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D1.3 "AU Green H2 scenarios"

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

WP leader: UNIGE

T1.3 "SWOT and PESTLE Analysis of African Green Hydrogen potential areas/contexts"

T1.4 "JUST GREEN AFRH2ICA Scenario Prioritization and KPI Panel"

T1.5 "KPI Assessment"

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Version	Date	Author/Contributor	Changes
0.1	09-10-2023	Stefano Barberis	Table of Content and template
0.2	From October to December 2023	IRESEN- JULICH – NWU – STRATH description of proposed Use Cases	Integration of UCs description
0.3	31-01-2024	UNIGE and AHP	Formatting and finalization
final	27-03-2024	UNIGE	Integration of aspects from Nairobi events in February 2024

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EXECUTIVE SUMMARY

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101101469

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This document is the Deliverable "D1.3 AU Green H2 scenarios", developed within WP1 of the JUST GREEN-AFRH2ICA project.

Following the overview of green hydrogen potential of African countries presented in D1.2, the document provides a quite detailed overview of the Use Cases that the consortium intends to model in WP2 and the KPIs to be considered during these modelling activities as well as main key indicators for green hydrogen roadmaps drafting in WP3 and to track project status. The report presents therefore:

- The use cases that the consortium identified as key representatives of Northern Africa (Chapter 2), Western Africa (Chapter 3), Central/Eastern Africa (Chapter 4) and Southern Africa (Chapter 5) in accordance with the "Green Hydrogen Hub" approach as presented in D1.2
- The peculiarities of each use case that brought to identify them as representatives of the local contexts and the challenges to model them as discussed both in M5 and M13 General Assemblies in Madrid and in Nairobi
- The KPI panel defined by UNIGE as coordinator, driven by the need of monitoring project advancement status (also in accordance with CHP JU TRUST KPIs) and the potential performances of the green hydrogen use cases identified.

The overall report contents will be wrapped up in Conclusions chapter: the outcomes of this deliverable (together with D1.2 ones) will be the guidelines for WP2 and WP3 project activities.

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1. INTRODUCTION

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

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

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

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

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

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

One of the goal of WP1 is therefore to understand (as much as possible from a quantitative point of view) how EU and AU can cooperate and support each other in this sense, understanding how much hydrogen EU could realistically needs and how much hydrogen AU could realistically produce and export. In this sense, WP1 aims to model and quantify this amount of hydrogen both looking at:

- Continental (like D1.2 chapter 2 analysis) and single country (like in D1.3 and in some country per country analysis presented in D1.2) level
- Domestic use and export purpose for green hydrogen production potential assessment

The present document constitutes the Deliverable D1.3 "AU Green H2 scenarios", developed within WP1 of the JUST GREEN-AFRH2ICA project.

The report aims to present the use cases that, under the guidance of the local consortium partners (IRESEN, JULICH, STRATH, NWU), were identified to be the key representatives of the local context according to the "Hydrogen Hubs/Hotspots" approach, ", thus specific areas where a significant hydrogen demand is already present where to install an off-grid green hydrogen production plant to fulfil such local demand to be potentially expanded to other local H2 users to be identified in a second moment or to potential export opportunities.

Furthermore, Use Cases have been identified also looking at local renewable energy potential and at the possibility to study different types of renewable energy sources - electrolysers coupling (PV, wind, geothermal, hydropower) thus to collect relevant insights also for replication all over the continent.

This approach drove the identification of the project Use Cases that has been reported in D1.3 according to the results of a thorough analysis that started from D1.1 and D1.2 activities/outcomes (particularly the country per country SWOT analysis thereby presented) and that was actively discussed in Madrid M5 General Assembly during a specific workshop (and further discussed in M13 General Assembly in Nairobi) also considering local data availability to drive potential modelling tools updates/enhancements to be performed by WP2 partners (JULICH, STRATH, IME, UNIGE) to make their modelling approach suitable for local contexts.

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Each use case is presented via an analysis of the following information that somehow reflect at local level the information analysed in the "Multi-aspects" green hydrogen potential presented in D1.2:

- Overall presentation of the area: geographic location, local drivers and barriers for the setting up of a "hydrogen hub", presence and assessment of local energy and civil infrastructures...
- Renewable Power plant presence (existing) and local renewable energy sources potential
- Current and potential hydrogen demand at local level (e.g. current NG demand)
- Local water sources assessment
- How to potentially export local hydrogen (analysis of potential export infrastructure available at local level)
- Stakeholders at local level
- Availability of data (e.g. local energy/Hydrogen demand, how to potentially suppose such demand and the amount of Hydrogen required at local level, what is the local available RES production...)

The report presents as well the KPI panel that has been identified to evaluate the performances of the identified use cases as well as to track the project progress in accordance to Grant Agreement objectives and expected outcomes as well as CHP JU TRUST and SRIA KPIs Panel. Nevertheless, it's relevant to highlight that as TRUST (Technology Reporting Using Structured Templates) approach is quite technology oriented, few KPIs coming from TRUST have been considered for the project.

Structure of the Deliverable

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

- Section 2 presents the description of the identified use cases in Morocco by IRESEN – part of this activity has also been presented in a recent scientific paper by IRESEN[1];
- Section 3 presents the description of the identified use cases in Ghana/Togo area by JULICH;
- Section 4 presents the description of the identified use cases in Kenya area by STRATH;

[1] Ilham Ourya, Nouhaila Nabil, Souad Abderafi, Noureddine Boutammachte, Samir Rachidi, Assessment of green hydrogen production in Morocco, using hybrid renewable sources (PV and wind), International Journal of Hydrogen Energy, Volume 48, Issue 96, 2023, Pages 37428-37442, ISSN 0360-3199, https://doi.org/10.1016/j.ijhydene.2022.12.362

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- Section 5 presents the description of the identified use cases in South Africa and Namibia by NWU
- Section 6 presents the description of the KPI identified to assess Use Cases modelling performances (according to WP2 modelling tools) as well as KPIs required by CHP TRUST ;
- Section 7 presents deliverable's conclusions and next steps.

Relation to Other Tasks and Deliverables

Starting from T1.1-T1.2 main outcomes, this Deliverable D1.3 is based on Task 1.3, Task 1.4 and Task 1.5 outcomes and it provides relevant inputs towards the final goal of WP1: setup the scene for WP2 and WP3 modelling and road mapping activities, particularly for what it concerns:

- Identification of relevant use cases to be modelled in WP2 as representatives of the African continent
- Identification of KPIs to evaluate the techno-economic viability of green hydrogen projects in Africa and to track project progress.

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2. NORTHERN AFRICA – MOROCCO USE CASES

Green hydrogen is regarded to be a promising energy vector poised to replace fossil fuels in the near future, mainly because of its many advantages. Firstly, it serves as a clean and environmentally friendly energy source, emitting only water vapor when utilized in fuel cells or combustion processes, thus significantly reducing greenhouse gas emissions. Its versatility is another crucial attribute, as it can be produced through electrolysis powered by renewable energy sources such as wind and solar. Additionally, hydrogen's high energy density makes it a potential candidate for long-term energy storage, enabling the efficient harnessing of intermittent renewable energy, a critical component in transitioning to a sustainable energy future. As scientific research and innovation progress, the potential of hydrogen to revolutionize the worldwide energy scene remains a promising solution for a more environmentally sustainable and secure energy future.

Due to its high renewable energy potential and its strategic geographical location between Europe and the rest of Africa, Morocco plans to be a leader in green fuel production through the Power to X concept, particularly through the production of green hydrogen. Consequently, the Moroccan government continues to prioritize the growth of the renewable energy sector.

In order to assess the feasibility of a country's transition to a hydrogen-based economy, the initial step involves evaluating and estimating the potential for hydrogen production from renewable energy sources. This evaluation provides the foundation for conducting specific technical and economic feasibility studies. The objective of this study is to assess the potential of green hydrogen in Morocco, as it is one of the countries involved in this initiative.

2.1 Use cases identification and drivers for use cases identification

The selection of sites for case studies has been done based on the availability of potential renewbale resources. Morocco demonstrates very high solar potential across the entire country (Fig. 1 a), with an average level of solar irradiation of around 5 kWh/m^2/day. With a

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daily average solar irradiation of 5.3 kWh/m2 and insolation reaching 3500h/year, solar energy is considered one of the most valuable renewable energy alternatives in Morocco. Additionally, wind power also shows huge potential across large parts of the country, especially in the southern part and along with most parts of the coastline (Fig. 1 b).

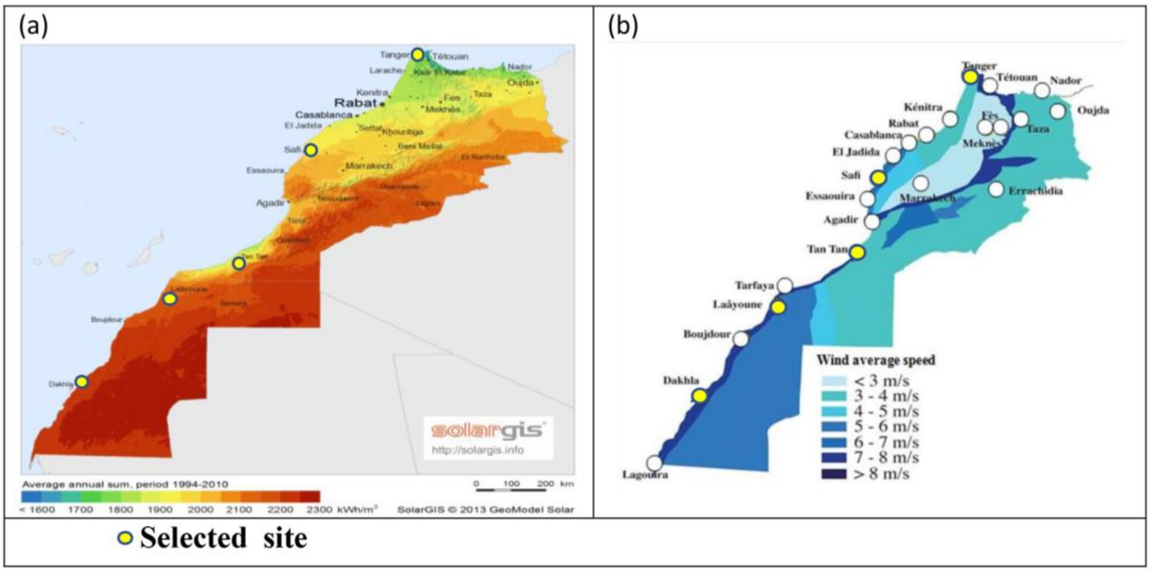

Figure 1: (a) Solar and (b) Wind potentials in Morocco.

Therefore, Morocco demonstrates a very high solar potential across the entire country, and a huge wind power potential across large parts of the country, especially in the northern (Tangier) part and the southern part (Dakhla- Laayoune) and on the coastline cities (Jorf Lasfar -Casablanca).

These are the three areas identified by IRESEN as potential “Hydrogen Hotspots” as representatives for Northern Africa:

- ***Tangier:*** A first one strongly dedicated to potential export opportunities both exploiting local port infrastructure as well as local natural gas pipelines, also foreseeing in the port a potential end user of hydrogen to catalyze the setup of a local hydrogen hub (as proved by projects like H2PORTS - https://h2ports.eu/ - and BalticSeaH2 Valley - https://balticseah2valley.eu/)
- ***Jorf Lasfar -Casablanca:*** a second one focused on an industrial area where different chemical complexes as well as steel manufacturing companies are active and where, thanks to the local port, the possibility to foresee the export of green hydrogen, green hydrogen derivatives (e.g. Ammonia locally produced) or low emission products

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manufactured by locally produced hydrogen (e.g. steel, refinery products). Natural gas driven power plants are also present in such area, giving the possibility to have relevant and constant hydrogen demand volumes.

This is an area that already attracted the interest of different investors and green hydrogen derivatives developers[2] as presented in D1.2

- ***Dakhla - Laayoune:*** a third one that could be seen more as a "green field" in the Southern part of the country with the possibility to install significant renewable power plant capacity and to exploit local port for export purposes too.

In the next paragraphs each of them will be presented more in detail

2.1.1 Tangier region (North of Morocco)

Tangier, a city in northern Morocco, offers several compelling reasons why it could be a suitable location for green hydrogen projects:

Figure 2: Tangiers location and main industrial areas and renewable potential (pictures from slides presented during M5 General Assembly)

[2] For example https://protonventures.com/news/new-ammonia-storage-project-awarded/

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- **Wind potential:** In the context of the Tangier region, which is in northern Morocco, it has significant wind potential due to its coastal location along the Strait of Gibraltar. This region experiences strong and consistent winds, which make it an ideal location for the deployment of large wind fields or wind farms.
- **Strategic Geographic Location:** Tangier is strategically located at the entrance to the Mediterranean Sea and the gateway to Europe. This position provides opportunities for exporting green hydrogen to European markets, which have a growing demand for clean energy sources, including hydrogen.
- **Coastline Regions for Available Seawater Resources:** Tangier is located along the northern coastline of Morocco, providing access to seawater resources. This geographical advantage can be important for technologies that utilize seawater, such as desalination.
- **Availability of Land:** Tangier offers available land for renewable energy infrastructure, such as solar arrays and wind turbines. The suitability of land, including factors like land ownership, topography, and soil quality, should be considered during the planning phase.
- **Availability of Infrastructure for Export (Ports) :** Tangier boasts a well-developed infrastructure and a major port, the Tangier-Med port, which is one of the largest and busiest ports in the Mediterranean region. This infrastructure is advantageous for exporting energy or importing equipment. The city also offers the possibility of building new infrastructures if required to support renewable energy projects.

Tangier, with its high renewable energy potential, diverse local industries, coastal location, available land, and robust infrastructure, presents itself as a promising location for green hydrogen projects.

2.1.2 Jorf Lasfar -Casablanca site (Industrial region)

The new port of Jorf Lasfar is located between the White Cape (to the north) and the current port of Jorf Lasfar (to the south). The identified site can leverage the following advantages:

i) availability of land in the backyard of the coastal areas to facilitate logistics operation as well as potential renewable power plant installations;

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ii) proximity to both the local industrial site, the former port and the existing motorway/civil infrastructure (thus facilitating import/export logistics)

iii) availability of a stable electric supply also thanks to local natural gas driven power plants

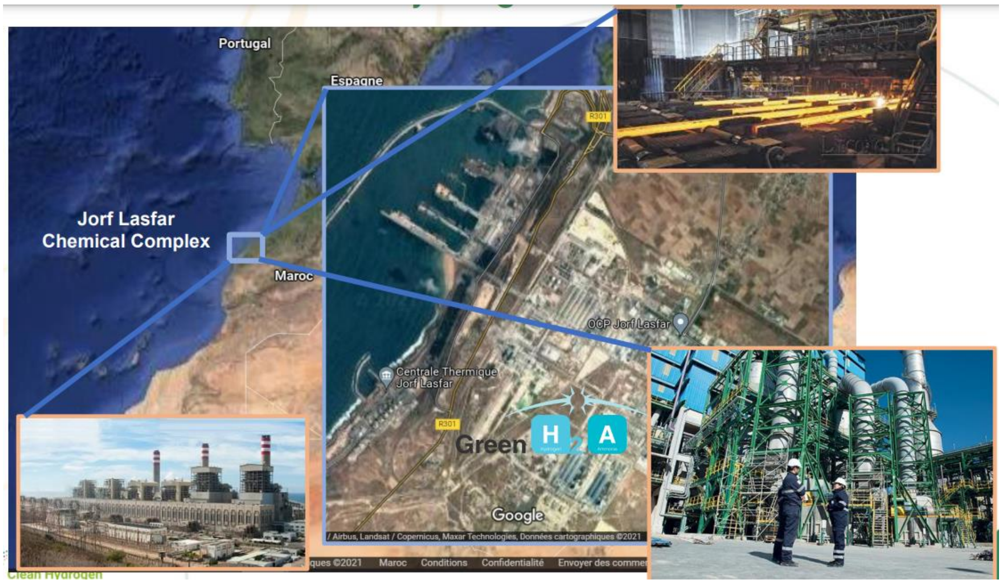

Figure 3: Jorf Lasfar location and main industrial areas (pictures from slides presented during M5 General Assembly)

- **Presence of Relevant Local H2 industrial End Users:** The presence of local relevant Hydrogen off-takers for fertilizers and ammonia production in the Jorf-Casablanca region is one of the key driver in the identificiation of this use case. Ammonia/fertilizer production is mostly related to the company named Office Chérifien des Phosphates (OCP). OCP is a major phosphate mining and processing company based in Morocco, and it plays a significant role in the global fertilizer and ammonia industry.

  The steel industry, including companies like MagrebSteel in Casablanca and SONASID in Jorf Lasfar in the Maghreb region, is another relevant potential future hydrogen off-takers for H2 driven DRI processes as well as for H2 combustion in the process. Companies like MagrebSteel and SONASID are prominent players in the steel industry within the Maghreb region, producing various steel products to meet domestic and international

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demand. Their operations are essential for supporting various industries and contributing to the economic development of the region and the broader global economy.

- **Coastline Regions for Available Seawater Resources:** The Jorf-Casablanca region in Morocco does have access to seawater resources as it is located along the country's coastline. Access to seawater is a fundamental requirement for green hydrogen production through a process known as seawater electrolysis. This process involves using electricity generated from renewable sources, such as wind or solar power, to split water into hydrogen and oxygen.
- **Availability of Infrastructure for Export (Ports) :** Jorf-Casablanca features a well-developed infrastructure, including the presence of ports (Port of Jorf Lasfar) and transportation facilities. The region has well-developed transportation networks, including road, rail. These infrastructures facilitate the movement of hydrogen and hydrogen-related equipment. Efficient logistics are crucial for reducing distribution costs and ensuring reliable supply chains.

2.1.3 Dakhla-Laayoune region (South of Morocco)

Dakhla-Laayoune is a region located in the southwestern part of Morocco. The region encompasses two main cities: Dakhla and Laayoune, which serve as its administrative and economic centers.

Thanks to its enormous green hydrogen potential and land availability, this area attracted the interest of different investors and green hydrogen project developers, like Polish company Green Capital group[3].

[3] https://www.moroccoworldnews.com/2023/10/358045/polish-green-capital-plans-massive-green-hydrogen-project-in-dakhla

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Figure 4: Dakhla-Laayoune location and main peculiarities as potential hydrogen hub (pictures from slides presented during M5 General Assembly)

- **Availability of Land:** The region offers vast open spaces, which are ideal for the deployment of renewable energy infrastructure, such as solar farms and wind turbines. The availability of land can make it easier to establish large-scale hydrogen production facilities.

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- **Renewable Energy Potential:** Dakhla's location, near the Moroccan Sahara desert, offers a strategic advantage for solar energy production due to its proximity to vast desert areas that are suitable for large-scale solar installations.

The Dakhla-Laayoune region, offers significant potential for the availability of renewable resources:

Solar Energy: The region offers abundant sunshine throughout the year, making it well-suited for solar energy production. Solar panels and concentrated solar power (CSP) technologies can be deployed to harness this energy for electricity generation and other applications.

Wind Energy: The coastal location of Dakhla and Laayoune makes the region favorable for wind energy development[4]. The area benefits from consistent winds, which can be harnessed by wind turbines to generate electricity. Wind farms can be established to capitalize on this resource.

- **Infrastructure Development:** The Dakhla-Laayoune region is marked by a well-established infrastructure and features a significant port, the Dakhla-Laayoune Port. This port, although currently in the planning stages, is a foreseen infrastructure project that holds great promise for the region's economic development and connectivity. Once constructed, the Dakhla-Laayoune Port is expected to play a pivotal role in supporting various industries, including fisheries, agriculture, and potentially renewable energy projects, making it a key driver of regional development and trade expansion. Morocco recently announced the launch of a newly built seawater desalination plant in Dakhla which will be beneficial for hydrogen production projects in the future too.

[4] Bakkari M, Bossoufi B, El Kafazi I, Bouderbala M, Karim M. A review of wind energy potential in Morocco: New challenges and perspectives. *Wind Engineering*. 2024;48(1):101-120. doi:10.1177/0309524X231200582

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2.2 Evaluation of green hydrogen and renewable energy production potential via dedicated modelling activities

In this section, IRESEN analysed via a techno-economic modelling approach, the potential of the different use cases. This first assessment, that drove the identification of the use cases in the framework of an overall Moroccan green hydrogen potential that IRESEN conducted and presented also in a recent publication

2.2.1 Wind potential assessment

Wind power is a renewable source of energy that is produced by converting kinetic energy to electrical energy utilizing a wind turbine (WT).

The calculation of the electrical energy generated by the location was made with reference to [1]. To do this, the wind turbines were first selected. The model selected was the SG 2.1e114 of the SIEMENS Gamesa brand, which has a nominal power of 2.1 MW and a rotor diameter of 114 m, and its use is recommended for sites with low and medium winds.

The output power produced by the WT depends on the wind speed, the efficiency of conversion, wind energy, and air density. Equation (1) defines the conversion of wind speed to the hub height [2].

$$\frac{v}{v_{ref}} = (\frac{h}{h_{ref}})^{\alpha} \tag{1}$$

where v denotes the wind speed (m/s) at the desired hub height h; α refers to the power law exponent ranging and for an open space, the value of α is usually taken as 1/7 [3]; h_{ref} is the reference height (m); and v_{ref} is the wind speed at h_{ref}.

The wind turbine power P_{WT} is represented in terms of wind speed as follows [2]:

$$P_{WT} = \begin{Bmatrix} 0 \\ P_R \times \frac{v^3 - v_{IN}^3}{v_R^3 - v_{IN}^3} \\ P_R \end{Bmatrix} \begin{matrix} if"v_{OFF} < v"or"v \leq v_{IN}" \\ if"v_{IN} \leq v \leq v_R" \\ if"v_R \leq v \leq v_{OFF}" \end{matrix} \tag{2}$$

where P_R and v_R define the rated power and rated wind speed, respectively; v denotes the

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wind speed; v_{OFF} and v_{IN} refer to the cut-off and the cut-in wind speed, respectively. Table 1 lists the parameters of the wind generator.

Then, the values of the hourly energy developed by the wind turbine (E_{wt}) in each district were calculated from its power curve (Fig.5). The area occupied by each wind turbine was calculated (A_{wt}) considering a separation distance between wind turbines of 10 times the rotor diameter (D) in the wind direction and 5 times the rotor diameter (D) in the perpendicular direction. The purpose of these distances is to avoid the generation of turbulence or wake effect produced by the wind as it crosses the blades of the wind turbine, which causes losses in the electrical energy generated.

Finally, the electrical energy generated hourly from wind energy ($E_{wt\ region}$) in each district was calculated using Eq. (3).

$$E_{WT\ region} = \frac{P_{WT} \times t}{A_{WT}} \qquad [\text{KWh/Km}^2] \tag{3}$$

where A_{wt} is the area occupied by each wind turbine (0.6498 km^2) and t is time (t= 1 hour).

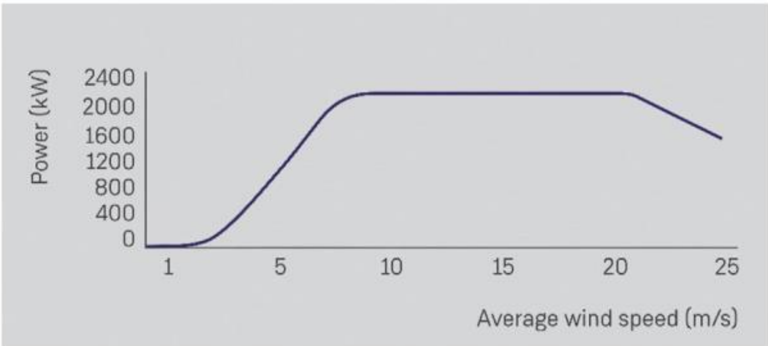

Figure 5: Power curve of the selected wind turbine (SIEMENS Gamesa SG 2.1-114) [4].

Table 1: Parameters of the wind generator

Parameter	Values	Unit
Cut-in velocity v_{IN}	1.5	m/s
Cut-out velocity v_{OFF}	25	m/s
Rated speed P_R	2100	W
Rated wind speed v_r	9	m/s
Area occupied by each wind A_{wt}	0.6498	Km^2

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2.2.2 Solar PV potential assessment

The PV model is a mathematical representation used to estimate the energy production of a PV system. Energy production can be estimated at different time scales, such as hourly, daily, or monthly. The hourly estimate is typically the most accurate because it records the detailed variations in energy production throughout the day.

To calculate the electrical energy generated by each location, photovoltaic panels were initially chosen. The selected model is the Yingli Energy YL405D, whose features are reported in Table 2.

Table 2: Main parameters of the PV module.

Parameter	Value	Unit
Nominal Power	405	W
Nominal efficiency	20.60	%
Module length	1.97	m
Module width	1	m
Temperature coeff. of power	-0.333	%
Nominal operating cell temperature	44.7	°C
Global irradiance reference	1000	W/m2
Cellule temperature reference	25	°C

The energy produced by a PV module is significantly influenced by the geographic location of the system, solar radiation, and the characteristics of the modules. Therefore, to calculate it, the cell temperature must be estimated first using Equation (4) [5].

$$T_c = T_{amb} + \frac{T_{NOCT}-20}{800} G_{ref} \quad (4)$$

where T_{amb} is the ambient temperature, T_{NOCT} is the nominal operating cell temperature and G_{ref} is the irradiation at reference conditions.

The hourly output energy of a PV system E_{PV} can be calculated by Equation (5)[6]:

$$E_{PV} = G_i \, A_{mod} \, \eta_{mod} \left(1 - \gamma \left(T_c - 25\right)\right) t \quad \text{[KWh]} \quad (5)$$

where G_i is the global solar irradiation on inclined surface, η_{mod} is the module efficiency, γ is the temperature factor and t is the time (t= 1hour).

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The area occupied by each photovoltaic module A_{PV} is calculated by using Equation (6) [7]:

$$A_{PV} = b\,(h\cos\beta + l) \quad [\text{Km}^2] \tag{6}$$

where, b is the length of the photovoltaic module, h is the height of the photovoltaic module, β is the tilt angle of the photovoltaic module and l is the minimum distance between rows. The minimum distance between rows is considered 6 cm, and this estimation was made with reference to [7].

The electrical energy generated hourly from solar energy is calculated in each region, using Equation (7) [7].

$$E_{PV\ region} = {E_{PV}}/{A_{PV}} \quad [\text{KWh/Km}^2] \tag{7}$$

2.2.3 Hybridization PV/wind turbine ratio

In light of Morocco's abundant renewable energy resources, strategic site selection has been carried out for implementing a hydrogen production model. The primary objective is to harness the synergy of solar and wind energy in generating hydrogen. Consequently, the chosen locations must possess both of these renewable energy sources. Morocco boasts world-class variable renewable energy resources, positioning it as a prospective leader in renewable energy production and the export of hydrogen-rich chemicals [8]. The country showcases exceptional solar potential throughout its territory, averaging approximately 5 kWh/m2/day of solar irradiation [9]. With a daily solar irradiation average of 5.3 kWh/m2 and an impressive 3500 hours of insolation per year, solar energy stands out as a prominent renewable energy option in Morocco. Furthermore, wind power exhibits significant potential, especially in the southern regions and along the coastline [10]. Wind energy has emerged as a promising alternative to address the rising electricity demand. Consequently, Morocco's extensive solar and wind potential, spanning various regions, particularly in the north, south, and coastal cities [9], creates a favorable environment for the establishment of PV-Wind facilities for green hydrogen production. As a result, four distinct case studies in different areas across Morocco have been selected for modeling and simulating a green hydrogen production system through water electrolysis: Dakhla, Laayoune (South of Morocco), Tangier (North of Morocco), and Jorf Lasfar (Middle coastline in Morocco).

As depicted in Fig. 6, the optimal setups uniformly integrate solar and wind energy sources,

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underscoring the compelling appeal of employing hybrid renewable energy resources for green hydrogen production. The specific PV-to-wind ratio varies across different scenarios. Despite the recent reduction in photovoltaic panel costs [11], all configurations prioritize a larger proportion of electricity derived from wind energy compared to that from solar energy. This preference arises from wind energy's inherent ability to generate electricity and green hydrogen continuously throughout the day, a feature not shared by solar energy. Notably, in the locations of Dakhla, Jorf Lasfar, and Laayoune, the wind energy ratio is notably high, constituting 64%, 79%, and 65% of the total energy capacity, respectively. Conversely, in Tangier, the wind energy ratio closely aligns with the solar energy ratio, accounting for 54% of the total energy capacity.

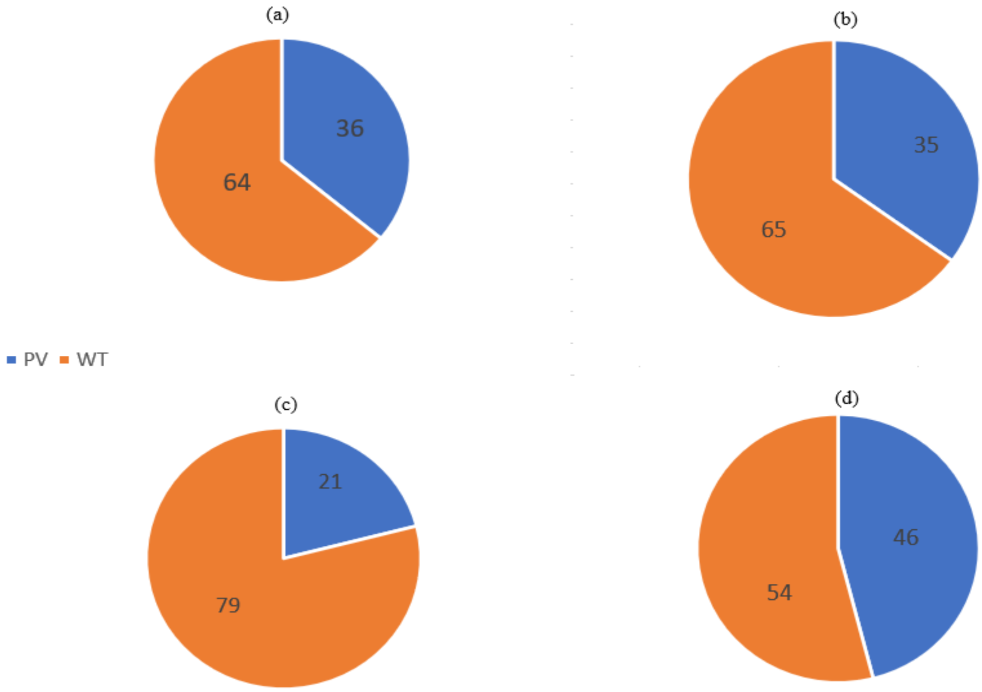

Figure 6: The ratio of PV (Photovoltaic) and Wind capacity for the cities under investigation is as follows: (a) Dakhla, (b) Laayoune, (c) Jorf Lasfar, and (d) Tangier.

The electricity generated by solar and wind energy systems can power the process of water electrolysis. Numerous electrolyzer technologies are available in the market : Alkaline, SOEC, and PEM. In this study the Alkaline electrolyser (AEL) was selected. This choice is due the

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primary advantage of selecting the alkaline electrolyzer is its widespread use and established track record in various applications.

2.2.4 Evaluation of the green hydrogen production potential

The hourly potential for hydrogen production from wind in each district, denoted as P_{H2}, is determined using the Equation presented in (8) [7]. This equation is based on the theoretical energy requirement for hydrogen production through water electrolysis in ideal conditions, where the electrolyzer efficiency is 100%, resulting in 55 kWh/kg H2 (at 25°C and 1 atm). This value corresponds to the energy needed to produce 1kg of Hydrogen ($E_{H2/kg}$). However, AEL electrolyzers typically operate with efficiency 65% [12].

$$P_{H2} = \frac{1000 \times \eta_e \times (\rho \times E_{PV\ region} + (1-\rho) \times E_{WT\ region})}{E_{H2/kg}} \quad [\text{Tons/Km}^2] \tag{8}$$

In this context, η_e represents the efficiency of the AEL electrolyzer (0.65), ρ defines the ratio of hybridization, $E_{PV\ region}$ *and* $E_{WT\ region}$ stand for the hourly electrical energy generation per unit area from PV and Wind energy, respectively, and $E_{H2/kg}$ corresponds to the energy needed to produce 1kg of Hydrogen (55 kWh/kg H_2).

To calculate the annual green hydrogen production potential for each district, we summed the values of hourly wind hydrogen production per unit area ($P_{H2\ region}$) throughout the entire year. We then multiplied these values by the area available for use. In order to assess suitable areas for the installation of PV and wind energy systems in the given region, several studies [13,14,15] apply the multicriteria decision making (MCDM) analysis and geographic information system (GIS) tools. Various factors, including installation constraints and environmental conditions, should be considered. Notably, wind speed, which has both cooling effects on technology and impacts on PV panel stability, should be identified for site selection. In this study, the assessment of PV and wind energy potential in each region is conducted on a per square kilometer basis.

To evaluate the solar and the wind resources of each studied region. The incident solar radiation, the temperature and wind speed were analyzed using the PVGIG (Photovoltaic

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Geographical Information System) web tool. PVGIS was developed by the JRC (Joint Research Center) of the European Commission to provide the necessary data to know the potential for electricity production from PV systems[16].

To assess the potential of hydrogen in Morocco, simulations were conducted for four key locations: Dakhla, and Laayoune, Jorf Lasfar and Tangier. In the initial step, we evaluated the meteorological data for each region, focusing on factors such as irradiation, temperature, and wind speed, spanning from 2020 to 2021. The Fig.7 illustrates the variation of these parameters for each region throughout the year, spanning 8760 hours.

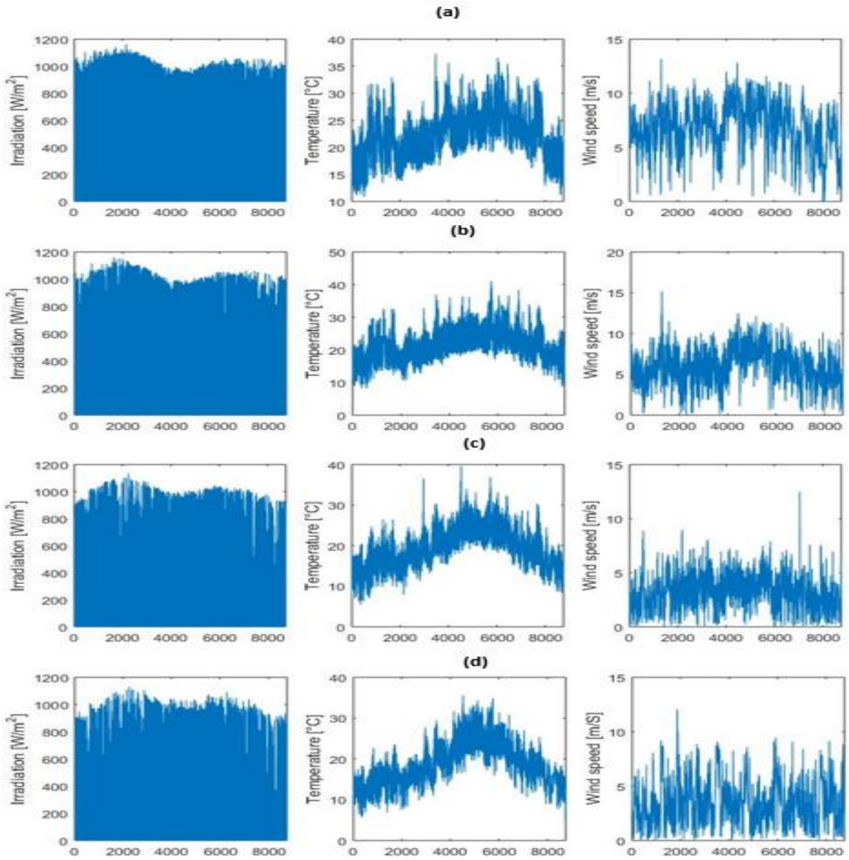

Figure 7: The Irradiation, temperature and wind speed for the cities under investigation is as follows: (a) Dakhla, (b) Laayoune, (c) Jorf Lasfar, and (d) Tangier.

The simulation outcomes are reported in Figs.8 and 9.

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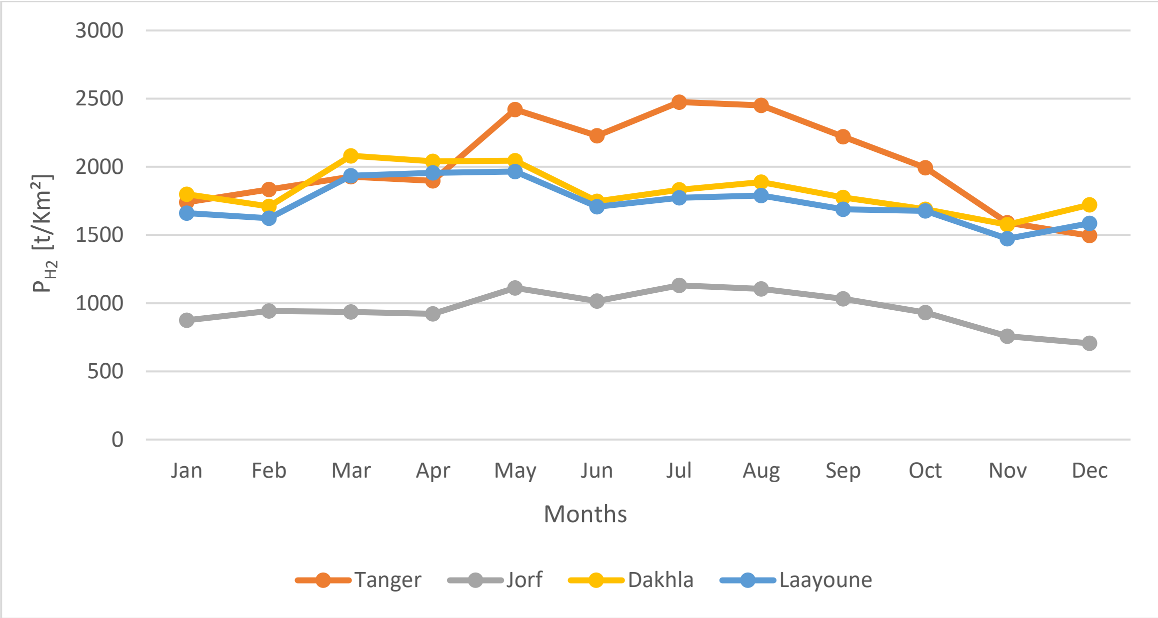

Figure 8: Monthly hydrogen production per each analysed use case

The first observation is that hydrogen production varies greatly from one region to another during spring and summer months, while this difference is less significant during the winter and fall months. In fact, the monthly hydrogen production varies depending on the site. In Tangier, it ranges between 1495.42 t/km^2 and 2474.85 t/km^2, and in Jorf Laasfar, it falls between 705.47 t/km^2 and 1130.72 t/km^2. In Dakhla, it ranges from 1722.421 t/km^2 to 1830.74 t/km^2, and in Laayoune, it varies from 1584.25 t/km^2 to 1772.7 Tons/km^2.The results show that the hydrogen production in the region of Tangier surpasses all the other regions in almost every month and the region of Jorf Laasfar represents the lowest value. Another important observation is that the highest amounts are produced in July and August in all regions. This is due to the high impact of the irradiation in these months, while, the lowest are recorded on December.

As shown in Fig. 8, the Jorf Laasfar location exhibits the lowest hydrogen production values at 10587.35 t/km^2/year. In contrast, Tangier, Dakhla, and Laayoune face considerably higher. These findings underscore the substantial potential for green hydrogen production in Morocco's sites, driven by their abundant renewable energy resources.

The comparative analysis allows us to deduce that Morocco is among the countries with the most promising future in terms of green hydrogen production. The exploitation of its abundant renewable energy resources and its proximity to the European continent is one of

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the promising avenues for the production and export of hydrogen as an energy carrier or to produce other green molecules like ammonia or methanol.

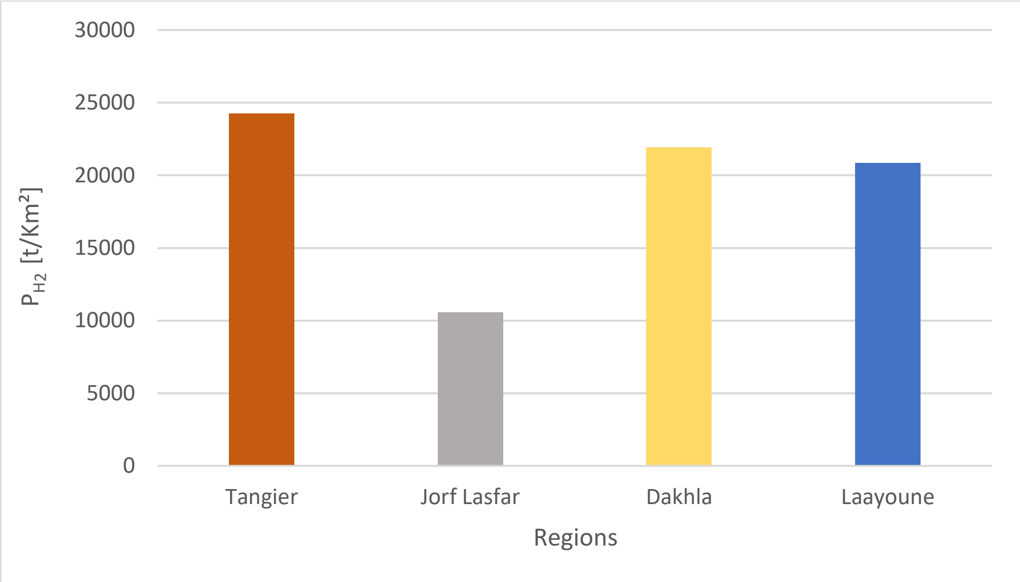

Figure 9: Annual hydrogen production in analysed regions

The proposed analysis performed by IRESEN assessed the renewable energy and hydrogen potential production in the four use cases to be analysed further in JUST GREEN AFRH2ICA WP2 activities. Dakhla, Laayoune (South of Morocco), Tangier (North of Morocco), and Jorf Lasfar (Middle costline in Morocco).

The results show that the Tangier, Dakhla, and Laayoune regions have the highest annual green hydrogen production mostly thank to a relevant wind production potential that properly integrates the local PV production that is similar in all the use cases.

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3 WESTERN AFRICA – GHANA/TOGO USE CASE

The use case selected for the Western Africa context involves primarily Ghana and Togo. Differently than the other use cases (to be presented in the other chapters of the report), this use case is (and will be) analysed via a regional modelling approach, more than a "Hydrogen hotspot approach" with the purpose of identifying most suitable areas where to locate the Hydrogen Hubs.

As discussed in deliverable D1.2, Ghana offers the most favorable national framework for green hydrogen in terms of socioeconomic and political environment, as well infrastructure readiness, while it has moderate potential in terms of green hydrogen production. The neighbouring country Togo, on the other hand, has relatively high potential in terms of green hydrogen production, while it does not stand out in terms of national framework indicators. In the north, large production potential from Burkina Faso could represent an additional future opportunity for regional cooperation for green hydrogen production. In the context of this analysis, two more specific areas were selected for the modelling of currently feasible use cases. The areas were selected based on the location of production potential, the presence of groundwater resources or access to seawater, the existence of power transmission lines, as well as the presence of a major port for potential export.

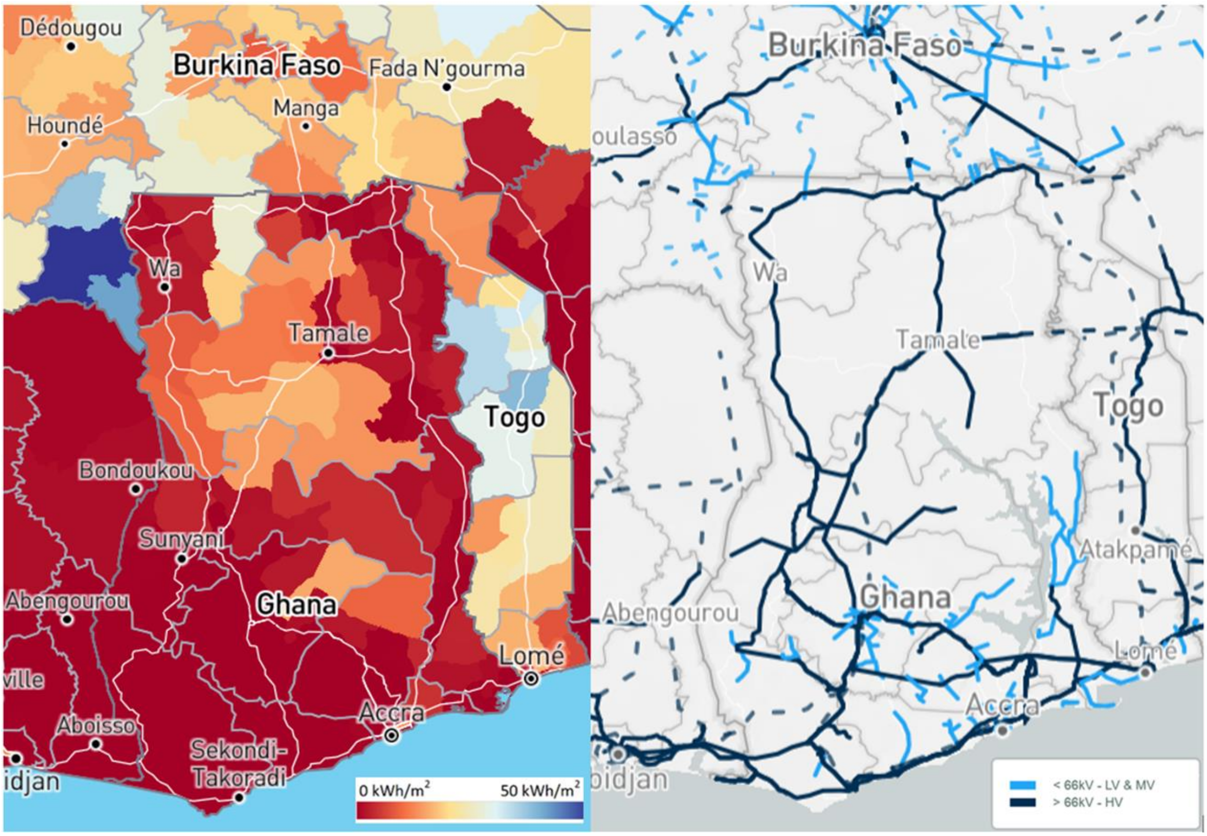

Figure 10 - Green hydrogen production potential per unit of area [1] (left panel) and power grid with existing and planned (dashed lines) transmission lines [2] (right panel)

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Fig. 10 provides on overview of the region of under consideration in terms of green hydrogen production potential and power grid infrastructure existing and planned infrastructure. A first area of approx. 60,000 km^2, which includes most of Togo and some regions of Ghana, was selected. The entire area is interconnected both through roads and power grid, and includes Accra and Lomé, as well as the port of Tema, which is located just to the east of Accra. With respect to Ghana, the area includes two large hydrogen regions[5] with good production potential (Sekyere East and Afram Plains in [17]). Regarding Togo, only the areas belonging to the Savanes Region (in the North) and the maritime areas east of Lomé were excluded. According to the estimate of [17], the selected area has a total maximum potential of approx. 1200 TWh of green hydrogen per year, most of which would be produced by RES located in Togo. A significant share of green hydrogen potential could be realized using on-site groundwater resources, especially in the major Ghanian production regions and in northernmost parts of the Togolese area (i.e., Bassar hydrogen region in [17]). In this regard, H2 Atlas provides an estimate of the share of production potential realizable by means of local groundwater resources.

A second potential use case was identified in Northern Ghana, in the hydrogen regions west and south of Tamale. The area of approx. 34,000 km^2 includes most of the Savannah Region and a small part of the Northern Region. The total estimated green hydrogen potential amounts to approx. 500 TWh, and approx. 70% of such a potential may be realized thanks to sustainable groundwater resources [17]. In contrast to the first use case, this region is more remote and less interconnected in terms of power grid, yet it is connected through major roads to the Accra-Tema area and has better groundwater resources allowing for on-site H2 (or derivatives) production.

Current installed capacity of RES in the first use case include:

- Akosombo hydroelectric power plant in Ghana (1020 MW) [18]
- Kpong hydroelectric power plant in Ghana (160 MW) [19]
- Nangbeto hydroelectric power plant in Togo (65.6 MW) [20]
- Blitta solar PV park in Togo, which was commissioned in 2021 (50 MW) [21]

Regarding the second use case, major RES capacity consists only of the Bui hydroelectric power plant (404 MW) [22], which is located on the southern border of the selected area. All in all, according to the last available data from IRENA for 2021, less the 8 TWh of electricity were generated in Ghana and Togo taken as a whole [23]. Major investments in additional RES capacity are needed, in order to generate a significant renewable electricity surplus for hydrogen production. Renewable electricity may also be fed into the grid in order to satisfy local demand and to increase energy access: in this regard considerable socioeconomic impacts can be expected particularly in Togo, as discussed in deliverable D1.2. In the first

[5] With "hydrogen region" we refer to the spatial units within the H2 Atlas, which do not necessarily reflect current administrative regions.

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use case, in the case of surpluses, electricity may finally be transported to coastal regions for producing hydrogen (or derivatives) by means of desalinated seawater. On the other hand, hydrogen (and derivatives) directly produced in interior regions: firstly, can meet local demand (e.g., in terms of power storage); secondly, can be transported to industrial hubs to satisfy domestic industrial demand; thirdly, can be transported to the Tema port for export.
As matter of fact, the main industrial hub in the region is in the Accra-Tema area, where also most of the domestic hydrogen-related industrial demand is located [24]. Industrial demand for hydrogen and derivatives currently consists of hydrogen used in refineries and in the food industry, ammonia in the fertilizer industry and methanol mostly used as a fuel [24]. The volumes of H2 imports are only 2.2 tons per year, whereas in the case of ammonia and especially methanol annual imports are more significant, at approx. 100 tons and 2000 tons, respectively [9]. While e-methanol represents a very relevant application, its more complex process of production (due to the need of carbon capture) implies a longer time horizon. In the case of Ghana, an application of green hydrogen with a very large potential in the short-term is represented by the production of fertilizers via ammonia. As in many other countries in the region, Ghana is heavily reliant on imports of fertilizers and was strongly affected by the recent hike in fertilizers prices [25]. Moreover, many countries in the region including Ghana and Togo underuse fertilizers: increasing fertilizers use could boost agricultural yields, while reducing long-term depletion soil's nutrients and the need for land for agricultural use [26].

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4 CENTRAL/EASTERN AFRICA – KENYA USE CASE

As presented in D1.2, the East African region has an abundance of renewable energy potential in wind, hydro, solar and geothermal power. However, most of these resources are yet to be exploited. Africa only contributes to less than 3% of the world's renewable energy capacity for electricity generation (IRENA, 2021). As of 2021, East Africa had a total installed electricity generation capacity of 11.5GW from renewable energies. Figure 11 - East Africa's Infographic on Renewable Energy

Figure 11 shows the inforgraphics on East Afica's renewable energy status and potential for increase.

Figure 11 - East Africa's Infographic on Renewable Energy

60% of the land area in Uganda, 68% in Kenya and 70% in Tanzania exhibit good potential for hydropower (Lecaros et al., 2019). This is attributed by the presence of lakes such as the Lake Turkana, Lake Victoria, Lake Kivu, Lake Malawi, the Great Rift Valley and the Nile Basin. Ethiopia is ranked 1st when it comes to highest installed capacity of hydropower, Uganda - 13th, Kenya - 15th, Tanzania - 17th, Rwanda - 28th and Burundi - 36th (IHA,*2020*).

In 2019, wind only accounted for 1.2% of Africa's energy source for electricity generation. However, this changed between 2010-2020 where the installed wind capacity grew to 28% on the continent. The East African region has average wind speeds of 5.5 meters per second and goes up to 8 meters per second in Ethiopia, Kenya and Somalia. The 310MW Lake Turkana wind plant in Kenya commissioned in 2018 is one of the largest renewable energy projects in the region that contribute to 95% of the generation capacity from wind on the continent.

Although countries in the East Africa are primarily dependent on hydroelectric power, there is also a significant, largely untapped potential for geothermal energy along the Great Rift Valley. According to (BGR, 2016) there is an untapped capacity of about 15 GW in geothermal power that is yet to be used for electricity generation. Kenya and Ethiopia are the

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two main African countries exploring geothermal power with Kenya having an effective capacity of 850MW as of 2023 while Ethiopia has a state-run project of 7.5MW.

More than 80% of the electricity in counties the Djibouti, Eritrea, Somalia, and South Sudan is produced from oil, while other East African nations continue to rely mostly on fossil fuels, namely oil and its derivatives.

Annual solar irradiation averages about 2,100 KWh per square meter (IRENA, 2022) in East Africa. Figure 12 how the top 5 countries each account to the regional energy supply.

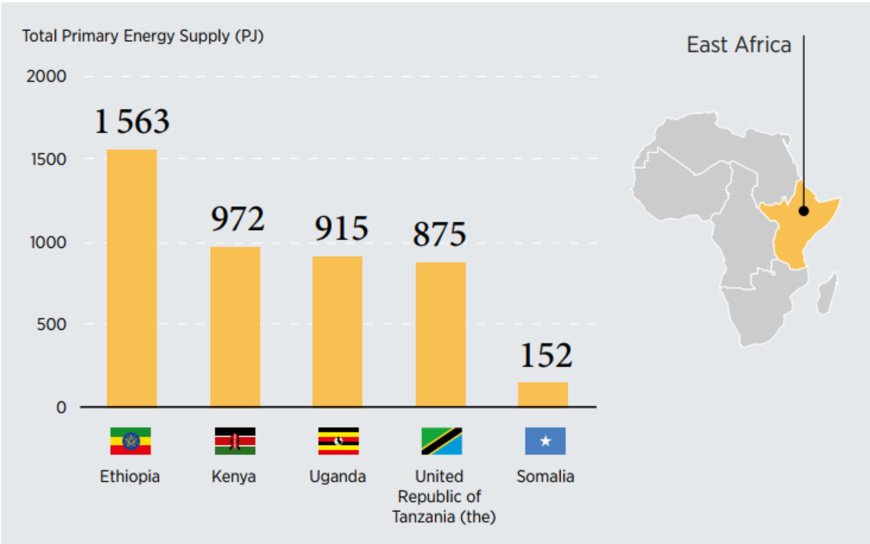

Figure 12 - Total Primary Energy Supply as of 2018, (Source: IRENA, 2022)

4.1 Kenya Case

Kenya's energy generation mix is currently at 82.6% sourced from renewable energy sources (*LCPD 2021*). The development of its renewable energy sources that include geothermal, wind, solar, biomass and hydro is the country's government priority in achieving its Vision 2030 goals of creating a reliable, adequate and cost effective energy supply pathway for the support of industrialization and economic growth. Figure 13 - Kenya's Energy Generation MixFigure 13 illustrates the country's energy mix. In the next sub-paragraphs, following information presented in D1.2, some aspects that have been analysed to identify the most relevant use cases to be then modelled in WP2 are presented and that assessed Kenyan hydrogen production and demand potential as well as water access and infrastructure availability.

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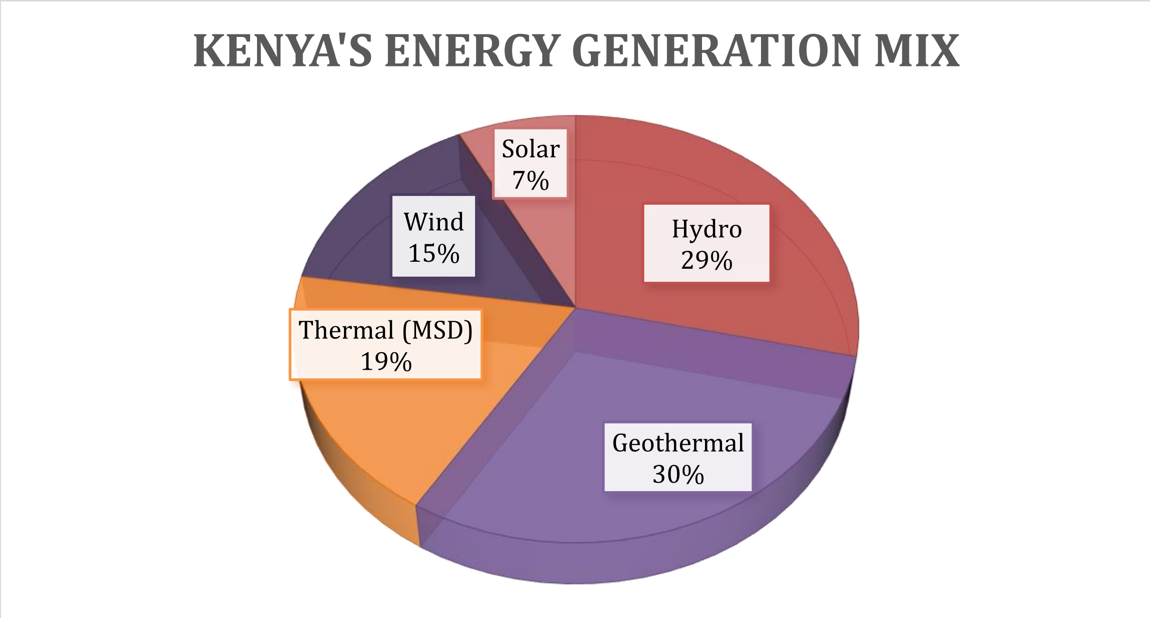

Figure 13 - Kenya's Energy Generation Mix

4.1.1 Geothermal energy

As also presented during JUST GREEN AFRH2ICA stakeholders workshop in Nairobi in February 2024, geothermal is the country's largest energy source for electricity production with an installed capacity of 940MW – approx. 30% of the country's total generation. Geothermal exploration in Kenya began in 1952 with the first unit of 15MW being commissioned for electricity generation in June 1981. The second unit was commissioned a year later and the generation capacity of the country has been increasing over the years. Olkaria 1 and Olkaria V have the largest installed capacity of geothermal capacity at 150MW and 172MW respectively. These are amongst the 19 geothermal power plants – that have a total installed capacity of approx 900MW - run by KENGEN which are situated in the Olkaria fields (that have been visited by the JUST GREEN AFRH2ICA consortium and CHP JU delegation in February 2024) and Eburru Hill (2.3MW) along the Great Rift Valley. The other field where geothermal power is currently being harnessed is in Menegai with a capacity of 35MW. Other sites are being explored in the country for mid and long-term geothermal exploration like in Suswa and Longonot area. Kenya, which is ranked the top geothermal producing in Africa and eight globally, uses geothermal to provide its base (continuous) load due to its low short-run marginal costs (*LCPD, 2021*). Figure 14 shows the geothermal sites

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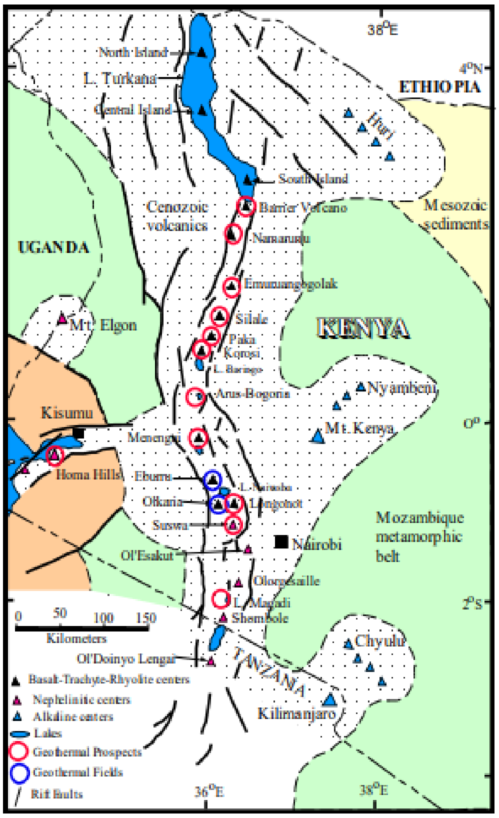
in the country. Studies have revealed that the country has an estimated potential of 4,000MW of geothermal energy (Simiyu, 2009). Most geothermal plants run on the single flash steam technology and the binary steam cycle technology. Despite being a dispatchable renewable energy sources, as reported by KENGEN during the visit by the consortium, it is relevant to mention that during the night (when the overall National Grid electricity demand decreases), Olkaria Geothermal units are often obliged to flash the geothermal steam and not produce electric power. In this sense the possibility of exploiting power-to-X solutions, seem to be strategic and relevant to avoid any renewable energy loss.

Interestingly, approximately 10% of Kenya's total available geothermal energy—equivalent to around 400 GWh out of the annual 4,000 GWh—remains untapped. This surplus capacity exceeds actual demand, particularly during the night when non-dispatchable renewable energy plants operate on a take or pay agreement. This scenario highlights a significant opportunity for utilizing excess geothermal energy to power electrolysis for green hydrogen production.



Rift Region (MW)	Potential
Central Rift	
Menengai	1,600MW
Eburru	250MW
	1,850MW
South Rift	
Olkaria	2,000MW
Longonot	750MW
Suswa	600MW
Lake Magadi	100MW
	3,450MW
North Rift	
Lake Baringo	200MW
Korosi	450MW
Paka	500MW
Silali	1,200MW
Emuruangogolak	650MW
Namarunu	400MW
Barrier	450MW
Arus Bogoria	400MW
	4,250MW
Nyanza	
Homa Hills	100MW
Akira	350MW

Figure 14 - Location of Geothermal Projects in Kenya (Source: LCPDP, 2021)

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4.1.2 Wind energy

Kenya currently has an installed wind capacity of 435.5 MW (LCP, 2021). According to Kenya's regulator, the Energy and Petroleum Regulatory Authority (EPRA), 73% of the country experiences favorable wind speeds of about 6 m/s with 4% of the country's land area experiencing wind speeds of 7.5 – 8.5 m/s and less than 1% experiencing wind speeds of between 8.5 – 9.5 m/s.

The largest wind farm in the country is the 310 MW Lake Turkana wind power farm (LTWP) that contributes approximately 17% of the country's installed capacity. The farm has 365 turbines each of 850 kW and is connected to the national grid through a 438km transmission line. The other wind farms are Ngong (25.5MW) and Kipeto Wind farm (100MW). The best wind sites are in the Northern side of the country covering Marsabit and Samburu counties which have average wind speeds of between 11-12.5 m/s while other potential sites for wind power farms include Meru, Nyeri, Kajiado and Nyandarua counties. There are 3 projects totally to 140MW in Kajiado and Meru counties that are currently under development set to be commissioned in 2024.

A study conducted in 2013 indicates that Kenya has a technical potential for wind power development of about 4,600MW (*LCPD, 2021*).

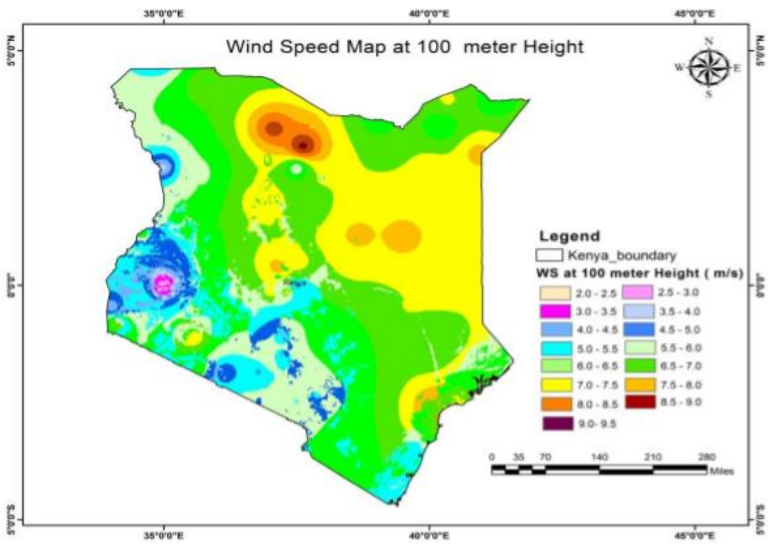

Figure 15 - Wind speed map of Kenya (Source: EPRA)

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4.1.3 Solar energy

Due to its unique location on the equator, Kenya experiences high solar irradiation rates with average sun peak sun hours of 5-7 hours and daily insolation of 4-6kWh/m2 (LCPD,2021). This means that solar energy systems in Kenya relatively experience consistent performance throughout the year, enhancing their reliability and efficiency compared to countries slightly further away from the equator. According to the Global Solar Atlas, Kenya's annual solar irradiation is about 2,261kwh/m^2 making it favorable for large scale and decentralized energy systems.

As of 2018, the solar PV installed capacity was 93MWp with the largest utility scale project being Garissa solar with 55MW installed capacity. According to EPRA, the government has approved EoIs of more than 35 projects with 6 projects currently under construction under the Feed-In Tariff. Despite the favorable conditions to harness energy from solar, Kenya has only tapped into a very small portion of the solar energy. Solar energy contributes to less than 10% of the country's energy mix. It is estimated that Kenya has a solar potential of about 15000MW.

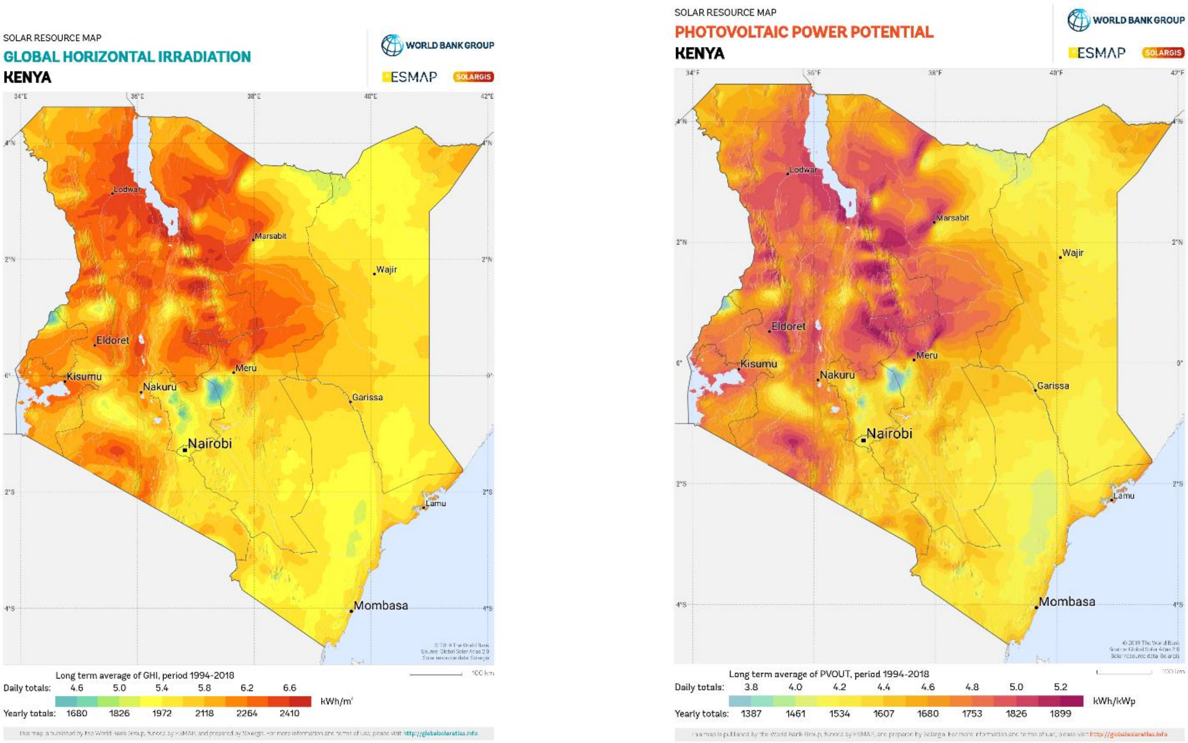

Figure 16 - Horizontal irradiation and PV Power Potential for Kenya (Source: Global Solar Atlas)

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4.1.4 Hydropower

Hydropower was first explored in the early 1920s with the early systems being small hydropower plants which included micro and mini hydro plants. The first of these power stations to be commissioned was the 1MW Ndula Power Station on Thika River in 1924. Kindaruma hydropower station was the first large scale project to be commissioned in 1968 with an installed capacity of 72MW.

According to the LCPDP report, Kenya has an installed hydropower capacity of 838 MW with Gitaru Hydroelectric Power Station, having the highest installed capacity of 225MW. It was commissioned in 1978 and has generated 4,710 GWh of electricity. Gitaru station is amongst the 10 hydropower plants run by KENGEN that include small hydro power plants totally to 98% of the installed hydropower plants. The rest of the plants are run by Independent Power Producers. Combined, these hydropower plants contribute to about 30% of the country's electricity generation.

Kenya's hydropower potential is estimated to be between 3,000-6,000MW. This is the potential energy available in the water bodies that can be harnessed to produce power. However, the undeveloped hydroelectric power potential is estimated at 1,484MW with 84% of it being dedicated to projects above 30MW. This potential is spread out in 5 main geographical regions which include Athi River basin (60MW), Tana River basin (790MW), Rift Valley basin (305MW) and Lake Victoria basin (329MW) (*LCPD, 2021*).

4.1.5 Potential hydrogen off-takers

Development of green hydrogen and its derivatives in Kenya is key driver to the country's energy transition. Through the Green Hydrogen Strategy and Roadmap, the approach of its development can place the country as a regional leader in keeping to the objective of the Paris Agreement, the Africa Agenda 2063, the sustainable development goals and Kenya's vision 2030.

However, to achieve commercial viability of a green hydrogen economy it is imperative that to identify early off-takers who have the willingness and ability to pay for green hydrogen

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and derivatives so as to drive market demand. Kenya has a unique and advantageous starting point as the country producing green hydrogen from clean and sustainable energy sources – geothermal energy, which is abundant. This presents an opportunity to drive economic growth, create socio-economic impact across the country and tackle effects of climate change despite the low emission factor of Kenya.

Green hydrogen has the potential to be applied across various sectors in Kenya such as agriculture, manufacturing, industry, transport and power. The industry sector – which includes manufacturing and transport- contributes to 18% of the country's GDP while the agriculture contributes to over 20% of the GDP. These two sectors have an impact in improving livelihoods, creating job opportunities and contributing to the domestic needs. Figure 17 illustrates the potential use cases of hydrogen in Kenya.

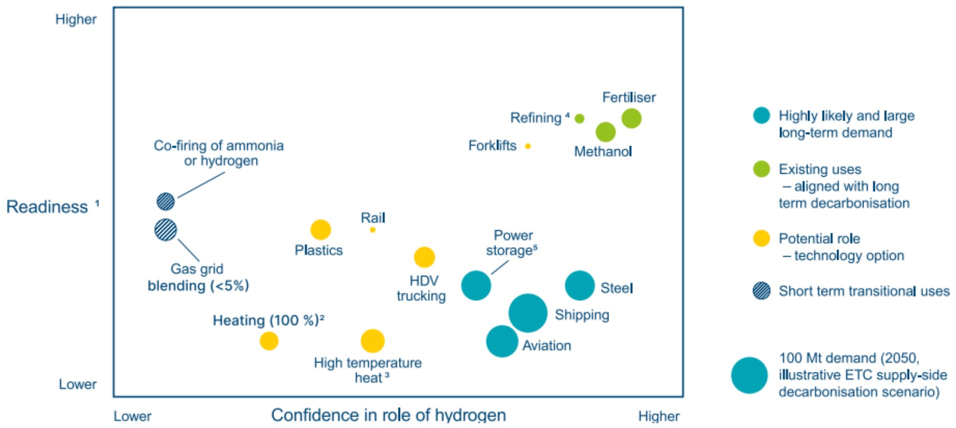

Figure 17 - Potential Use Cases for Hydrogen in Kenya (Source: GH2 Kenyan Strategy)

Table 3 is a summary of the key industrial pathways to drive the use of green hydrogen as outlined in the Baseline and Sector Analysis studies performed with the support of GIZ in 2022 and 2023. The table summarizes the technical, economic and climate change mitigation potential.

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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 ongoing 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

Table 3: A summary of the recommended industrial pathways. (Source: PtX Baseline Study)

- ***Fertilizers and Agricultural sector***

Kenya's agriculture sector, which is heavily reliant on nitrogen fertilizer, imports around 600,000 to 700,000 tons of it each year. These fertilizers are traditionally made using hydrogen derived from fossil fuels, with ammonia being a key intermediate product. Unfortunately, this method is a significant contributor to global CO2 emissions, with ammonia production accounting for about 1.3% of these emissions. This situation has led to

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a concerted effort to move towards more sustainable practices, specifically through decarbonization.

The Kenya Green Hydrogen Strategy suggests that shifting to the production of green ammonia could require an investment of around $1.5 to $2 billion. This cost would encompass the full production cycle, including the power generation required to produce between 170,000 and 280,000 tons of green ammonia annually. By making this change, Kenya could potentially satisfy its nitrogen fertilizer requirements domestically, reducing its reliance on imports. Achieving this goal would necessitate an electrolyzer capacity of 350 to 450 MW, supported by a renewable energy generation capacity of 600 MW to 100 MW. Such a move would not only address environmental concerns but also contribute to the achievement of global sustainable development goals.

Talus Renewables, a US startup company, has been the first company to design and build a commercial modular green ammonia and fertilizer production plant in the world and in Africa. The small fertilizer plant, which sits on 3 acres of land, is based at the Kenya Nut Company in Naivasha and is set to produce 330 t of green ammonia annually. The plant uses an alkaline electrolyser that is powered by a 2MW solar farm that is aimed at lowering the cost of fertilizer by 30-60% and secure local supply, carbon-free. Through a 15 year off-take agreement, Talus will supply Kenya Nut company, who grow a variety of crops including macadamia, cashew nuts, coffee, chocolates and oils, with fertilizer. The plant is set to expand in future from currently producing one ton of fertilizer a day to 200 t per day.

Figure 18 - The ammonia plant at Kenya Nut (Source: Talus Renewables)

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KenGen, the country's key energy producer, has embarked on conducting a feasibility to assess the technical, financial, economic, environmental and social viability of setting up a green ammonia production demonstration facility. The results from the study will influence the design of a 5MW green hydrogen demonstration plant and fertilizer production facility in Olkaria (to exploit particularly above mentioned excess of geothermal power production usually not exploited during the night period), that could possibly be scaled up to a commercial plant of 100MW. The facility will utilize geothermal as the main energy source. This plant is set to be completed in 2025 (*MoEP, 2023*). Ammonia, a derivative of hydrogen, holds significance not only in agricultural fertilizer production but also in various industrial applications, such as chemical products, explosives, and synthetic fiber manufacturing.

Fortescue Fortune Industries (FFI), a global Australian energy firm is set to develop a 300MW green ammonia and fertilizer production facility in Naivasha. This is part of the Investment Support and Implementation Agreement signed between FFI and the Government of Kenya. The project aims to supply affordable fertilizer to meet Kenya's local demand with the possibility of export, while also supporting the transition from fossil fuel for fertilizer production, a significant contributor to GHG emissions. The project is set to completed in 2025/26 (GeoEnergy, 2023).

These are amongst the strategic investment actions that align with Kenya's goal to reduce its reliance on imported fertilizers, a vulnerability that has subjected the country to fluctuations in global commodity prices. The substantial investment in domestic fertilizer production, estimated at an annual average of $290 million for the past five years, holds tremendous promise. It is poised to enhance food security, reduce import costs, and bolster the agricultural sector. The country's vast geothermal potential, capable of producing up to 1.5 Mt of green hydrogen, equivalent to 8 Mt of ammonia annually, positions Kenya favorably for self-sufficiency in fertilizer production and spurring growth in value-added industrial and manufacturing sectors.

- ***Methanol Production and chemical sector***

Kenya's current dependence on importing about 5,000 t of methanol annually, mainly from Saudi Arabia and Egypt, could see a transformative shift with the potential for domestic production of green methanol. This eco-friendly fuel, which is gaining popularity especially

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for commercial transportation, is produced using hydrogen and is integral in the manufacture of chemicals like formaldehyde, acetic acid, and various polymers.

By transitioning to local production, Kenya could significantly revamp its industrial sector within the chemical industry. Producing green methanol domestically would require generating around 1,000 tonnes of hydrogen per year. To achieve this, an electrolyzer of 10-15 MW capacity would be necessary, supported by 15-20 MW of renewable energy sources. This move, while environmentally beneficial, also presents substantial economic opportunities for the country. The total investment needed for establishing the entire production and power generation chain is estimated to be between USD 35-40 million. This development, as outlined in a 2023 report by the Ministry of Energy and GIZ, represents a strategic shift in Kenya's approach to its chemical industry and energy needs.

- ***Transport Sector***

Green hydrogen, beyond its use in green ammonia and methanol production, has significant potential in revolutionizing Kenya's transportation sector. This includes its application in fuel cell vehicles, such as trucks and forklifts, for both road transport and aviation, offering a cleaner alternative to traditional fossil fuels. However, transitioning to a hydrogen-based transport sector involves more than just the availability of green hydrogen; it requires a dedicated transport infrastructure, capital investment, and the development of a reliable market.

- ***Natural Gas replacement in combustion and other purposes***

Though the demand of natural gas is currently not high in East Africa, it is set to change due to the developments coming up in Mozambique and Tanzania. Tanzania has been exploring natural gas for the past 50 years with its first commercialization done on the Songo Songo Island in 2004. The country has drilled about 67 wells between 1952 and 2013 for both exploration and development with 53 wells being in onshore basins and 12 in offshore basins. The gas from these wells are mostly used for domestic consumption whose demand has been increasing annually from 5.2 billion cubic feet in 2006 to 110 billion cubic feet in 2017 (Tanzania Embassy, 2021). In 2023, Tanzania pitched for a further exploration of 26 sites, both onshore and offshore that is estimated to cost $42 billion (The East African, 2023).

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This will be the country's first licensing round since 2013 once the final investment design is made 2028.

In Kenya, natural gas, valued for its environmental advantages and cost-effectiveness, is gaining attention for power generation. However, its supply is constrained by transportation infrastructure, primarily pipelines and liquefied natural gas (LNG) logistics. LNG, involving liquefaction at the source, shipment, and re-gasification at the destination, forms a significant part of its overall cost. Despite these challenges, Kenya sees potential in developing domestic natural gas resources or using LNG as an alternative, diversifying its power generation sources. The exploration and potential use of LNG align with environmental benefits and offer economic advantages across various sectors, including industrial, household, and transport.

4.1.6 Water sources assessment

90% of Kenya's total annual renewable supply comes from 5 basins which include the Rift Valley Basin, the Ewaso Ng'iro North Basin, the Tana Basin, the Lake Victoria (North and South) Basin, and the Athi Basin. The Lake Victoria Basin is the most productive basin accounting for 59% of the surface water and 54% of the total renewable freshwater in Kenya. 75% of the surface water, which includes freshwater bodies that are sent into wetlands, stream systems and lakes, is as a result of the rainfall runoff from the five 'water towers' in central and western Kenya (*Winrock,2021,*). The Rift Valley Basin, an enclosed drainage area without any external outflows, originates from the Mau Forest Complex. It constitutes to 14% of Kenya's surface water. This basin encompasses Lake Turkana, the largest permanent desert lake globally, and includes a variety of lakes such as Baringo, Naivasha, and Magadi, which vary in water type from fresh to brackish to saline.

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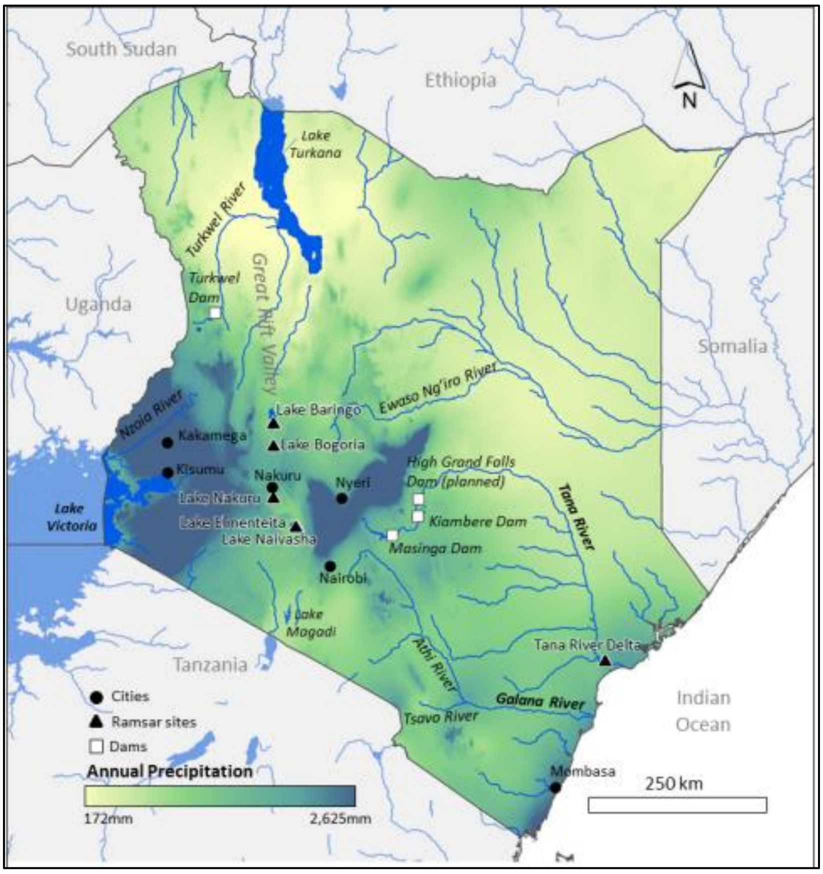

Figure 19 - Map of Kenya's Water Resources (Source: Kenya Country Profile)

The Rift Valley basin has lakes that would be highly considered for the planning and development of hydrogen project. According to the Technical Assistance Facility (TAF) Team that helped to develop the Green Hydrogen Strategy for Kenya, 0.1% of Lake Naivasha's freshwater could produce some 70,000 tonnes of hydrogen per year equivalent to some 500 MW installed electrolyser capacity.

Renewable groundwater sources, like boreholes make up for less than 12% of the Kenya's total renewable supply. In Turkana County, a region often affected by drought, the salinity levels in shallow groundwater sources are consistently high. However, recent research has discovered vast deep aquifer systems in the area, with an estimated volume of about 250,000 million cubic meters (MCM). Preliminary tests suggest that these deep aquifers possess naturally elevated salinity levels, which could make the water unsuitable for agricultural and household purposes.

Kenya's most productive aquifers are typically found in the confined volcanic rock formations beneath the Rift Valley and Nairobi, as well as in the unconfined sedimentary formations in

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the Athi and Tana regions (Winrock,2021.). The aquifers located in the Lake Victoria Basin are less productive because of their small size. Nonetheless, they benefit from high recharge rates, estimated at around 30%. Table 4 below shows some of the largest and common lakes in the country

Table 4: List of Lakes in Kenya

Lake	Water Type	Basin
Lake Victoria	Freshwater	Lake Victoria
Lake Naivasha	Freshwater	Rift Valley
Lake Baringo	Freshwater	Rift Valley
Lake Ellis (Mt. Kenya)	Freshwater	Tana River
Lake Bogoria	Saltwater	Rift Valley
Lake Turkana	Saltwater	Rift Valley
Lake Elementaita	Saltwater	Rift Valley
Lake.Magadi	Saltwater	Rift Valley
Lake Nakuru	Saltwater	Rift Valley

As mentioned, Kenya enjoys abundant water resources from rivers, lakes, aquifers, and access to seawater along its coastline. Rivers such as Tana, Athi, Ewaso Ng'iro traverse different regions feeding and joining streams from Lake Victoria, Turkana and Naivasha. Underground, the country has aquifers which act as reserves during the dry seasons. The coast offers further strategic advantage by providing access to seawater (*MWS,2018*).

The Ministry of Water, Sanitation, and Irrigation, governed by the Water Act 2016, plays a pivotal role in overseeing and managing the nation's water resources. For green hydrogen production, the ministry is responsible for allocating water usage rights ensuring sustainable water for supply for the electrolysis process of green hydrogen production. The National Water Policy 2021 supports access to water for economic uses, including industrial electrolysis. The policy is a tool to foster economic growth in industries requiring water-intensive processes while ensuring compliance with water usage guidelines and regulations.

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However, climate-induced issues, such as droughts and flooding, pose challenges to consistent water supply. Kenya has faced recurrent extreme weather events especially in arid and semi-arid regions putting stress on available water resources (NDMA, 2023) Conversely, the country also struggles with flooding especially in the flat and coastal areas.

According to the Winrock 2018 report, Kenya is experiencing acute water scarcity. A significant portion (33%) of its total freshwater reserves is being consumed by key economic sectors – agriculture, industry. Additionally, the availability of renewable water per individual is alarmingly low at 617 cubic meters annually, which is far below the threshold of 1,000 cubic meters for water scarcity as defined by the Falkenmark Water Stress Index. This situation indicates a critical shortage of water resources.

Kenya, known for its climatic diversity, witnesses a wide array of rainfall patterns, with some areas receiving heavy rainfall during specific seasons while others grapple with sporadic and often limited rainfall throughout the year. The country's annual precipitation is typically 680-700mm with the western region receiving over 2,000mm of precipitation annually and less than 250mm in the northern ASALS (World Bank Group, 2021). The coastal areas, for instance experience the long rain season from April to June, which average precipitation of 200mm with May being the wettest month. The short rain seasons are in January and February (12.5mm) and in March and December (35mm).

These diverse rainfall patterns create a significant impact on water availability, which holds substantial ramifications for green hydrogen production initiatives in the country. Areas reliant on consistent water sources for hydrogen production, such as those with geothermal energy production sites like the Kenyan Rift Valley, face heightened challenges during prolonged dry spells. However, according to the Long Rains National report by the Ministry of East African Community, Arid and Semi-Arid Lands and Regional Development, cumulative rainfall amounts were nearly average in 2023 recording between 75%-125% of the long-term average in the northern and southern Rift Valley. Naivasha experiences annual mean precipitations of 656.mm with the highest precipitation being 917.2mm and the lowest being 336mm(Ayugi et al., 2016) . Studies that have been conducted to measure the changing rainfall patterns during the peak seasons of March, April and May in Rift Valley

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indicate that the precipitation has increased steadily by 18mm between 1976 and 2005. It was noted that though the precipitation increased, the number of rainfall days reduced.
The Water Resources Authority (WRA), responsible for managing and regulating water resources reports that the irregular rainfall exacerbates the strain on water resources in these regions. This could affect the availability of water essential for electrolysis processes used in green hydrogen production. Regions experiencing extended dry spells witness diminished water reserves, which could directly impact hydrogen production capacities. Moreover, Kenya's National Drought Management Authority (NDMA) highlights that the recurrence of droughts intensifies the competition for water resources, thereby impeding the steady supply required for green hydrogen production facilities. This unpredictability in water availability creates vulnerabilities for Kenya's ambitions in green hydrogen, especially in areas where water scarcity hampers consistent production capacities.
Understanding these intricate rainfall patterns and their implications on water resources becomes pivotal for strategizing green hydrogen production in Kenya.

4.1.7 Infrastructure to be valorised for hydrogen export

the lack of infrastructure for large-scale storage and transportation of green hydrogen is one of the major challenge particularly looking at potential export purposes of the green hydrogen production. One potential avenue to address this shortfall lies in repurposing closed refineries, which could serve as viable sites for the establishment of infrastructure dedicated to hydrogen-related purposes. The absence of gas infrastructure in Kenya has underscored the importance of repurposing such closed facilities to meet the growing demand for storage and transportation infrastructure in the green hydrogen sector.

The realization of Kenya’s green hydrogen export ambition hinges on critical investment considerations. Factors such as operating and capital expenditure, electricity costs, and infrastructure development play pivotal roles in determining the viability and success of these facilities. The integration of renewable energy sources into the production process is crucial as well to ensure the hydrogen produced meets the standards of the importing

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countries. In February 2023, the European Commission adopted two delegated acts under the Renewable Energy directive that will ensure that all renewable fuels of non-biological origin (RFNBOs) are produced from renewable energy, which includes green (renewable) hydrogen. The first delegated act ensures that the electrolysers used to produce the hydrogen, that will be intended for export to the EU countries, is connected to new or additional renewable energy sources. This will ensure that the production of hydrogen doesn't affect or divert away existing electricity demand from the grid thus supporting decarbonization while complementing electrification efforts. The second delegated act provides a methodology for calculating the life-cycle greenhouse gas emissions saved across the full lifecycle of the hydrogen and its associated fuels. The act states that the emissions saved must be more than 70% for the green hydrogen to be considered green, according to EU standards (European Commission, 2023).

4.1.8 Stakeholders at local level

Within the public, private, civil and academic institutions, cohesive efforts are being realized for Kenya's in achieving a sustainable energy future. International developers are also closely involved in driving innovation, policy and investment into green hydrogen production. This collaborative ecosystem facilitates knowledge sharing, technological advancement as well as strategic actions to create a conducive environment for green hydrogen adoption. It is through such partnerships that Kenya is able to handle the challenges that come with implementing hydrogen technology as well as creating paths towards a more resilient and low-carbon economy.

Below a categorized list of the stakeholders involved in Kenya's green hydrogen sector is presented (some of them participated during February 2024 workshops and events organized by JUST GREEN AFRH2ICA consortium in Nairobi).

Private Sector Players:

1. SOWITEC Kenya – is developing grid scale solar and wind projects throughout the country, currently they are venturing into the local production of clean methanol.
2. Toyota Tsusho Corporation CFAO Kenya Ltd – is contributing towards the construction of a geothermal power plant in Menengai region of Kenya as an EPC

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contractor as well as establishing green hydrogen production to meet its energy needs for various uses including trucks, forklifts, and port equipment.

3. Kenya Renewable Energy Association (KEREA) - is an umbrella body for the promotion of renewable energy in Kenya.
4. Kenya Association of Manufacturers (KAM) – is promoting the adoption of green hydrogen technology across diverse industries to enhance sustainability and innovation.
5. Electricity Sector Association of Kenya (ESAK) – is supporting Kenya's transition to 100 percent clean energy by 2030 including green hydrogen productions as a sustainable energy carrier.

Government Ministries and Bodies:

1. Ministry of Energy and Petroleum (MoEP) – develops strategies for clean energy solutions, including policies promoting green hydrogen adoption.
2. Ministry of Agriculture and Livestock Development – is working on integrating green hydrogen initiatives into sustainable agricultural practices for enhancing productivity.
3. Ministry of Investments, Trade, and Industry – plays a crucial role in creating an enabling environment to drive adoption of green hydrogen technologies in Kenya's industrial and trade sectors.
4. Ministry of Roads and Transport – is involved in implementing sustainable transport solutions, including hydrogen-powered vehicles, for cleaner mobility.
5. Ministry of Environment, Climate Change, and Forestry (MoECCF) – is leading the adoption and development policies and strategies for the implementation of green hydrogen technologies for achieving carbon neutrality and reducing greenhouse gas emissions.
6. National Treasury and Economic Planning Ministry - Oversees financial aspects and planning strategies related to green hydrogen initiatives.

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Public Sector Institutions:

1. Kenya Bureau of Standards (KEBS) – is working to ensure adherence to quality standards in hydrogen-related processes and products.
2. Kenya Electricity Generating Company PLC (KenGen) – is the leading electricity generation company in Kenya including the development, management and operation of green hydrogen power plants.
3. Kenya Power and Lighting Company (KPLC) – owns and operates most of the electricity transmissions and distribution systems, in this case they shall develop the infrastructure and mechanisms to distribute green hydrogen within the country's energy system.
4. Energy and Petroleum Regulatory Authority (EPRA) – is responsible for developing and implementing policy and regulations relevant to green hydrogen production.
5. National Environment Management Authority of Kenya (NEMA) – will play a key role in ensuring that all hydrogen production activities are safe to mitigate environmental risks.
6. Water Resources Authority (WRA) – is responsible for issues water utility rights as well as overseeing the water supply needed for electrolysis.
7. Geothermal Development Company (GDC) – is the only company issued with a license to develop and operate geothermal resources that will be used to produce green hydrogen.
8. Kenya Electricity Transmission Company Ltd (KETRACO) – will play the role of evacuating power from the generation plants to designated load areas for hydrogen production.
9. Rural Electrification and Renewable Energy Corporation (REREC) – is promoting and supporting the integration and utilization of green hydrogen as a renewable energy source for rural communities.
10. Kenya National Trading Corporation (KNTC) – operating under the ministry of trade, the company will facilitate the import and export of green hydrogen related equipment and technology.

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11. Kenya Agricultural and Livestock Research Organisation (KALRO) – operating also under the ministry of trade, the institution is providing research relevant to green hydrogen as well as exploring sustainable practices for producing green hydrogen fertilizer.
12. Fertilizer and Animal Foodstuffs Board (FAFB) – operating under the ministry of agriculture, the body oversees the quality and distribution of fertilizers in the country.
13. Agriculture and Food Authority (AFA) - also operating under the ministry of agriculture, the
    agency shall provide guidance on sustainable practices for green hydrogen fertilizer.
14. Kenya Civil Aviation Authority (KCAA) – operating under the ministry of roads and transport, the body will play a crucial role in developing regulation and guidelines for green hydrogen in the aviation and automotive sector.

Associations and Organizations:

1. Kenya Tea Development Agency (KTDA) – will play an indirect role of promoting green hydrogen technologies among smallholder tea farmers that could benefit from the green hydrogen fertilizer.
2. Kenya Private Sector Alliance (KEPSA) – as the umbrella body for the private sector has established a working group on the development and promotion of the green hydrogen sector.
3. Kenya Association of Manufacturers (KAM) – represents the interest of local manufacturers
   in the green hydrogen sector.
4. Kenya Renewable Energy Association (KEREA) – advocates, supports and represents the interest related to green hydrogen across various sectors and industries.
5. Electricity Sector Association of Kenya (ESAK) – holds dear the interest of stakeholders in the electricity sector including independent power producers, project developers, consultants, contractors, and civil society in the electricity sector.

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International Companies and project developers:

1. HDF Energy
2. MET Development S.p.A
3. Westgass Hydrogen
4. SOWITEC Kenya
5. Fortescue Future Industries (FFI)

Academia:

1. Jomo Kenyatta University of Agriculture and Technology
2. Kenyatta University
3. Strathmore University
4. Machakos University
5. Technical University of Kenya

Development finance institutions:

1. European Investment Bank (EIB)
2. Agence Française de Développement (AfD)
3. Kreditanstalt für Wiederaufbau (KfW)
4. Japan International Cooperation Agency (JICA)
5. Foreign, Commonwealth & Development Office (FCDO)
6. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)

4.2 Identified and proposed Use Cases

According to all above mentioned aspects and targeting a perfect matching of excellent spots in terms of renewable energy potential/green hydrogen production and local hydrogen demand , Kenya's ambitious plans for local hydrogen exploration encompasses establishing key production hubs across strategic locations like Mombasa – Nairobi connection areas, Olkaria, and Nairobi Capital city district. Furthermore, the potential exploitation of existing renewable power plants (like Olkaria geothermal power plant and other large PV production plants like the 50 MW Garissa PV Plant) was considered as well.

This preliminary analysis, brought to the identification (for Madrid M5 General Assembly) of five potential locations as reported in the figure 20.

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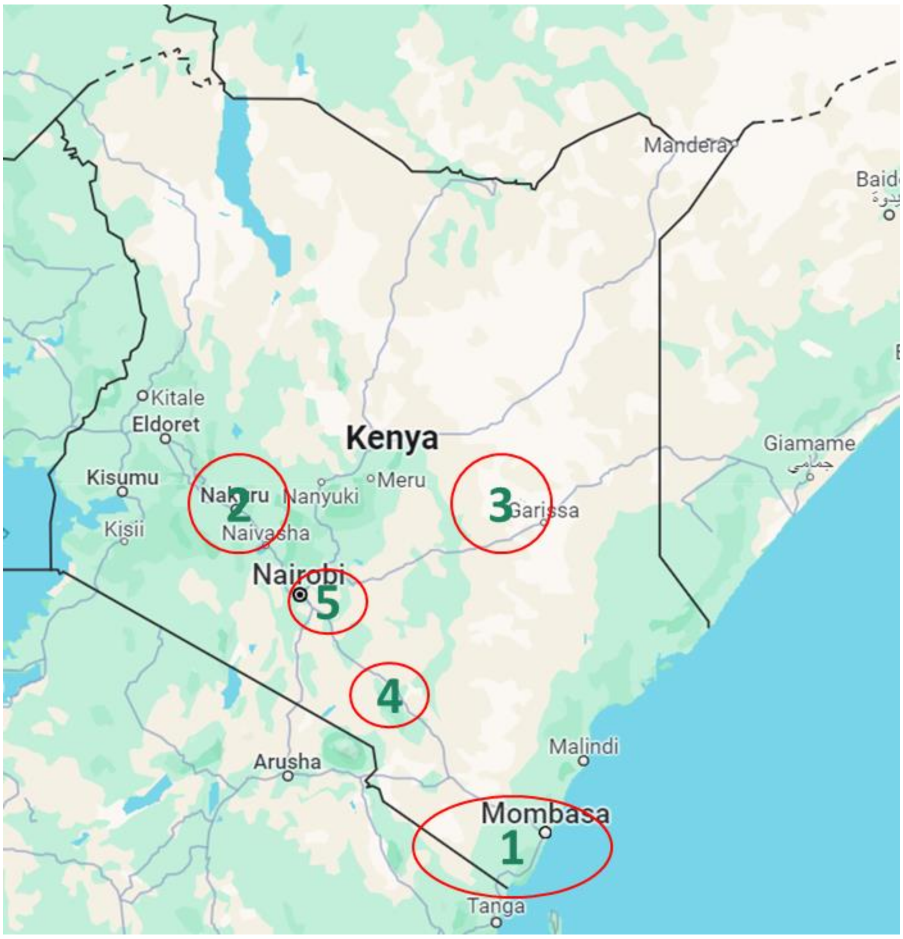

Figure 20 – Five preliminarily identified use cases

1 Mombasa and Tanzania Borders Area: also to exploit local renewable power production exchange between the two countries as well as the local industrial demand and port infrastructure around Mombasa port

2 Rift Valley/Olkaria Geothermal Area: where to exploit above mentioned geothermal power plant surplus despite a low local H_2 demand, except for agricultural purposes

3 Garissa Solar Power Plant Area: in order to valorise the local solar power production also looking at a potential PV plant expansion. A critical challenge here is for sure the lack of relevant water sources, lack of local civil and energy infrastructure as well as the political instability risk of the area.

4 Industrial area between Nairobi and Mombasa: in order to take advantage of existing railway and road infrastructure to facilitate hydrogen logistics as well as of local potential hydrogen off-takers

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5 Nairobi Capital city area: in order to evaluate a potential usage of hydrogen not only in the industries of the district, but also in the local transport sector. Nevertheless this area presents issues for what it concerns the health and safety management of potential large scale hydrogen production and storage plants.

Each of these areas offers unique advantages, making them prime candidates for setting up hydrogen production facilities.

All these areas were duly analysed by STRATH and they were also the topic of discussion of working groups organized during 15th February 2024 project training and stakeholders event training group in Nairobi (Fig.21)

Figure 21 – Working groups on the proposed use cases for green hydrogen production in Kenya

Thanks to the feedback collected during the February 2024 events, STRATH identified at the end three main use cases that will be the focus of WP2 modelling activities.

1) **Olkaria geothermal plant area:** situated within the Kenyan Rift Valley, stands out as a region with immense geothermal energy potential. The area's high load factor of above 90% for geothermal energy production and accessibility to a large water body like Lake Naivasha and river streams position it as a lucrative site for establishing hydrogen production facilities.
2) **Mombasa port area:** also looking at Tanzania cross-border cooperation as well as exploitation of local energy and port infrastructure to facilitate hydrogen logistics for both domestic (local relevant industrial demand) and export market. Kenya's bustling coastal city, emerges indeed as a potential hub for hydrogen production and export due to its proximity to essential transport networks and abundant water sources. As the premier port catering to the supply chain needs of Eastern Africa, Mombasa Port holds a pivotal position in facilitating trade among nations like Ethiopia, Uganda,

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South Sudan, Rwanda, Burundi, northern Tanzania, and the Democratic Republic of Congo. Its role extends beyond being the primary gateway; Mombasa is a linchpin for exports, handling various commodities like coffee, tea, and minerals. Simultaneously, it serves as a hub for imports, including vital substances like hydrogen, ammonia, methanol, and nitrogenous fertilizers. The existing infrastructure, including transport networks such as roads and railways, further bolsters Mombasa's significance as a key port for facilitating the import and export of goods, potentially including hydrogen-related products. As an added advantage the city's coastal position near seawater allows potential for electrolysis.

3) **Nairobi Capital District:** Nairobi, Kenya's vibrant capital, serves as a central node with multiple power sources and well- developed infrastructure. Its strategic positioning in close proximity to power network nodes like Suswa and significant industrial parks makes it an attractive potential location for hydrogen production facilities. The city is also the primary aviation gateway in Kenya, Jomo Kenyatta International Airport (JKIA) plays a crucial role as a regional hub for air transport. While the direct transportation of hydrogen via aircraft might present challenges due to safety and logistics concerns, the airport's role extends beyond direct shipping. It serves as a vital logistical hub where hydrogen-related technologies, equipment, and expertise may be imported or exported, facilitating the development and expansion of the hydrogen sector in the region.

It is relevant to highlight that, particularly in the near term as presented in D1.2, Kenya might not achieve cost competitiveness in exporting hydrogen derivatives to global markets for different reasons (mostly complex access to a proper transport and energy infrastructure that can facilitate. However, it has the potential to emerge as a key regional contributor also to develop a domestic green hydrogen and green fertilizer market, by building a hydrogen industry that leverages its strengths. These include its abundant resources, a growing economy with an expanding industrial and manufacturing sector, and a strategic geographical position featuring established trade routes

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5 SOUTHERN AFRICA – SOUTH AFRICA/NAMIBIA USE CASES

As presented in D1.2, South Africa could be considered as target for projects dedicated both for domestic and export markets, targeting the production of green "products" (steel, metals, cement, fertilizers…) and hydrogen and carriers to be shipped to Europe/Asia/America mostly by vessels. As done in the previous chapters, in the next paragraphs an analysis of the factors that brought to the identification of the Use cases identified as potential hotspots for green hydrogen production to be modelled in WP2 is presented.

One aspect that is relevant to be considered in South Africa is the interaction with the surrounding countries for what it concerns import/export of (renewable) electricity, something that could be valorised by South Africa and surrounding countries via Power-to-Hydrogen support.

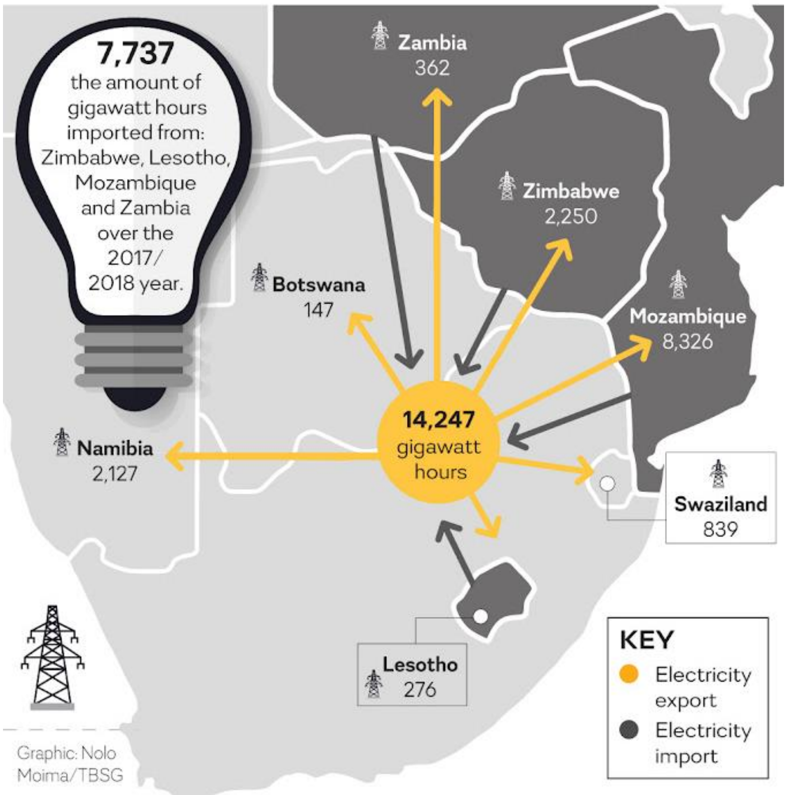

Figure 22 – Energy import/export with surrounding countries

5.1 Renewable Power plant presence and potential

In the following paragraphs an overview of existing and planned largest renewable power plants are presented in order to identify areas of major interest for green hydrogen hub installation.

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5.1.1 Wind Farms

Cookhouse Wind Farm, located near Great Fish River in South Africa's Eastern Cape province and stands as one of the country's largest wind farms. It plays a pivotal role in benefiting the nearby communities of Adelaide, Bedford, Cookhouse, and Somerset East through its socio-economic development initiatives, aimed at enhancing and empowering these local areas. Each year, the wind farm contributes over 340,000 MWh (139 MW installed capacity) of crucial green energy to South Africa's national grid, solidifying its position as one of the nation's leading wind farms in terms of generating capacity.

Brought to operation in 2014, the Jeffreys Bay wind facility, valued at R2 billion and having a capacity of 138 MW, is situated between Jeffreys Bay and Humansdorp in the Eastern Cape province. Established under the REIPPP framework, the farm is a property of Globeleq and produces 460,000 MWh annually, sufficient to electrify 100,000 homes. This is in line with a 20-year PPA inked with Eskom. With its sixty Siemens 2.3 MW turbines, the facility prevents the release of 420,000 tons of carbon annually.

Situated in the Eastern Cape province of South Africa, the Oyster Bay wind farm is a functioning facility established by Enel Green Power South Africa. With an installed capacity of 140 MW, it can generate 568 GWh of electricity annually, reducing around 590,000 tons of CO_2 emissions. The construction started in May 2019, and by July 2021, the plant was operation.

Initiated by the China Longyuan Power Group Corporation via its branch Longyuan SA, the Longyuan Mulilo De Aar 2 North Wind initiative, valued at R5 billion, is situated in the Northern Cape province. With a comprehensive capacity of 144 MW and built during the REIPPP's Third Bid Window, the farm consists of 96 turbines. Finalized in 2013, it stands as South Africa's most expansive project in terms of installed capacity.

The Roggeveld Wind Farm, located in Western Cape province, holds the distinction of being South Africa's largest wind farm in terms of installed capacity with 147 MW. In April 2018, it secured its power purchase agreement (PPA) and promptly achieved financial closure. Initially developed by G7 and subsequently acquired by Building Energy, it stands as South Africa's most efficient wind farm, offering the lowest electricity rates in the country. It began operations in March 2022, contributing vital electricity to the national grid.

5.1.2 Solar Farms

In recent years, South Africa has finished constructing several impressive solar farms, enhancing its rapidly growing renewable energy industry. Specifically, in the Northern Cape region, there are approximately 20 projects linked to the grid, boasting a combined capacity of 900MW. The table below shows some of the biggest solar farms in the country,

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an exhaustive list of solar farms can be found on this link: https://list.solar/plants/largest-plants/south-africa/

Table 5: List of Major PV Plants in South Africa

Name	Location	Capacity	Land size (ha)
De Aar project	Northern Cape	175 MW	2674
Kathu Solar Park	Northern Cape	100 MW	800
Jasper Solar Power	Northern Cape	96 MW	
Mulilo-Sonnedix-Prieska	Northern Cape	75 MW	125
Xina Solar One	Northern Cape	100 MW	
Letsatsi Solar Park	Free State	150 MW	100
Lesedi Solar Park	Northern Cape	150 MW	

5.2 Potential and Future Hydrogen Demand in South Africa

The South African Cabinet has officially approved the implementation of the Green Hydrogen Commercialisation Strategy (GHCS) (South African Governmet News Agency, 2023). This strategy builds on the Hydrogen South Africa Strategy, which the Cabinet had previously endorsed in 2007, setting the groundwork for the nation's transition to a hydrogen economy. It's essential to recognize that the most cost-effective and efficient method of decarbonization is to directly utilize renewable energy whenever feasible. The process of producing hydrogen involves conversion losses, with roughly 50% of electrical energy being converted into chemical energy in hydrogen. Moreover, the electrolyzers used to generate hydrogen demand significant capital investment. Nevertheless, green hydrogen is particularly suited for certain sectors: these include long-haul heavy transportation like maritime shipping, commercial aviation, rail, and extensive heavy trucking, along with specific manufacturing sectors such as steel, cement, plastics, and ammonia production. The mining sector is also exploring green hydrogen to fuel trucks and specialized machinery. A recent report by Deloitte estimated that by 2030, clean hydrogen trade between major regions will accounts for over 30 MtH_2 eq. Sub-Saharan Africa exports accounts to 19%, which is about 6 Mt of hydrogen per year (Deloitte, 2023). Table 6 below shows green hydrogen projects (some gazetted by SA government), stakeholders, locations as well as export and domestic production capacities. While we acknowledge the progress made through the signing of MOUs and the ongoing feasibility studies, we await further clarity on the Final Investment Decision (FID) status for the projects.

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Table 6: Potential domestic and export hydrogen capacities in Southern Africa

Project planned	Stakeholders	Status	Location	Export/ Domestic	Production/demand Capacity & time-line
Hydrogen valley	Anglo American, Department of science and Innovation, Engi, Bambili	* #	Limpopo hub (Inland) Johannesburg hub (Inland Durban hub (Port) Richards bay hub (Port)	Domestic Domestic Domestic Export/Domestic	185 kt H_2 demand by 2030
Green Ammonia	HIVE Hydrogen, UK	* #	Port of Ngqura in Nelson Mandela Bay	Export	Production: 780kt pa NH_3, 2026
Boegoebaai green hydrogen project	Sasol, IDC	* #	Namakwa Special, Northern Cape, Boegoes bay & Saldana bay (Ports)	Export	Production: 400kt pa H_2, 2030
Green Ammonia	HYPHEN	* #	Namibia - Lüderitz Port	Export	Production: 350 ktpa H_2 : 2Mtpa NH_3, 2026
Prieska Power Cluster	Mahlako	*	Prieska Northern Cape	Domestic	70ktpa H2, 398 ktpa NH_3
Sasol HySHiFT: Sustainable Aviation Fuel (PTL-Kerosene)	HyshiFT Consortium (Sasol, Linde, ENERTRAG, HYDREGEN)	* #	Secunda, Mpumalanga	Domestic	15ktpa H_2
Sasolburg 60MW H2 production	Sasol	* #	Sasolburg, Free State	Domestic	1.8 ktpa H2 10.2 ktpa NH3
Ubuntu Green Hydrogen Project	Ubuntu Green Energy	* #	Northern Cape		Production: 800 tpa H_2, 4.5 ktpa NH3
Rhynbow H2 freight corridor project	Anglo American, Engi, Bambili	*	Limpopo-Gauteng-KZN.	Domestic	500 t H_2/day

* Waiting for Final Investment Decision (FID)

https://gazettes.africa/archive/za/2022/za-government-gazette-dated-2022-12-06-no-47658.pdf **INFRASTRUCTURE PROJECTS GAZETTE NOVEMBER 2022 (**Projects registered with Infrastructure South Africa and holding Strategic Integrated Projects (SIP) letters based on the Gazette published)

5.3 Water assessment

Green hydrogen is emerging as a promising solution in the search for clean and renewable energy sources. Unlike traditional hydrogen production methods, which often rely on fossil fuels and produce carbon emissions, green hydrogen production is eco-friendly. The process of creating green hydrogen involves the electrolysis of water, where electricity (preferably from renewable sources like wind or solar) is used to split water into its basic components: hydrogen and oxygen. South Africa, with its abundant solar and wind resources, has the potential to produce renewable electricity needed for the electrolysis process. However, there's a significant challenge: water availability. As a country classified as water-scarce, the use of vast amounts of freshwater for hydrogen production could exacerbate existing water challenges. By using desalinated water for green hydrogen production, South Africa can leverage its vast coastal regions and ensure that its freshwater resources are not further strained.

5.4 Potential export of hydrogen and export infrastructure available at local level

South Africa, with its potential for renewable energy generation, is an interesting candidate for producing green hydrogen, which can be shipped through abovemetioned ports/habours

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to Europe for energy or indutrial use. Two of the proposed methods to ship hydrogen are as liquid hydrogen (LH_2) and in the form of ammonia (NH_3). These methods have historical precedent and have been used for various purposes for many years.

In South Africa, potential hydrogen hubs on the West Coast and in the Eastern Cape are being considered for their strategic connections to renewable energy resources. Saldanha Bay on the West Coast offers established infrastructure, while Boegoe Bay is a greenfield development. In the Eastern Cape, Ngqura and Port of Durban are options, with the latter facing congestion issues. Richards Bay, known for its trading port and offshore wind potential, is also in the mix. Inland, the Vaal Triangle is attractive for its concentrated industrial activity (Sasol's Sasolburg plant, ArcelorMittal's (AMSA) steelworks, and Safripol's polymer processing). These hubs aim to leverage renewable resources and serve as export opportunities, particularly to EU markets. Boegoe Bay, Saldanha, and the Vaal have excellent solar resources, while Coega and Richards Bay excel in wind resources. Proximity to Renewable Energy Development Zones (REDZ) influences the feasibility of solar and wind farms, with Durban and Richards Bay being relatively distant from REDZ areas. Durban's port congestion and limited land make it less favorable, while Richards Bay is promising due to its industrial activity. The Vaal is well-suited for domestic hydrogen deployment, especially in the Platinum Group Metals (PGM) industry, while Coega leans towards export markets, leveraging its port access. Saldanha Bay boasts existing infrastructure and local demand, making it attractive for domestic hydrogen use.

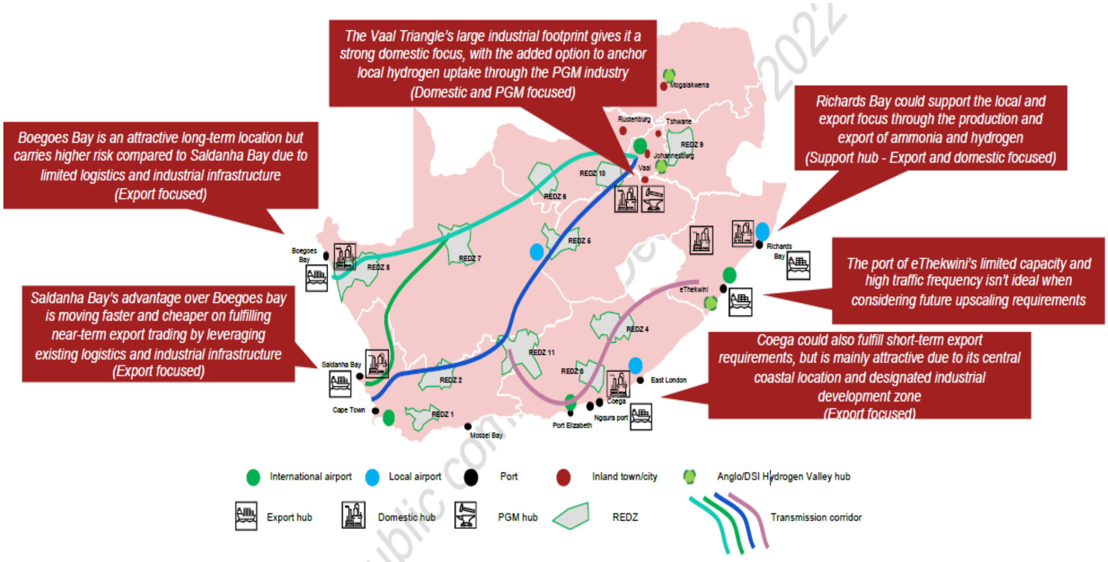

Figure 23 – Areas of potential interest where to develop green hydrogen hub in South Africa (looking at both domestic and export purposes) – Source: Industrial development corporation, South Africa

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5.5 Identified Use Cases

According to what presented in the previous paragraph (as well as aspects wrapped up in figure 23) the following use cases were identified:

- ***Goega, Eastern Cape Province:*** targeting exploitation of local wind farms and the local special economic zone investment incentives. Relevant industrial hydrogen end users should be better explored as local hydrogen off-takers (except for chemical and pharmaceutical end users indeed in the areas, no hard to abate industries seem to be present). Nevertheless, this area attracted interest from EU green hydrogen project promoters like HIVE Energy (https://www.hiveenergy.co.uk/2022/11/23/green-ammonia-project-coega-is-supporting-just-energy-transition/) looking at production of green ammonia at local level.
- ***Saldanha Bay, Western Cape Province:*** targeting mostly the potential exploitation of hydrogen in local hard to abate industries (mostly steel manufacturing plants, often managed by EU industries), but also considering potential export of H2 and hydrogen carriers via the local port infrastructure. This area already attracted the interest of different hydrogen project promoters like the Irish Phelan Green Energy (https://www.greenbuildingafrica.co.za/irelands-phelan-green-energy-announces-r47-billion-green-hydrogen-project-in-saldanha-south-africa/ - mostly looking at export opportunities) and ArcelorMittal (for production of green steel at local level via green hydrogen driven DRI - https://solarquarter.com/2023/10/31/arcelormittal-south-africa-explores-green-hydrogen-for-sustainable-dri-production/)
- ***Boegoebaai Bay, Northern Cape Province:*** targeting both domestic (for agricultural and industrial applications) and export hydrogen opportunities, also looking at cooperation with Namibia with the so called Northern Cape Green Hydrogen Strategy (https://www.ncgh2.co.za/) and exploiting local ports of Swakopmund in Namibia too.

Tables presented during M5 General Assembly in Madrid are presented in the following pages to present the three above mentioned use cases

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Table 7: Goega Bay, Eastern Cape Province brief presentation

NAME OF THE AREA	**Goega, Eastern Cape Province**
Size of the area	90 km^2 (Industrial park)
Type of potential local demand of hydrogen	Manufacturing (Automotive, FMCG, Pharmaceuticals)
RES Presence and potential	1800 kWh/m^2, wind 6,7 m/s, Cookhouse REDZ
H2 Development plans in the areas and their time horizon	20 kpta H2,780 ktpa Green NH3 by 2026
Data Availability	Partial
Relevance for the region	Access to the Easter Cape and Western Cape markets, Incentivised renewable energy production, local hydrogen uptake through the manufacturing industry
Presence of infrastructure looking at potential export to EU	Eastern transmission corridor, Port of Ngqura (18m depth),

Table 8: Saldanha Bay, Western Cape Province: brief presentation

NAME OF THE AREA	**Saldanha Bay, Wetern Cape**
Size of the area	2 015 km^2, Saldanha Bay local municipality (Western Cape province)
Type of potential local demand of hydrogen	AMSA Green Steel project, Agriculture, Mining
RES Presence and potential	Solar: 2100 kWh/m^2, wind 7,7 m/s, Overberg and Komsburg Renewable Enegy development zones
H2 Development plans in the areas and their time horizon	Domestic and Export plans

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Data Availability	Partial
Relevance for the region	Best quality renewable energy resource; Access Europe market; Possibility to anchor local hydrogen uptake through industrial activity; Easy access to resources (e.g., Ocean water, desalination plants)
Presence of infrastructure looking at potential export to EU	Port infrastructure

Table 9: Boegoebaai Bay, Northern Cape Province brief presentation

NAME OF THE AREA	**Boegoebaai Bay**
Size of the area	9 608 km² (Richtersveld Local municipality, Northern Cape Province)
Type of potential local demand of hydrogen	Agriculture, Mining (iron, Manganese), Manufacturing (Cement, Steel)
RES Presence and potential	Solar-2100 kWh/m^2; Wind 6,3 m/s
H2 Development plans in the areas and their time horizon	Domestic and Export: 400 kt pa hydrogen by 2030; MoA Signed
Data Availability	Partial
Relevance for the region	Best renewable energy resource in South Africa, sustainable water source, Namakwa Special Economic Zone
Presence of infrastructure looking at potential export to EU	Northern Power Transmision corridor, Port infrastructure,

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6 JUST GREEN AFRH2ICA KPI PANEL

As a CSA, it is not straightforward to define the KPIs to be monitored to track the project progresses and the achievement of project targets, particularly looking at a potential integration/link with TRUST KPI Panel and CHP JU SRIA KPIs.

Despite some KPIs defined in the Grant Agreement (as targets to be achieved WP per WP) a set of relevant KPIs for describing the performances of the different use cases (WP2) as well as the impacts that would derive from the implementation of green hydrogen roadmaps to be developed in African countries (WP3) have been identified by UNIGE as coordinator and they are hereby presented in this chapter, with specific reference to the following categories.

6.1 Green hydrogen scenarios KPIs

The following KPIs can be calculated for scenarios/hydrogen hubs to be modelled in WP2 and they will be relevant information (particularly to setup specific and achievable targets) for WP3 roadmaps formulation.

Table 10: KPIs identified for WP2-WP3 activities

KPI	Unit of Measurement	Application to WP2 activities	Application to WP3 activities
GREEN HYDROGEN PRODUCTION AND RENEWABLE ENERGY PROMOTION			
Electrolysers capacity installation	MW	X	X
Green hydrogen production	t/yr	X	X
Renewable energy produced and exploited by the electrolyser	MWh/yr	X	X
Additional renewable power capacity to be setup of green hydrogen production	MW	X	X
Electrolyser Potential Capacity Factor	%	X	-
Renewable energy produced and not exploited by the electrolyser	MWh/yr	X	-
ECONOMIC PERFORMANCES			
CAPEX/Mobilized investments for the setup of the hydrogen hub or the roadmap deployment	€	X	X
Average LCOH	€/kg	X	X[6]
Annual OPEX for plant O&M	€/yr	X	X

[6] Referring to a span or an average value that makes project viable in a country/area

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Pay Back Period	yrs	X	X[6]
Net Present Value	€	X	X[6]
SOCIAL IMPACT ON THE LOCAL COMMUNITY			
Number of jobs to be created at local level in a certain time horizon	-	-	X
Size of the enlarged area where the green hydrogen hub can have an impact	km^2	X	-
Additional economic value triggered by the deployment of the projects in sectors not directly related to the project setup itself (range)	M€	-	X
Cost intensity of the proposed hydrogen distribution scenario both for domestic and export market	€/kg of H_2	X	-
ENVIRONMENTAL PERFORMANCES			
Primary energy savings for the identified hydrogen production hub *(in comparison with steam methane reforming and with electrolysis driven by local national grid electricity)*	MWh_{EP}/yr	X	X
CO_2 savings for the identified hydrogen production hub *(in comparison with steam methane reforming and with electrolysis driven by local national grid electricity)*	CO_2/yr	X	X
Primary energy savings for the identified hydrogen users	MWh_{EP}/yr	X	X
CO_2 savings for the identified hydrogen users	CO_2/yr	X	X
CO_2 intensity of the proposed hydrogen distribution scenario both for domestic and export market	CO_2/kg of H_2	X	X
POLICIES AND REPLICATION ASPECTS			
Number of potential replication Hydrogen Hubs identified similar to the Use Case modelled *(as reference for the identified use case for being archetype for the African Hydrogen sector)*	-	X	-
Number of countries starting the setup or enhancement of hydrogen roadmapping/policies planning	-	-	X

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6.2 Other project activities

Further than these performances KPIs, the current KPIs address some specific activities mostly performed in WP4 (related to training activities) and WP5 (related to stakeholders activities). KPIs used to track the effectiveness of D&C activities have been reported in D5.1 and constantly updated.

Table 11: KPIs identified for Training and Stakeholders engagement activities

WP4 TRAINING ACTIVITIES		
KPI	**Unit of Measurement**	**How to monitor**
Number of stakeholders trained on JGA topics ***(from the GA** – target value: >200**)***	-	Registration to physical events and e-learning activities
Number of stakeholders trained on JGA topics – e-learning activities	-	Registered users on the e-learning platform
Level of satisfaction of the proposed e-learning activities	%	a) % of trainees following both e-learning package 1 and 2 b) % of satisfaction by trainees from the final satisfaction survey
Number of stakeholders trained on JGA topics – physical events	-	Registration to physical events
Number of EU/AU institutions involved in the JGA training activities	-	Registration to physical events and e-learning activities
Number of training events ***(from the GA** – target value: 20**)***	-	Organization of training initiatives by the consortium

WP5 STAKEHOLDER ENGAGEMENT ACTIVITIES		
KPI	**Unit of Measurement**	**How to monitor**
Number of stakeholders involved in all stakeholders driven activities ***(from the GA** – target value: 25**)***	-	Surveys respondents Events participants
Number of AU countries engaged/involved in state of	-	Assessment presented in D1.2

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the art/WP1 activities ***(from the GA** – target value: 10**)***		
Level of satisfaction/agreement of the proposed project results activities by the project stakeholders ***(from the GA** – target value: 70%**)***	%	% of satisfaction by stakeholders from the final project survey and event
Number of stakeholders registered to the AFRH2ICA platform ***(from the GA** – target value: 150**)***	-	Registered users to the platform
Number of countries of origin of stakeholders interacting with the project	-	Registration to training platform, stakeholders events, respondents to stakeholders survey, Registered users to the platform

6.3 TRUST and CHP JU SRIA KPIs

Further than the KPIs mentioned in the previous sub-paragraphs, the consortium analysed the KPIs presented in the TRUST KPI panel and the CHP JU SRIA identifying the following KPIs as relevant indicators to be monitored for JUST GREEN AFRH2ICA too and where the project can contribute.

According to TRUST/Multi Annual Work Programme KPIs, all of them are classified in different classes and templates. Here in the following, the KPIs identified by UNIGE as coordinator.

KPIs identified are reported in Table 12 (TRUST and MAWP CHP JU Annual KPIs) and in Table 13 (TRUST Annual KPIs). While Table 12 activities refer mostly to technological KPIs that could be monitored in JUST GREEN AFRH2ICA in WP2 and WP3 activities, Table 13 also foresees a precise monitoring approach to stakeholders engagement as well as of Dissemination and Communication activities

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Table 12: TRUST and MAWP CHP JU Annual KPIs

Template	Parameter class	Order	Parameter	Definition	Is MAWP KPI?	Unit
H2 carriers	OPERATIONAL	15	KPI - Delivery Cost	Total costs of delivering/storing hydrogen including all the steps involved in the process (including CAPEX and OPEX costs)	yes	EUR/kg
H2 carriers	OPERATIONAL	16	KPI - Hydrogen carrier delivery cost (for 3000km ship transfer)	Total cost attributable to a hydrogen carrier system to supply, on average, 1000 tpd of Hydrogen over a round trip distance of 3000 km, expressed on a Per KG hydrogen delivered basis.Hydrogen supply conditions:20 bar and ambient temperature, Hydrogen delivery pressure: 20 bar and ambient temperature, ISO14687 quality.Total cost includes Opex and Capex elements required, including cost for inventorising the supply chain, as well as operational make up cost due to carrier loss/degradation. SRIA	yes	EUR/kg

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H2 carriers	OPERATIONAL	17	KPI - Hydrogen carrier specific energy consumption	Carrier energy consumption for 3000km distance. Boundaries: from hydrogen conversion into a dispatchable form to the hydrogen recovered, including carrier supply chain/degradation, except hydrogen production. Total quantity of energy required by the hydrogen carrier system (including shipping) to deliver hydrogen from supply point to delivery point under the boundary conditions as specified for KPI 3	yes	kWh input/kg H2 recovered
H2 carriers	OPERATIONAL	18	KPI- OPEX (hydrogenation unit)	"Actual annual operational and maintenance costs per unit of hydrogen output per day, including running costs, labor, maintenance, repairs & excluding taxes. Potential stack replacements are included while electricity costs are not included.	yes	EUR/(kg/d)/yr
H2 carriers	OPERATIONAL	19	KPI - OPEX (dehydrogenation unit)	Operational and maintenance costs per unit of hydrogen carrier coverted	yes	EUR/(kg/d)/yr
Education	OPERATIONAL	1	KPI - Trained pupils per country in primary and secondary education	Number of trained pupils per country (primary and secondary education) |Please on the comment box indicate the "Country1- number, Country2-Number,.."	yes	
Education	OPERATIONAL	2	KPI - Trained people per country in higher education	Number of trained people per country (Higher education)|Please on the comment box indicate the "Country1- number, Country2-Number,.."	yes	

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Education	OPERATIONAL	3	KPI - Trained professionals per country	Number of trained professionals per country (qualified workers, technicians and engineers) |Please on the comment box indicate the "Country1- number, Country2-Number,.."	yes	
Education	OPERATIONAL	4	KPI - Universities/ Institutes offering courses on hydrogen	Number of educative centres and/or universities offering higher education course modules and/or fully dedicated educational programmes on hydrogen and/or fuel cells (included in existing curricula and not full academic diploma on hydrogen exclusively)|Please on the comment box indicate the "Country1-number, Country2-Number,.."	yes	
Electrolysis	DESCRIPTIVE	18	Area occupied by unit	Average specific space requirement of a MW system comprising all auxiliary systems to meet standard boundary conditions in 1) and built up as indoor installation	yes	m2/MW
Electrolysis	DESCRIPTIVE	19	KPI- Electricity consumption @ nominal capacity	Electrical energy demand at nominal hydrogen production rate of the system at standard boundary conditions	yes	kWh/kg
Electrolysis	DESCRIPTIVE	20	KPI - Capital cost €/(kg/d)	Capital cost are based on 100 MW production volume for a single company and on a 10-year system lifetime running in steady state operation, whereby end of life is defined as 10% increase in energy required for production of hydrogen. Stack replacements are not included in capital	yes	€/(kg/d)

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				cost. Cost are for installation on a pre-prepared site (fundament/building and necessary connections are available). Transformers and rectifiers are to be included in the capital cost		
Electrolysis	DESCRIPTIVE	21	KPI - Capital cost €/kW	Capital cost are based on 100 MW production volume for a single company and on a 10-year system lifetime running in steady state operation, whereby end of life is defined as 10% increase in energy required for production of hydrogen. Stack replacements are not included in capital cost. Cost are for installation on a pre-prepared site (fundament/building and necessary connections are available). Transformers and rectifiers are to be included in the capital cost	yes	€/kW
Electrolysis	DESCRIPTIVE	22	KPI - O&M cost	Operation and maintenance cost averaged over the first 10 years of the system. routine maintenance and "wear and tear" (rotating parts, cleaning of equipment, ...). Potential stack replacements are NOT included in O&M cost. Electricity costs are not included in O&M cost	yes	€/(kg/d)/yr

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Table 13: KPIs identified from the annual CHP JU KPIs

Template	Parameter class	Order	Parameter	Definition	Unit
H2 carriers	DESCRIPTIVE	1	Country	Country in which the system is located	
H2 carriers	DESCRIPTIVE	2	Deployment date	Date at which the system was first put in operation	
H2 carriers	DESCRIPTIVE	3	Hydrogen Carrier	Please specify the type of the H2 carrier, including its nature, the full name and the unique numerical identifier assigned by the Chemical Abstracts Service (CAS) - if applicable	
H2 carriers	DESCRIPTIVE	4	KPI - Volumetric capacity of H2 carrier	KPI - Volumetric capacity of the H2 carrier expressed in kg H2 per unit of volume of carrier (excluding the tank, the BoP and any other components belonging to the system)	H2 kg/m3
H2 carriers	DESCRIPTIVE	18	Footprint (hydrogenation)	Footprint of the hydrogenation unit	m2
H2 carriers	DESCRIPTIVE	19	Footprint (dehydrogenation)	Footprint of the dehydrogenation unit (if different from the hydrogenation unit)	m2
H2 carriers	DESCRIPTIVE	20	Hydrogen storage capacity	Maximum amount of H2 that can be stored in the system - if applicable	kg
H2 carriers	DESCRIPTIVE	21	Hydrogen transportation capacity	Amount of H2 transported per trailer, include the size of the trailer in the comment field in tonnes - if applicable	kg

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H2 carriers	DESCRIPTIVE	22	KPI -Total roundtrip efficiency - rated	Energy content of the hydrogen at the outlet divided by the sum of: the energy content of the hydrogen at the inlet and any energy input in the process (including hydrogenation, dehydrogenation and transportation of the H2 carrier)	%
H2 carriers	DESCRIPTIVE	23	KPI- CAPEX (hydrogenation unit)	Actual cost of the hydrogenation unit including manufacturing(equip., materials, labor, utilities).Costs are for installation on a pre-prepared site (building and necessary connections are available).This includes the cost of the carriers(No taxes incl.	EUR
H2 carriers	DESCRIPTIVE	24	KPI- CAPEX (dehydrogeneration unit)	Actual cost of the dehydrogenation unit including manufacturing (equipment, materials, labor, utilities). Costs are for installation on a pre-prepared site (foundations/building and necessary connections are available). Taxes are not included.	EUR
H2 carriers	DESCRIPTIVE	25	KPI - CAPEX (trailer/tanks)	Capital cost of trailer/tank to transport/store H2 carrier	EUR
H2 carriers	OPERATIONAL	7	H2 handled	Amount of H2 fed/released in/from the system over the timeframe of this data collection exercise	kg
H2 carriers	OPERATIONAL	8	Critical raw materials	Critical raw materials used as catalysts or as carriers in the full system. Please refer to the name of the catalyst and the	mg/H2 kg

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				amount used per kg of H2 transported/stored	
H2 carriers	OPERATIONAL	9	KPI - Total roundtrip efficiency	Energy content of the hydrogen at the outlet divided by the sum of: the energy content of the hydrogen at the inlet and any energy input in the process (including hydrogenation, dehydrogenation and transportation of the H2 carrier)	%
H2 carriers	OPERATIONAL	15	KPI - Delivery Cost	Total costs of delivering/storing hydrogen including all the steps involved in the process (including CAPEX and OPEX costs)	EUR/kg
H2 carriers	OPERATIONAL	16	KPI - Hydrogen carrier delivery cost (for 3000km ship transfer)	Total cost attributable to a hydrogen carrier system to supply, on average, 1000 tpd of Hydrogen over a round trip distance of 3000 km, expressed on a Per KG hydrogen delivered basis.Hydrogen supply conditions:20 bar and ambient temperature, Hydrogen delivery pressure: 20 bar and ambient temperature, ISO14687 quality.Total cost includes Opex and Capex elements required, including cost for inventorising the supply chain, as well as operational make up cost due to carrier loss/degradation. SRIA	EUR/kg

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H2 carriers	OPERATIONAL	17	KPI - Hydrogen carrier specific energy consumption	Carrier energy consumption for 3000km distance. Boundaries: from hydrogen conversion into a dispatchable form to the hydrogen recovered, including carrier supply chain/degradation, except hydrogen production. Total quantity of energy required by the hydrogen carrier system (including shipping) to deliver hydrogen from supply point to delivery point under the boundary conditions as specified for KPI 3	kWh input/kg H2 recovered
H2 carriers	OPERATIONAL	18	KPI- OPEX (hydrogenation unit)	"Actual annual operational and maintenance costs per unit of hydrogen output per day, including running costs, labor, maintenance, repairs & excluding taxes. Potential stack replacements are included while electricity costs are not included.	EUR/(kg/d)/yr
H2 carriers	OPERATIONAL	19	KPI - OPEX (dehydrogenation unit)	Operational and maintenance costs per unit of hydrogen carrier coverted	EUR/(kg/d)/yr
H2 carriers	OPERATIONAL	20	KPI - OPEX (trailer/tank)	Operational and maintenance costs per unit of hydrogen carrier transferred	EUR/(kg/d)/yr
Education	DESCRIPTIVE	3	Training topic(s)	Topics addressed in the training	
Education	DESCRIPTIVE	4	Training type	Indicate the intended type of training	
Education	DESCRIPTIVE	5	Training material	Indicate the type of material developed for the training	
Education	DESCRIPTIVE	6	Training lanugage(s)	Indicate the language in which the training is or will be delivered	

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Education	DESCRIPTIVE	7	Training course: name & brief description	Name and brief descri[tion of the training for which you are reporting here	
Education	DESCRIPTIVE	8	Training duration	Overall training duration	h
Education	DESCRIPTIVE	9	Training attendance method	Indicate how trainees will attend the training	
Education	DESCRIPTIVE	10	Training website	url with training info	
Education	DESCRIPTIVE	11	Is there a passing test/exam?	Indicate whether the training involves a level test to verify successful knowledge acquisition	
Education	DESCRIPTIVE	12	Awarding of a diploma/certification	Indicate whether the trainees receive any kind of certification for either attendance of the course and/or passing of a level test. Please indicate the name of any certificate awarded in the comment field.	
Education	OPERATIONAL	1	KPI - Trained pupils per country in primary and secondary education	Number of trained pupils per country (primary and secondary education) |Please on the comment box indicate the "Country1- number, Country2- Number,.."	
Education	OPERATIONAL	2	KPI - Trained people per country in higher education	Number of trained people per country (Higher education)|Please on the comment box indicate the "Country1- number, Country2-Number,.."	
Education	OPERATIONAL	3	KPI - Trained professionals per country	Number of trained professionals per country (qualified workers, technicians and engineers) |Please on the comment box indicate the "Country1- number, Country2-Number,.."	

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Education	OPERATIONAL	4	KPI - Universities/ Institutes offering courses on hydrogen	Number of educative centres and/or universities offering higher education course modules and/or fully dedicated educational programmes on hydrogen and/or fuel cells (included in existing curricula and not full academic diploma on hydrogen exclusively)|Please on the comment box indicate the "Country1-number, Country2-Number,.."	
Education	OPERATIONAL	5	Age of Trainees	Define the age of the trainees	
Education	OPERATIONAL	6	Training location(s) in reference period	Indicate where the training has taken plance during the reference period, i.e. between start and end date for reporting	
Education	OPERATIONAL	7	Trainees per country in the reference period	Number of trainees trained in each country (country of training location) during the reference period, i.e. between start and end date for reporting.|Please use the folllowing structure: "Country1-number, Country2-Number,.." (only indicating the countries in which trainees have been trained). If online-only training: indicate location of trainee IP address. In the comment: you can indicate number of trainees per country OF ORIGIN (of residence).	
Education	OPERATIONAL	8	Nr of diplomas/certificates issued in the project	Total number of person having received a training diploma/certificate since project start until the end date for reporting.|If the training is not intended	

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				to award any diplomas/certificates please indicate "not applicable" in the comment field.	
Education	OPERATIONAL	9	Number of people trained in reference period	Number of persons trained during the reference period, i.e. between start and end date for reporting	
Electrolysis	DESCRIPTIVE	4	Country	Country in which the electrolyser is located	
Electrolysis	DESCRIPTIVE	6	Technology	Indicate the electrolyser technology	
Electrolysis	DESCRIPTIVE	7	Electrolyser manufacturer	Manufacturer of the electrolyser	
Electrolysis	DESCRIPTIVE	8	Stack manufacturer	Manufacturer of the stack(s)	
Electrolysis	DESCRIPTIVE	11	Nominal system electrical power	Nominal capacity of the system, in terms of power, rated value	kW
Electrolysis	DESCRIPTIVE	13	System minimum power	Minimum power for which the system is designed, as a percentage of nominal power	%
Electrolysis	DESCRIPTIVE	14	Hydrogen production capacity	Nominal hydrogen production capacity	kg/h
Electrolysis	DESCRIPTIVE	18	Area occupied by unit	Average specific space requirement of a MW system comprising all auxiliary systems to meet standard boundary conditions in 1) and built up as indoor installation	m2/MW
Electrolysis	DESCRIPTIVE	19	KPI- Electricity consumption @ nominal capacity	Electrical energy demand at nominal hydrogen production rate of the system at standard boundary conditions	kWh/kg
Electrolysis	DESCRIPTIVE	20	KPI - Capital cost €/(kg/d)	Capital cost are based on 100 MW production volume for a single company	€/(kg/d)

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				and on a 10-year system lifetime running in steady state operation, whereby end of life is defined as 10% increase in energy required for production of hydrogen. Stack replacements are not included in capital cost. Cost are for installation on a pre-prepared site (fundament/building and necessary connections are available). Transformers and rectifiers are to be included in the capital cost	
Electrolysis	DESCRIPTIVE	21	KPI - Capital cost €/kW	Capital cost are based on 100 MW production volume for a single company and on a 10-year system lifetime running in steady state operation, whereby end of life is defined as 10% increase in energy required for production of hydrogen. Stack replacements are not included in capital cost. Cost are for installation on a pre-prepared site (fundament/building and necessary connections are available). Transformers and rectifiers are to be included in the capital cost	€/kW
Electrolysis	DESCRIPTIVE	22	KPI - O&M cost	Operation and maintenance cost averaged over the first 10 years of the system. routine maintenance and "wear and tear" (rotating parts, cleaning of equipment, ...). Potential stack	€/(kg/d)/yr

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				replacements are NOT included in O&M cost. Electricity costs are not included in O&M cost	
Electrolysis	OPERATIONAL	5	KPI - Use of critical raw materials as catalysts	For AEMEL it refers mainly to IrOx as the anode catalyst and Pt/C as the cathode catalyst. For PEMEL these are mainly iridium and ruthenium as the anode catalyst (2,0 mg/cm2) and platinum as the cathode catalyst (0,5 mmg/cm2). For AEL it is ruthenium for the cathode (mostly as RuO2). PLease inidcate the type of catalyst in and if it is gor cathode or anode in the comment box	mg/W
Electrolysis	OPERATIONAL	6	KPI - Roundtrip electrical efficiency (only for SOEL)	Roundtrip electrical efficiency is defined as energy discharged measured on the primary point of connection (POC) divided by the electric energy absorbed, measured on all the POC (primary and auxiliary), over one electrical energy storage system standard charging/discharging cycle in specified operating conditions	%
Electrolysis	OPERATIONAL	11	Fraction of renewable energy input	Percentage of electricity used for production covered by GoAs or direct electricity connection. If not available or not possible to calculate it should be reported as zero. - If the % is above zero please clarify in comments how it is covered (e.g. by	%

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				certificates, direct connection etc.). - If it is grid-based please use 0 and state in the comments Grid-based.	
Electrolysis	OPERATIONAL	12	Hours of operation	Total number of hours of operation (excluding downtime) within the timeframe of this data collection exercise	h
Electrolysis	OPERATIONAL	13	Quantity of hydrogen produced	Total amount of hydrogen produced over the timeframe of this data collection exercise	t
Electrolysis	OPERATIONAL	14	Cost of the hydrogen produced	Levelized Cost of Hydrogen produced, including OPEX and CAPEX, over the timeframe of this data collection exercise	€/kg
Dissemination_Exploitation	DESCRIPTIVE	2	Dissemination Activities in total	How many dissemination activities performed since the beginning of the project	
Dissemination_Exploitation	DESCRIPTIVE	3	Dissemination Activities within the timeframe of this data collection exercise	How many dissemination activities performed within the timeframe of this data collection exercise	
Dissemination_Exploitation	DESCRIPTIVE	4	Presentation of results in conferences, events and workshops	How many presentation of the results of the project were performed in conferences, events and workshops within the timeframe of this data collection exercise	
Dissemination_Exploitation	DESCRIPTIVE	5	Peer-Reviewed Scientific Publications	How many peer-reviewed scientific publications made within the timeframe of this data collection exercise	

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Dissemination_Exploitation	DESCRIPTIVE	6	Peer-Reviewed Scientific Publications in Open Research Europe	How many peer-reviewed scientific publications made within the timeframe of this data collection exercise published through the Open Research Europe platform	
Dissemination_Exploitation	DESCRIPTIVE	7	Education & Training Activities	How many education and training activities performed by the project within the timeframe of this data collection exercise	
Dissemination_Exploitation	DESCRIPTIVE	8	Meetings with stakeholders	In how many meetings did the project arranged/participated to disseminate the results within the timeframe of this data collection exercise	
Dissemination_Exploitation	DESCRIPTIVE	9	Other Dissemination Activities	Are there any other dissemination of results activities not included above within the timeframe of this data collection exercise	
Dissemination_Exploitation	DESCRIPTIVE	10	Scientific/Research Communities	How many dissemination activities targeted the scientific/research communities within the timeframe of this data collection exercise	
Dissemination_Exploitation	DESCRIPTIVE	11	Industry/Business Partners	How many dissemination activities targeted industrial or business partners within the timeframe of this data collection exercise	
Dissemination_Exploitation	DESCRIPTIVE	12	EU Institutions / Policy Makers	How many dissemination activities targeted the EU Institutions or other policy makers within the timeframe of this data collection exercise	

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Dissemination_Exploitation	DESCRIPTIVE	13	Standardisation Bodies	How many dissemination activities targeted the standardisation bodies within the timeframe of this data collection exercise	
Dissemination_Exploitation	DESCRIPTIVE	14	Society / Specific End-Users Communities	How many dissemination activities targeted society or specific end-users communities within the timeframe of this data collection exercise	
Dissemination_Exploitation	DESCRIPTIVE	15	Other Target Audiences	How many dissemination activities targeted other audiences not included above within the timeframe of this data collection exercise	
Dissemination_Exploitation	DESCRIPTIVE	16	Delivered Dissemination Activities	How many of the planned dissemination activities delivered within the timeframe of this data collection exercise	
Dissemination_Exploitation	DESCRIPTIVE	17	On-going Dissemination Activities	How many of the planned dissemination activities are still on-going	
Dissemination_Exploitation	DESCRIPTIVE	18	Postponed or Cancelled Dissemination Activities	How many of the planned dissemination activities were postponed or cancelled within the timeframe of this data collection exercise	
Dissemination_Exploitation	DESCRIPTIVE	23	Potential Investors / Users	Did the project manage to successfully promote the results to potential investors to upscale commercial production or to users communities (researchers or end users) within the timeframe of this data collection exercise	

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Dissemination_Exploitation	DESCRIPTIVE	28	Industry/Business Partners	Was there any exploitation activities towards industry/business partners	
Dissemination_Exploitation	DESCRIPTIVE	29	Research Communities	Was there any exploitation activities towards research communities	
Dissemination_Exploitation	DESCRIPTIVE	30	Standardisation Bodies	Was there any exploitation activities towards standardisation bodies	
Dissemination_Exploitation	DESCRIPTIVE	31	Innovators	Was there any exploitation activities towards innovators	
Dissemination_Exploitation	DESCRIPTIVE	32	End Users	Was there any exploitation activities towards end users	
Dissemination_Exploitation	DESCRIPTIVE	33	Other Audience	Was there any exploitation activities towards other audiences not included above	
Dissemination_Exploitation	DESCRIPTIVE	34	Other Audience_	Please elaborate to any other audiences addressed within the timeframe of this data collection exercise	
Dissemination_Exploitation	DESCRIPTIVE	35	Lack of Regulation, Codes or Standards	Was the project implementation hindered due to lack of regulations, codes or standards	
Dissemination_Exploitation	DESCRIPTIVE	36	Lack of Financing	Was the project implementation hindered due to lack of financing	
Dissemination_Exploitation	DESCRIPTIVE	37	Lack of Labor Skills	Was the project implementation hindered due to lack of labor skills	
Dissemination_Exploitation	DESCRIPTIVE	38	Trade Issues	Was the project implementation hindered due to trade issues	

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Paragraphs below reports the KPIs identified from the CHP JU SRIA: it is relevant to highlight that, despite few KPIs from the SRIA (due to the fact that most of ANNEX 2-3-4-5-6 KPIs are technology oriented) SRIA KPIs are identified as relevant to be monitored in JUST GREEN AFRH2ICA activities, the project has relevant connection to the SRIA objectives for aspects related to Common R&I Roadmaps (ANNEX 7 – e.g. for the promotion of Hydrogen Hubs in industrial site covered by Processes4Planet), strategic R&D and implementation initiatives (e.g. related to Hydrogen Valleys and hydrogen import/export initiatives).

ANNEX 2 - Renewable Hydrogen production

The SRIA identify KPIs for all the Electrolysis technologies.

Aspects related to CAPEX/O&M Cost, electricity consumption at nominal capacity and Use of critical raw materials as catalysts via KPIs also reported in Tab.12 and Tab.13 can be evaluated in all the scenarios modelled in WP2 also looking at targets imposed by the SRIA for 2030 for example (Common time horizon for JUST GREEN AFRH2ICA)

ANNEX 3 – Hydrogen Storage and Distribution

It is relevant to highlight that in the scenarios to be modelled in WP2, produced hydrogen will be evaluated mostly to be stored in above-ground pressurized storage (for aspects related to CAPEX/OPEX and overall energy consumption needs) and/or to be used to produce hydrogen carriers.

In this sense KPIs mentioned in Table 12 of the ANNEX 3 of SRIA (like hydrogen carrier deliveray cost – 3000 km Ship transfer or hydrogen carrier specific energy consumption) will be evaluated in the scenarios to be modelled in WP2 particularly for the use cases looking at export opportunities. Such KPIs are also reported in Tab.12 and Tab.13

Furthermore KPIs related cost for transportation via hydrogen pipelines or road transport of compressed/liquid hydrogen as well as of shipping of bulk liquid hydrogen. All KPIs reported in Table 13 of the ANNEX 3.

ANNEX 4 - State-of-the-art and future targets – Hydrogen end use: transport applications

ANNEX 5 - State-of-the-art and future targets – Hydrogen end use: stationary applications

KPIs reported in these two SRIA annexes are not relevant for JUST GREEN AFRH2ICA Activities

ANNEX 6 - State-of-the-art and future targets – Cross-cutting issues

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KPIs mentioned in Table 24 of the ANNEX 6 of SRIA are relevant for Training activities of JUST GREEN AFRH2ICA Project and they are covered by the KPIs reported in table 11 of this document, particularly KPIs like

- Trained professionals
- Universities/Institutes offering courses on hydrogen

With a specific reference to trainees in *Tier 3 countries: rest of EU countries and associated countries* further than consortium partners' countries. While the KPI "Trained pupils in primary and secondary education" is not relevant for the project as JUST GREEN AFRH2ICA training plan targets mostly university students, researchers and hydrogen stakeholders and actors.

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CONCLUSION

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This Deliverable “D1.3 AU Green H2 scenarios”, developed within WP1 aims to present a quite detailed overview of the Green Hydrogen scenarios to be modelled in WP2 by the consortium as representative use cases for the African continent.

In this sense, also starting from the results presented in D1.2 and according to the results of a workshop organized during the M5 General Assembly, the following use cases have been identified (figure 24).

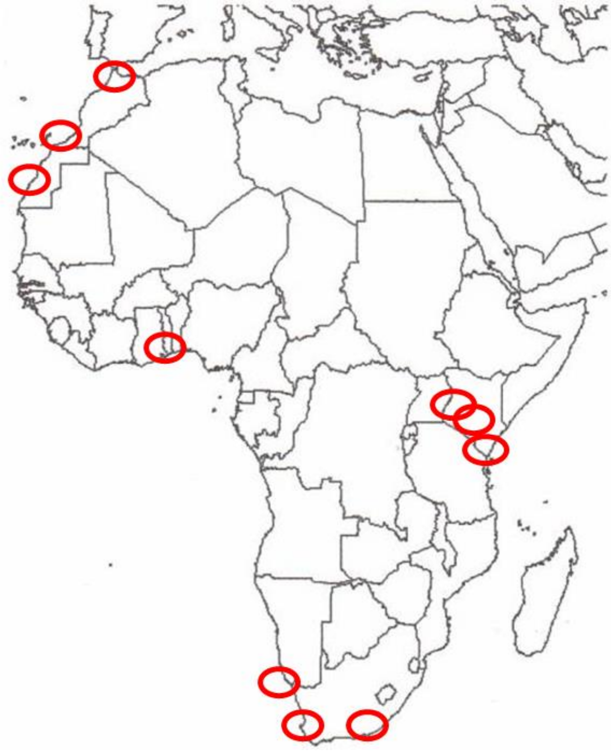

Figure 24 – JUST GREEN AFRH2ICA representative Use cases to be modelled in WP2

- **NORTHERN AFRICA:** Morocco (Jorf Lasfar, Dakhla - Laayoune , Tangiers area…)
- **CENTRAL/WESTERN AFRICA:** Kenya (Rift Valley Geothermal Area, Mombasa/Tanzania Borders area, Nairobi Capital city district…)
- **WEST AFRICA:** Ghana/Togo area (SekyereEast District, Accra, Lomé and Sokodé – Tema Port area)
- **SOUTHERN AFRICA:** South Africa (Goega Industrial Park, Saldanha Bay, Boegoebaai Bay and Namibia Borders/Swakopmund area)
-

All these use cases, were identified mostly targeting the following guidelines:

- Exploit a large local renewable potential or existing power plant
- Have access to sustainable and manageable water sources
- Presence in the surrounding of significant potential hydrogen off-takers
- Possibility to exploit locally civil and energy infrastructure

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- Decent availability of data or at least decent possibility to evaluate local data (in terms of demand and production) starting from National data or literature data
- Possibility to unlock both domestic and international export markets opportunities

Some of the identified use cases can also be reconnected to potential/on-going green hydrogen initiatives in the different African countries as presented in this report or in D1.2

Looking at future analysis, further than double check the local data availability to enable WP2 modelling activities, it is relevant to highlight that the analysis of local relevant stakeholders and their potential involvement in the development of green hydrogen projects is something to be considered particularly to guarantee a JUST approach in the future development and exploitation of green hydrogen potential to be investigated in all these use cases, but also to share relevant data for modelling the use cases themselves.

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