1.50	1.50	3.00	3.00	0.00	0.00	0.00
	6.11	Land availability (also for international investors)		1.5	1	1	1	2	2	0	0	0
6.2		Legal / regulatory processes		1.2	-0.08	-0.50	-1.48	-0.88	-0.88	-0.88	-0.88	-0.88
	6.21	Legal / regulatory frame exists (incl. safety standards etc.)		1.0	-1	-1	-1	-1	-1	-1	-1	-1
	6.22	Similar processes / projects in the past / present		1.2	1	0	-2	0	0	0	0	0
	6.23	Doing business / bureaucracy / corruption		1.0	-2	-1	-1	-1	-1	-1	-1	-1
	6.24	Project already pre-developed (in Kenya) / documents etc. (in part) available		1.5	1	0	-1	-1	-1	-1	-2	-2

		Candidate (site/use)									
				Use	Manufact. - light ind. / commodities (for regional ind. consumers)	Manufact. - light ind. / commodities (for regional ind. consumers)	Manufact. - light ind. / commodities (for regional ind. consumers)	Manufact. - light ind. / commodities (for regional ind. consumers)	Manufact. - light ind. / commodities (for regional ind. consumers)	Manufact. - light ind. / commodities (for regional ind. consumers)	Manufact. - light ind. / commodities (methanol, for regional ind. consumers)
		- 2 = -- = insufficient - 1 = - = sufficient (but rather negative) 0 = o = satifactory (neutral) + 1 = + = good + 2 = ++ = very g ood		Site	Olkaria	Mombasa	Nairobi	Lamu / LAPPSET	7-Forks dam area / Thika with lower hydropower costs	Western Kenya (Kisumu/Eldoret)	Olkaria / Rift V. (CO2 geothermal or CO2 wells)
				ID							
				Name	Olkaria Manufact. - light ind. / commodities (for regional ind. consumers)	Mombasa Manufact. - light ind. / commodities (for regional ind. consumers)	Nairobi Manufact. - light ind. / commodities (for regional ind. consumers)	Lamu / LAPPSET Manufact. - light ind. / commodities (for regional ind. consumers)	7-Forks fertilizer+ (regional industry)	Western Kenya fertilizer+ (regional industry, export)	Olkaria / Rift V. (CO2 geothermal or CO2 wells) Manufact. - light ind. / commodities
				Result	0.63	1.01	0.83	0.34	0.67	0.29	0.17
				Rank	8	1	3	24	7	28	37
Categ ories			Weighting PESTEL force	Importance of assessment criteria (country view /objectives study) / Gaps: Obstacles / Knock-out criteria	Low	Low	Low	High	Low	Low	Some
				count - 2 = -- = insufficient	1	0	0	5	0	1	2
				Enablers, niches, low hanging fruits	Some	High	High	Some	Some	Some	Low
3.2		Workers / population safety		1.3	0.9	0.9	0.9	0.7	0.7	0.7	0.8
	3.21	Harmful substances		1.5	1.20	1.20	1.20	1.20	1.20	1.20	1.15
	3.22	Technical Standards / regulation exists / enforced		1.0	0	0	0	0	0	0	1
	0.01										
	0.02										
	0.03										
	0.04										
	0.05										
4		Technical	25%		0.8	1.2	1.2	0.2	1.0	0.5	0.3
4.1		Technology readiness		1.2	1.67	1.67	1.67	1.67	1.67	1.67	0.77
	4.11	Global level: proven and available (off the shelf) vs. pilot or research		1.5	2	2	2	2	2	2	1
	4.12	Regional/national level: as above, in country, region		1.2	0	0	0	0	0	0	-1
	4.13	Innovation potential / learning curve		1.0	2	2	2	2	2	2	2
4.2		Project design		1.0	0.80	0.80	0.80	0.80	0.80	0.80	0.20
	4.21	Suitable project / unit size		1.0	2	2	2	2	2	2	0
	4.22	Flexibility of technology (in terms of operation, adaption to supply/demand)		1.0	2	2	2	2	2	2	1
	4.23	Construction/implementation schedule (short/long, easy/complicated)		1.0	1	1	1	1	1	1	-1
	4.24	Safety standards easy to fulfil		1.0	0	0	0	0	0	0	0
	4.25	Project already pre-developed (in Kenya) / documents, prel. design etc. (in part) available		1.0	-1	-1	-1	-1	-1	-1	1
4.3		Frame / external conditions: location / infrastructure		1.0	0.00	1.00	1.00	-2.00	0.50	-1.00	0.00
	4.31	Supply / evacuation of input/output (e.g. infrastructure exists, easy to be build)		1.0	0	1	1	-2	0	0	1
	4.32	Knowhow (O&M, R&D) available (research organisations, service companies, experts)		1.0	0	1	1	-2	1	-2	-1
5		Environmental	15%		-0.7	1.3	-0.2	0.5	0.0	-1.0	-0.2
5.1		Local environmental impact (immission few km) to wider environmental impact / national		1.3	-0.67	1.33	-0.17	0.50	0.00	-1.00	-0.17
	5.11	Environmental impact: soil, air, water		1.5	0	0	0	-1	-1	-1	1
	5.12	Mitigation measures available / possible (at certain costs/regulatory requirements)		1.0	1	1	1	0	0	0	1
	5.13	Water availability and needs		1.5	-2	2	-1	2	1	-1	-2
6		Legal	10%		0.7	0.7	0.7	0.7	0.2	0.2	0.3
6.1		Land use		1.5	3.00	3.00	3.00	3.00	1.50	1.50	1.50
	6.11	Land availability (also for international investors)		1.5	2	2	2	2	1	1	1
6.2		Legal / regulatory processes		1.2	-0.93	-0.93	-0.93	-0.93	-0.93	-0.93	-0.55
	6.21	Legal / regulatory frame exists (incl. safety standards etc.)		1.0	-1	-1	-1	-1	-1	-1	-1
	6.22	Similar processes / projects in the past / present		1.2	-1	-1	-1	-1	-1	-1	-1
	6.23	Doing business / bureaucracy / corruption		1.0	0	0	0	0	0	0	0
	6.24	Project already pre-developed (in Kenya) / documents etc. (in part) available		1.5	-1	-1	-1	-1	-1	-1	0

Candidate (site/use)

- 2 = -- = insufficient
- 1 = - = sufficient (but rather negative)
0 = o = satifactory (neutral)
+ 1 = + = good
+ 2 = ++ = very g ood

Categories		Criterion	Weighting PESTEL force	Importance of assessment criteria (country view /objectives study)	Western Kenya (CO_2 bagasse)	Mombasa (CO_2 bagasse)	Olkaria	Mombasa/Coast	Nairobi	Mombasa	Mombasa/Coast
		Use			Manufact. - light ind. / commodities (methanol, for regional ind. consumers)	Manufact. - light ind. / commodities (methanol, for regional ind. consumers)	Manufact. - heavy ind. (steel)	Manufact. - heavy ind. (steel)	Manufact. - heavy ind. (steel)	Manufact. - heavy ind. (petroleum/refining, heavy chemistry)	Manufact. - heavy ind. (cement)
		Site			Western Kenya (CO_2 bagasse)	Mombasa (CO_2 bagasse)	Olkaria	Mombasa/Coast	Nairobi	Mombasa	Mombasa/Coast
		ID									
		Name			Western Kenya (CO_2 bagasse) Manufact. - light ind. / commodities (methanol, for	Mombasa (CO_2 bagasse) Manufact. - light ind. / commodities (methanol, for	Olkaria Manufact. - heavy ind. (steel)	Mombasa/Coast Manufact. - heavy ind. (steel)	Nairobi Manufact. - heavy ind. (steel)	Mombasa Manufact. - heavy ind. (petroleum/refinin g, heavy chemistry)	Mombasa/Coast Manufact. - heavy ind. (cement)
		Result			0.03	0.27	0.12	0.46	0.37	0.20	0.29
		Rank			42	29	39	16	22	34	26
		Gaps: Obstacles / Knock-out criteria			Some	Low	Some	Low	Low	Very High	Some
		count - 2 = -- = insufficient			2	1	2	1	1	7	2
		Enablers, niches, low hanging fruits			Low	Low	Some	High	High	Some	Low
3.2		Workers / population safety		1.3	0.8	0.8	1.8	1.8	1.8	1.8	1.0
	3.21	Harmful substances		1.5	1.15	1.15	1.95	1.95	1.95	1.95	1.65
	3.22	Technical Standards / regulation exists / enforced		1.0	1	1	2	2	2	2	2
	0.01										
	0.02										
	0.03										
	0.04										
	0.05										
4		Technical	25%		-0.1	0.1	-0.31	-0.14	0.19	-0.28	-0.30
4.1		Technology readiness		1.2	0.77	0.77	-0.23	-0.23	-0.23	-0.13	-0.90
	4.11	Global level: proven and available (off the shelf) vs. pilot or research		1.5	1	1	-1	-1	-1	0	-1
	4.12	Regional/national level: as above, in country, region		1.2	-1	-1	-1	-1	-1	-2	-1
	4.13	Innovation potential / learning curve		1.0	2	2	2	2	2	2	0
4.2		Project design		1.0	0.00	0.00	-0.20	-0.20	-0.20	-1.20	0.00
	4.21	Suitable project / unit size		1.0	0	0	-1	-1	-1	-2	0
	4.22	Flexibility of technology (in terms of operation, adaption to supply/demand)		1.0	0	0	1	1	1	0	0
	4.23	Construction/implementation schedule (short/long, easy/complicated)		1.0	-1	-1	-2	-2	-2	-2	0
	4.24	Safety standards easy to fulfil		1.0	0	0	0	0	0	0	0
	4.25	Project already pre-developed (in Kenya) / documents, prel. design etc. (in part) available		1.0	1	1	1	1	1	-2	0
4.3		Frame / external conditions: location / infrastructure		1.0	-1.00	-0.50	-0.50	0.00	1.00	0.50	0.00
	4.31	Supply / evacuation of input/output (e.g. infrastructure exists, easy to be build)		1.0	0	0	-1	0	1	0	0
	4.32	Knowhow (O&M, R&D) available (research organisations, service companies, experts)		1.0	-2	-1	0	0	1	1	0
5		Environmental	15%		0.3	1.8	-1.17	0.83	-0.67	0.83	1.83
5.1		Local environmental impact (immission few km) to wider environmental impact / national		1.3	0.33	1.83	-1.17	0.83	-0.67	0.83	1.83
	5.11	Environmental impact: soil, air, water		1.5	1	1	-1	-1	-1	-1	1
	5.12	Mitigation measures available / possible (at certain costs/regulatory requirements)		1.0	1	1	1	1	1	1	1
	5.13	Water availability and needs		1.5	-1	2	-2	2	-1	2	2
6		Legal	10%		0.2	-0.3	0.60	0.10	0.10	0.89	0.79
6.1		Land use		1.5	1.50	0.00	1.50	0.00	0.00	3.00	3.00
	6.11	Land availability (also for international investors)		1.5	1	0	1	0	0	2	2
6.2		Legal / regulatory processes		1.2	-0.93	-0.93	0.30	0.30	0.30	-0.33	-0.63
	6.21	Legal / regulatory frame exists (incl. safety standards etc.)		1.0	-1	-1	0	0	0	0	0
	6.22	Similar processes / projects in the past / present		1.2	-1	-1	1	1	1	1	0
	6.23	Doing business / bureaucracy / corruption		1.0	0	0	0	0	0	-1	-1
	6.24	Project already pre-developed (in Kenya) / documents etc. (in part) available		1.5	-1	-1	0	0	0	-1	-1

Candidate (site/use)

- 2 = -- = insufficient
- 1 = - = sufficient (but rather negative)
0 = o = satifactory (neutral)
+ 1 = + = good
+ 2 = ++ = very g ood

Categ ories		Criterion	Weighting PESTEL force	Importance of assessment criteria (country view /objectives study)	Nairobi Manufact. - heavy ind. (cement)	Western Kenya / Rift Valley Mining (on and off grid)	Lamu / LAPPSET Mining (on and off grid)	Mombasa/Coast Mining (on and off grid)	Olkaria Electricity - peaking / storage / back-up	Nairobi Electricity - peaking / storage / back-up	Mombasa Electricity - peaking / storage / back-up
		Use			Manufact. - heavy ind. (cement)	Mining (on and off grid)	Mining (on and off grid)	Mining (on and off grid)	Electricity - peaking / storage / back-up	Electricity - peaking / storage / back-up	Electricity - peaking / storage / back-up
		Site			Nairobi	Western Kenya / Rift Valley	Lamu / LAPPSET	Mombasa/Coast	Olkaria	Nairobi	Mombasa
		ID									
		Result			0.18	0.25	0.36	0.51	0.43	0.46	0.80
		Rank			36	32	23	10	18	15	4
		Gaps: Obstacles / Knock-out criteria			Some	Low	Low	Low	Some	Some	Low
		count - 2 = -- = insufficient			2	0	1	0	2	2	0
		Enablers, niches, low hanging fruits			Low	Low	Low	Low	Some	Some	Some
3.2		Workers / population safety		1.3	-0.75	0.00	0.00	0.00	0.00	0.00	0.00
	3.21	Harmful substances		1.5	-1	0	0	0	0	0	0
	3.22	Technical Standards / regulation exists / enforced		1.0	0	0	0	0	0	0	0
	0.01										
	0.02										
	0.03										
	0.04										
	0.05										
4		Technical	25%		0.03	0.1	-0.2	0.3	0.8	0.6	0.6
4.1		Technology readiness		1.2	-0.90	0.33	0.33	0.33	-0.07	-0.07	-0.07
	4.11	Global level: proven and available (off the shelf) vs. pilot or research		1.5	-1	0	0	0	0	0	0
	4.12	Regional/national level: as above, in country, region		1.2	-1	0	0	0	-1	-1	-1
	4.13	Innovation potential / learning curve		1.0	0	1	1	1	1	1	1
4.2		Project design		1.0	0.00	0.60	0.60	0.60	1.00	1.00	1.00
	4.21	Suitable project / unit size		1.0	0	2	2	2	2	2	2
	4.22	Flexibility of technology (in terms of operation, adaption to supply/demand)		1.0	0	0	0	0	2	2	2
	4.23	Construction/implementation schedule (short/long, easy/complicated)		1.0	0	1	1	1	1	1	1
	4.24	Safety standards easy to fulfil		1.0	0	0	0	0	0	0	0
	4.25	Project already pre-developed (in Kenya) / documents, prel. design etc. (in part) available		1.0	0	0	0	0	0	0	0
4.3		Frame / external conditions: location / infrastructure		1.0	1.00	-0.50	-1.50	0.00	1.50	1.00	1.00
	4.31	Supply / evacuation of input/output (e.g. infrastructure exists, easy to be build)		1.0	1	0	-1	0	2	1	1
	4.32	Knowhow (O&M, R&D) available (research organisations, service companies, experts)		1.0	1	-1	-2	0	1	1	1
5		Environmental	15%		0.33	0.3	1.8	1.8	0.3	0.8	1.8
5.1		Local environmental impact (immission few km) to wider environmental impact / national		1.3	0.33	0.33	1.83	1.83	0.33	0.83	1.83
	5.11	Environmental impact: soil, air, water		1.5	1	1	1	1	1	1	1
	5.12	Mitigation measures available / possible (at certain costs/regulatory requirements)		1.0	1	1	1	1	1	1	1
	5.13	Water availability and needs		1.5	-1	-1	2	2	-1	0	2
6		Legal	10%		0.79	1.0	1.0	1.0	1.1	1.1	1.3
6.1		Land use		1.5	3.00	3.00	3.00	3.00	3.00	3.00	3.00
	6.11	Land availability (also for international investors)		1.5	2	2	2	2	2	2	2
6.2		Legal / regulatory processes		1.2	-0.63	-0.08	-0.08	-0.08	0.18	0.18	0.85
	6.21	Legal / regulatory frame exists (incl. safety standards etc.)		1.0	0	0	0	0	0	0	0
	6.22	Similar processes / projects in the past / present		1.2	0	1	1	1	1	1	2
	6.23	Doing business / bureaucracy / corruption		1.0	-1	0	0	0	1	1	1
	6.24	Project already pre-developed (in Kenya) / documents etc. (in part) available		1.5	-1	-1	-1	-2	-1	-1	0

Candidate (site/use)

- 2 = -- = insufficient
- 1 = - = sufficient (but rather negative)
0 = o = satisfactory (neutral)
+ 1 = + = good
+ 2 = ++ = very g ood

Categ ories		Weighting PESTEL force	Importance of assessment criteria (country view /objectives study)								
				Use	Electricity - peaking / storage / back-up	Electricity - peaking / storage / back-up	Electricity - peaking / storage / back-up	Electricity - peaking / storage / back-up	Electricity - Off-grid supply	Transport - H2 for railway, road transport, urban mobility (public transport)	Transport - H2 for railway, road transport, urban mobility (public transport)
				Site	Lake Turkana (wind)	Lamu / LAPPSET	7-Forks dam area / Thika with lower hydropower costs	Western Kenya (Kisumu/Eldoret)	All Kenya	Nairobi	Mombasa
				ID							
				Name	Lake Turkana (wind) Electricity - peaking / storage / back-up	Lamu / LAPPSET Electricity - peaking / storage / back-up	7-Forks dam area / Thika with lower hydropower costs Electricity - peaking / storage / back-up	Western Kenya (Kisumu/Eldoret) Electricity - peaking / storage / back-up	All Kenya Electricity - Off-grid supply	Nairobi Transport - H2 for railway, road transport, urban mobility (public transport)	Mombasa Transport - H2 for railway, road transport, urban mobility (public transport)
				Result	0.26	0.20	0.47	0.32	0.76	-0.03	0.19
				Rank	30	33	13	25	5	43	35
				Gaps: Obstacles / Knock-out criteria	Some	Very High	Some	Some	Low	High	High
				count - 2 = -- = insufficient	3	7	2	2	0	5	5
				Enablers, niches, low hanging fruits	Some	Some	Some	Some	High	Some	Some
3.2	Workers / population safety		1.3		0.7	0.7	0.7	0.7	0.83	1.7	1.7
3.21	Harmful substances		1.5		1.35	1.35	1.60	1.60	0.80	1.95	1.95
3.22	Technical Standards / regulation exists / enforced		1.0		0	0	0	0	0	0	0
0.01											
0.02											
0.03											
0.04											
0.05											
4	Technical	25%			0.3	-0.4	0.5	0.3	0.59	-0.8	-0.8
4.1	Technology readiness		1.2		-0.07	-0.07	-0.07	-0.07	1.17	-0.63	-0.63
4.11	Global level: proven and available (off the shelf) vs. pilot or research		1.5		0	0	0	0	1	-1	-1
4.12	Regional/national level: as above, in country, region		1.2		-1	-1	-1	-1	0	-2	-2
4.13	Innovation potential / learning curve		1.0		1	1	1	1	2	2	2
4.2	Project design		1.0		1.00	1.00	1.00	1.00	0.60	-0.40	-0.40
4.21	Suitable project / unit size		1.0		2	2	2	2	2	0	0
4.22	Flexibility of technology (in terms of operation, adaption to supply/demand)		1.0		2	2	2	2	-1	-1	-1
4.23	Construction/implementation schedule (short/long, easy/complicated)		1.0		1	1	1	1	1	-1	-1
4.24	Safety standards easy to fulfil		1.0		0	0	0	0	0	0	0
4.25	Project already pre-developed (in Kenya) / documents, prel. design etc. (in part) available		1.0		0	0	0	0	1	0	0
4.3	Frame / external conditions: location / infrastructure		1.0		0.00	-2.00	0.50	0.00	0.00	-1.50	-1.50
4.31	Supply / evacuation of input/output (e.g. infrastructure exists, easy to be build)		1.0		0	-2	0	1	1	-1	-1
4.32	Knowhow (O&M, R&D) available (research organisations, service companies, experts)		1.0		0	-2	1	-1	-1	-2	-2
5	Environmental	15%			0.8	1.8	1.8	0.8	0.17	0.00	1.50
5.1	Local environmental impact (immission few km) to wider environmental impact / national		1.3		0.83	1.83	1.83	0.83	0.17	0.00	1.50
5.11	Environmental impact: soil, air, water		1.5		1	1	1	1	1	1	1
5.12	Mitigation measures available / possible (at certain costs/regulatory requirements)		1.0		1	1	1	1	-1	0	0
5.13	Water availability and needs		1.5		0	2	2	0	0	-1	1
6	Legal	10%			1.0	1.1	0.6	0.5	1.39	0.1	0.1
6.1	Land use		1.5		3.00	3.00	1.50	1.50	3.00	1.50	1.50
6.11	Land availability (also for international investors)		1.5		2	2	1	1	2	1	1
6.2	Legal / regulatory processes		1.2		-0.08	0.18	0.18	-0.08	1.18	-1.30	-1.30
6.21	Legal / regulatory frame exists (incl. safety standards etc.)		1.0		0	0	0	0	1	-2	-2
6.22	Similar processes / projects in the past / present		1.2		1	1	1	1	1	-1	-1
6.23	Doing business / bureaucracy / corruption		1.0		0	1	1	0	1	-2	-2
6.24	Project already pre-developed (in Kenya) / documents etc. (in part) available		1.5		-1	-1	-1	-1	1	0	0

Candidate (site/use)							
Use	Transport - H2 for railway, road transport, urban mobility (public transport)	Transport - H2 for port logistics etc.	Transport - H2 for railway	Transport - H2 for public transport, local utility	Transport - ammonia for ships, export	Transport - ammonia for ships, export	Transport - ammonia for ships, export
Site	Olkaria	Mombasa	Mombasa	Nairobi	Nairobi	Mombasa	Olkaria
ID							
Name	Olkaria Transport - H2 for railway, road transport, urban mobility (public transport)	Mombasa Transport - H2 for port logistics etc.	Mombasa Transport - H2 for railway	Nairobi Transport - H2 for public transport, local utility	Nairobi Transport - ammonia for ships, export	Mombasa Transport - ammonia for ships, export	Olkaria Transport - ammonia for ships, export
Result	-0.23	0.99	0.47	0.58	-0.21	0.25	-0.25
Rank	45	2	12	9	44	31	46
Gaps: Obstacles / Knock-out criteria	Very High	Low	Some	Low	Some	Some	High
count - 2 = -- = insufficient	8	0	2	1	3	2	4
Enablers, niches, low hanging fruits	Some	Very High	High	High	Low	Low	Low

- 2 = -- = insufficient
- 1 = - = sufficient (but rather negative)
0 = o = satifactory (neutral)
+ 1 = + = good
+ 2 = ++ = very g ood

Categories		Criterion	Weighting PESTEL force	Importance of assessment criteria (country view /objectives study)	Olkaria H2 railway/road/urban	Mombasa H2 port logistics	Mombasa H2 railway	Nairobi H2 public transport	Nairobi ammonia ships	Mombasa ammonia ships	Olkaria ammonia ships
3.2		Workers / population safety		1.3	-0.75	0.75	-0.75	0.00	-0.75	0.00	-0.75
	3.21	Harmful substances		1.5	-1	1	-1	0	-1	0	-1
	3.22	Technical Standards / regulation exists / enforced		1.0	0	0	0	0	0	0	0
	0.01										
	0.02										
	0.03										
	0.04										
	0.05										
4		Technical	25%		-0.8	0.7	-0.3	0.1	-0.3	-0.3	-0.4
4.1		Technology readiness		1.2	-0.63	1.27	-0.13	0.37	-1.13	-1.13	-1.13
	4.11	Global level: proven and available (off the shelf) vs. pilot or research		1.5	-1	2	0	1	-2	-2	-2
	4.12	Regional/national level: as above, in country, region		1.2	-2	-1	-2	-2	-2	-2	-2
	4.13	Innovation potential / learning curve		1.0	2	2	2	2	2	2	2
4.2		Project design		1.0	-0.40	0.20	-0.40	-0.20	-0.20	-0.20	-0.20
	4.21	Suitable project / unit size		1.0	0	-1	0	-1	-1	-1	-1
	4.22	Flexibility of technology (in terms of operation, adaption to supply/demand)		1.0	-1	-1	-1	-1	1	1	1
	4.23	Construction/implementation schedule (short/long, easy/complicated)		1.0	-1	1	-1	0	-1	-1	-1
	4.24	Safety standards easy to fulfil		1.0	0	1	0	0	0	0	0
	4.25	Project already pre-developed (in Kenya) / documents, prel. design etc. (in part) available		1.0	0	1	0	1	0	0	0
4.3		Frame / external conditions: location / infrastructure		1.0	-1.50	0.50	-0.50	0.00	0.50	0.50	0.00
	4.31	Supply / evacuation of input/output (e.g. infrastructure exists, easy to be build)		1.0	-1	1	0	1	1	1	1
	4.32	Knowhow (O&M, R&D) available (research organisations, service companies, experts)		1.0	-2	0	-1	-1	0	0	-1
5		Environmental	15%		-0.50	1.50	1.50	0.50	-0.7	0.8	-1.2
5.1		Local environmental impact (immission few km) to wider environmental impact / national		1.3	-0.50	1.50	1.50	0.50	-0.67	0.83	-1.17
	5.11	Environmental impact: soil, air, water		1.5	1	1	1	1	-1	-1	-2
	5.12	Mitigation measures available / possible (at certain costs/regulatory requirements)		1.0	0	0	0	0	1	1	1
	5.13	Water availability and needs		1.5	-2	2	2	0	-1	2	-2
6		Legal	10%		-0.1	1.3	0.7	1.1	-0.1	0.9	0.4
6.1		Land use		1.5	1.50	3.00	3.00	3.00	0.00	3.00	1.50
	6.11	Land availability (also for international investors)		1.5	1	2	2	2	0	2	1
6.2		Legal / regulatory processes		1.2	-1.68	0.93	-0.83	0.18	-0.33	-0.33	-0.33
	6.21	Legal / regulatory frame exists (incl. safety standards etc.)		1.0	-2	0	-1	-1	0	0	0
	6.22	Similar processes / projects in the past / present		1.2	-1	1	1	1	1	1	1
	6.23	Doing business / bureaucracy / corruption		1.0	-2	1	-2	-1	-1	-1	-1
	6.24	Project already pre-developed (in Kenya) / documents etc. (in part) available		1.5	-1	1	-1	1	-1	-1	-1

Candidate (site/use)	Use	Transport - e-fuels (H2 for regional only) for aviation	Transport - e-fuels (H2 for regional only) for aviation	Transport - e-fuels (H2 for regional only) for aviation
	Site	Nairobi	Olkaria	Mombasa
	ID			
	Name	Nairobi Transport - e-fuels (H2 for regional only) for aviation	Olkaria Transport - e-fuels (H2 for regional only) for aviation	Mombasa Transport - e-fuels (H2 for regional only) for aviation
	Result	0.29	0.11	0.40
	Rank	27	40	19
	Gaps: Obstacles / Knock-out criteria	Some	Some	High
	count - 2 = -- = insufficient	2	3	4
	Enablers, niches, low hanging fruits	Some	Some	Some

- 2 = -- = insufficient
- 1 = - = sufficient (but rather negative)
0 = o = satifactory (neutral)
+ 1 = + = good
+ 2 = ++ = very g ood

Categ ories			Weighting PESTEL force	Importance of assessment criteria (country view /objectives study)	Nairobi		Olkaria		Mombasa	
3.2		Workers / population safety		1.3	-0.50		-0.50		-0.50	
	3.21	Harmful substances		1.5		0		0		0
	3.22	Technical Standards / regulation exists / enforced		1.0		-1		-1		-1
	0.01									
	0.02									
	0.03									
	0.04									
	0.05									
4		Technical	25%		0.6		0.3		0.6	
4.1		Technology readiness		1.2	0.27		0.27		0.27	
	4.11	Global level: proven and available (off the shelf) vs. pilot or research		1.5		0		0		0
	4.12	Regional/national level: as above, in country, region		1.2		-1		-1		-1
	4.13	Innovation potential / learning curve		1.0		2		2		2
4.2		Project design		1.0	1.60		1.60		1.60	
	4.21	Suitable project / unit size		1.0		-1		-1		-1
	4.22	Flexibility of technology (in terms of operation, adaption to supply/demand)		1.0		1		1		1
	4.23	Construction/implementation schedule (short/long, easy/complicated)		1.0		1		1		1
	4.24	Safety standards easy to fulfil		1.0		1		1		1
	4.25	Project already pre-developed (in Kenya) / documents, prel. design etc. (in part) available		1.0		0		0		0
4.3		Frame / external conditions: location / infrastructure		1.0	0.00		-1.00		0.00	
	4.31	Supply / evacuation of input/output (e.g. infrastructure exists, easy to be build)		1.0		1		-1		1
	4.32	Knowhow (O&M, R&D) available (research organisations, service companies, experts)		1.0		-1		-1		-1
5		Environmental	15%		-0.2		-0.7		1.3	
5.1		Local environmental impact (immission few km) to wider environmental impact / national		1.3	-0.17		-0.67		1.33	
	5.11	Environmental impact: soil, air, water		1.5		0		0		0
	5.12	Mitigation measures available / possible (at certain costs/regulatory requirements)		1.0		1		1		1
	5.13	Water availability and needs		1.5		-1		-2		2
6		Legal	10%		0.5		1.0		1.0	
6.1		Land use		1.5	1.50		3.00		3.00	
	6.11	Land availability (also for international investors)		1.5		1		2		2
6.2		Legal / regulatory processes		1.2	0.05		0.05		0.05	
	6.21	Legal / regulatory frame exists (incl. safety standards etc.)		1.0		-1		-1		-1
	6.22	Similar processes / projects in the past / present		1.2		1		1		1
	6.23	Doing business / bureaucracy / corruption		1.0		0		0		0
	6.24	Project already pre-developed (in Kenya) / documents etc. (in part) available		1.5		0		0		0

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