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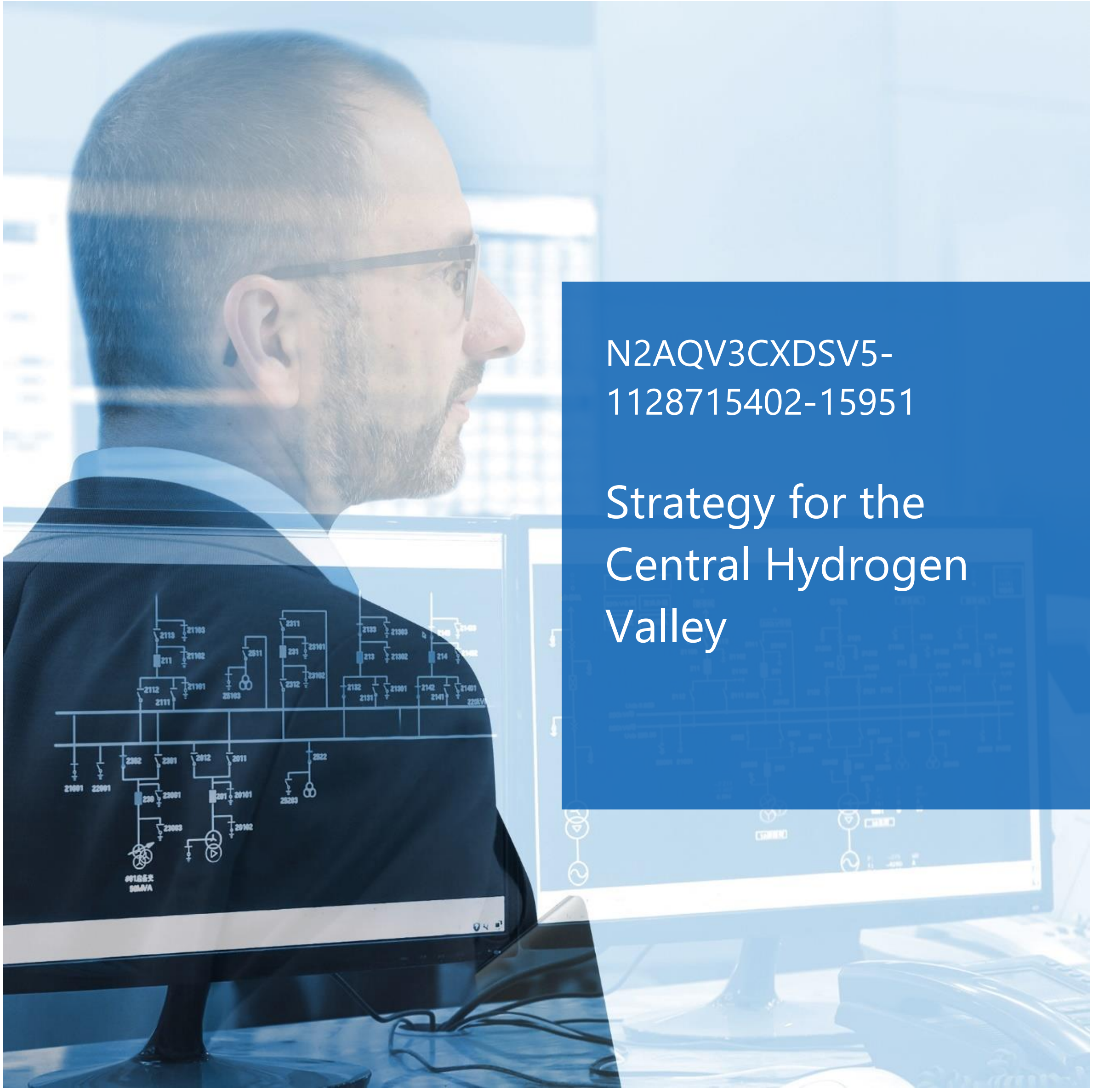

N2AQV3CXDSV5-1128715402-15951

Strategy for the Central Hydrogen Valley

FIS0000728

Consultancy for the Feasibility Study on three (3) Hydrogen Valleys as identified in the Green Hydrogen Strategy (GHS): Central Region

Environmental Investment Fund of Namibia (EIF)

ENGINEERING + CONSULTING

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Document revision record

Rev.	Date	Details of revision	Fichtner Doc Ref.	Prepared by	Checked by	Approved by
0	22.12.2023	First issuance	N2AQV3CXDSV5-1128715402-15656	FDAL	GMZ	GMZ
1	13.02.2024	Final version (incl. comments)	N2AQV3CXDSV5-1128715402-15656	FDAL	MGRK	GMZ
2	14.03.2024	Final version_updated	N2AQV3CXDSV5-1128715402-15951	FDAL	MGRK	GMZ

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Abbreviations

Abbrev.	Description
ASU	Air Separation Unit
CAPEX	Capital Expenditures
CAN	Calcium Ammonium Nitrate
CO_2	Carbon Dioxide
DAC	Direct Air Capture
e-fuels	Synthetic fuels (incl. e-kerosene, e-gasoline, e-diesel)
ELY	Electrolyzer
FTE	Full Time Equivalent
GHS	Green Hydrogen Strategy
GIS	Geographical Information System
GSA	Global Solar Atlas
GWA	Global Wind Atlas
H_2	Hydrogen
kTPA	Thousand Tons Per Annum
LAN	Limestone Ammonium Nitrate
LCO"X"	Levelized costs of anything (e.g., Electricity, Hydrogen)
MCA	Multi Criteria Analysis
MeOH	Methanol
MTPA	Million Tons Per Annum

Abbrev.	Description
N_2	Nitrogen
NDC	Nationally Determined Contributions
NH_3	Ammonia
NPK	Fertilizer based on diverse combinations of Nitrogen (N), Phosphorus (P), and Potassium (K)
OPEX	Operational Expenditures
PtX	Power to X
PPP	Public Private Partnerships
PV	Photovoltaics
RDI	Research, Development and Innovation
RfP	Request for Proposal
RO	Reverse osmosis
SSP	Single Superphosphate
SWRO	Seawater Reverse Osmosis
TPA	Tons per Annum
UAN	Urea Ammonium Nitrate
WACC	Weighted Average Cost of Capital
WT	Wind Turbine

1 Introduction

In November 2022 the Ministry of Mines and Energy of Namibia published Namibia's Green Hydrogen and Derivatives Strategy. According to the strategy, Namibia aims to produce around 10-12 million tons per annum (MTPA) hydrogen equivalent by 2050 and to export hydrogen derivatives such as ammonia, methanol, synthetic fuels and hot briquetted iron. For this purpose, the hydrogen strategy foresees the development of three hydrogen valleys in the southern, central and northern regions of Namibia as shown in Figure 1.

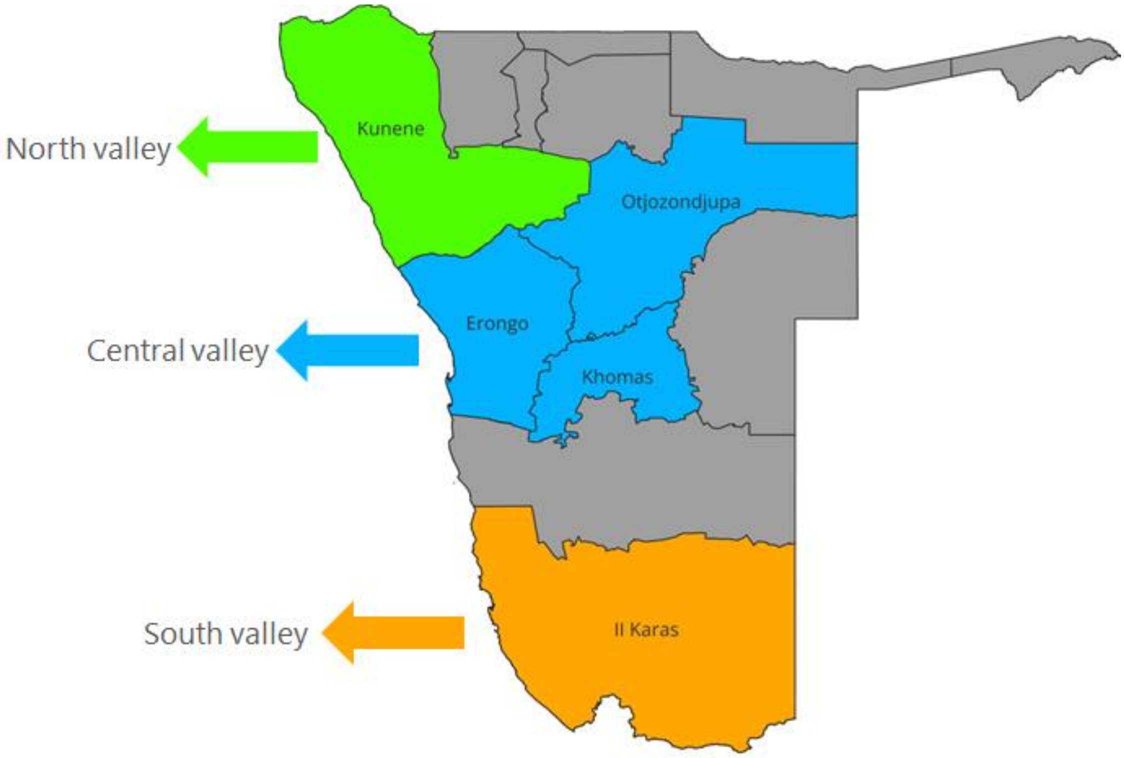


Figure 1: Three hydrogen valleys foreseen in Namibia's green hydrogen strategy

With this background, the Environmental Investment Fund of Namibia (in the following "EIF") assigned Fichtner GmbH & Co. KG to provide "Consultancy for the Feasibility Study on three (3) Hydrogen Valleys as identified in the Green Hydrogen Strategy (GHS): Central Region", with focus on the Central Hydrogen Valley comprising Erongo, Khomas and Otjozondjupa. The overall objective of the assignment is the determination of the potential for green hydrogen (as well as derivatives such as ammonia and methanol) powered by renewable energies.

The assignment comprises 6 main tasks: analysis of Geographical Information System (GIS)-data, high-level environmental and social impact assessment, potential for solar PV and onshore wind, hydrogen production potential and required infrastructure, evaluation of enablers and a strategy study combining the results of the previous tasks.

This document presents the developed strategy (Task 6, as shown in Figure 2) based on the findings of the previous tasks. A general overview of the main findings is given in Section 2, followed by the identified opportunities for Namibia, in general, and the Central Hydrogen Valley specifically (Section 3) and closing with the proposed roadmap for strategy implementation (Section 4) Detailed information about the analyses performed for each of the previous tasks (1 to 5) can be found in the specific reports prepared.

Figure 2: Tasks to be performed for the feasibility study of the Central Hydrogen Valley

2 Main Findings

The analyses performed for the different tasks of the project offer the basis for the definition of a strategy for the Central Hydrogen Valley in Namibia. The following sections summarize the main findings of the previous tasks.

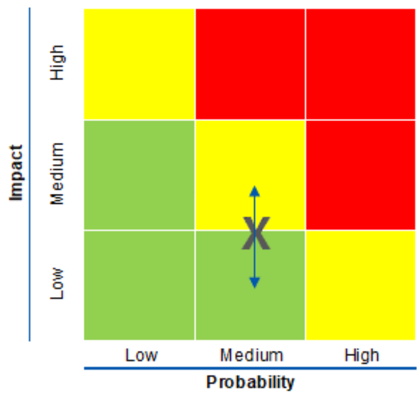
2.1 Environmental and social aspects

A high-level environmental and social impact assessment has been performed by Fichtner aiming at evaluating different aspects for the implementation of green hydrogen projects in the Central Hydrogen Valley, based on available information and GIS-data and identifying potential risks related to these aspects.

Different environmental and social aspects have been evaluated and potential associated risks (or red flags) have been identified. The aspects evaluated and the main findings for each of them are:

Protected areas

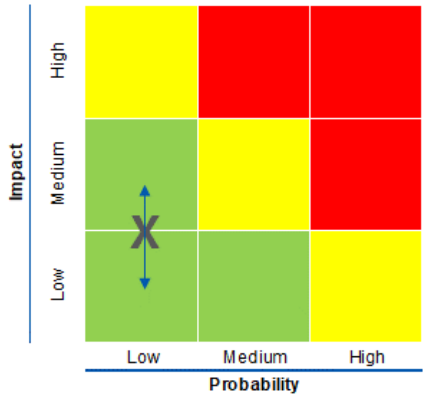
These include national parks, community forests, reserves and conservancies, among others.



It should be highlighted that not all protected areas have the same status of protection and that according to current regulations, conservation areas might imply specific (and more stringent) constraints for project implementation but do not automatically imply a strict exclusion. One exception is the Ramsar sites, which have been considered strict exclusion areas for project development.

Relevant for the protected areas is also the direct link between them and tourism, which is an important contributor to GDP. Therefore, a detailed review of the protected areas must be done prior to selecting a specific location within it and a full ESIA must be undertaken to ensure limited impact.

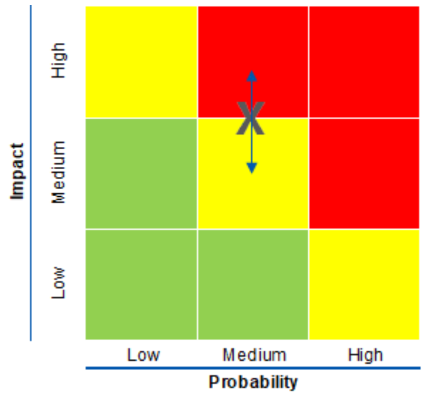
Biodiversity



Namibia has a unique biodiversity in wildlife, flora and fauna and the implementation of renewable energy technologies are not exempt from impacting these ecosystems. While important fauna is covered by the protected areas, this is not always the case for important flora (incl. lichens, welwitschia, quiver tree and devils claw). The implementation of PV plants can affect mainly important flora and the implementation of wind plants affects mainly important bird areas (Ramsar sites, migratory species, birds of prey).

Specific site investigations conducted by ornithologists and ecologists will have to be undertaken prior to any site determination. These shall consider the requirements and guidelines set out in the legal framework for forestry management in Namibia, including but not limited to the Forestry Act 12 of 2001, the Forestry Regulations 2015 and the Community Forestry Management Guideline, as well as the Water, Mining, Forestry and Wildlife Acts and Regulations.

Land use



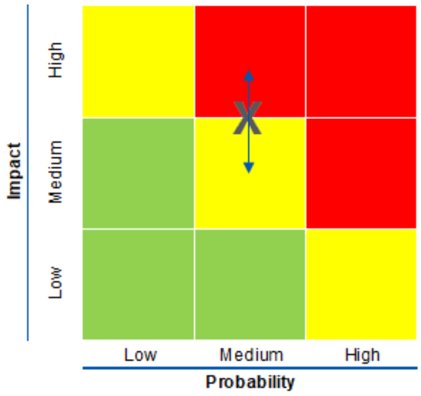
A potential impact of the implementation of green hydrogen projects arises from competing land use in order to implement renewable energy power generation projects (PV and wind) on areas that are currently being used for e.g., agriculture.

Due to the limited availability of areas suitable for crop cultivation in the Central Hydrogen Valley, some zones might be defined for agriculture use only and not allowed for other uses. These competing uses must be carefully evaluated in a case-by-case basis to not turn the projects unsustainable and non-financeable by international institutions.

Potentially, in some cases an integration of uses can be achieved through e.g., agri-voltaics.

Hydrography

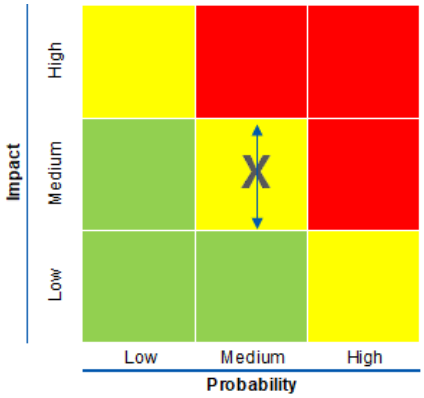
Namibia is already considered a water stressed country and with further effects of the climate change, the situation is prone to worsen. The proper management of available water resources takes on a central role in the development of a green hydrogen economy, due to the additional pressure on current water systems. Therefore, it is crucial to consider the restrictions on water availability for project development.



In conclusion, considering the current situation in Namibia, available water resources have to be prioritized for human consumption and environmental well-being. The development and implementation of green hydrogen projects shall rely, exclusively, on water resources obtained through seawater desalination, in order to no further increase the current water-stress level.

Heritage and sites of cultural significance

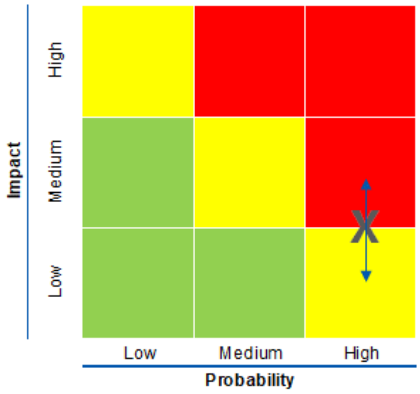
Namibia is a country with many places of heritage and cultural significance, which require special protection and might therefore imply a strict or a partial exclusion for project development.



Any new construction site should be investigated by an archeologist and, if needed, an anthropologist and prior to the start of any construction activities, a chance find procedure must be developed and all staff on site must be trained on it.

Mining areas

Mining is one main productive activity in Namibia, with a GDP's contribution of approx. 12%. Depending on the materials being mined, some of the mining areas might result in a strict exclusion for project development (e.g., diamonds mining areas), while others could be considered partially.

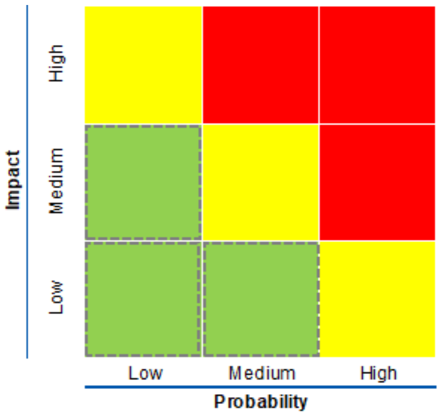


Therefore, it is important to have consultations with the Ministry of Mines and Energy regarding mining licenses issued for a zone and restrictions for other activities to be implemented within these areas.

Mining areas are not considered per se a strict exclusion criterion. On the contrary, due to its abundance, it is necessary to find ways of alignment and identify synergies between both sectors, mining and green hydrogen.

Stakeholders engagement

Social acceptance will be a critical factor determining the level of deployment achieved in the long-term in the implementation of green hydrogen and derivatives projects. The perception of affected communities of the benefits or disadvantages of the implementation of these projects in their territories will influence their sustainability.



Due to this, it is crucial that the relevant stakeholders (incl. national, regional and local authorities, communities and NGOs) are engaged in an early phase on all discussions, advances and decisions not only on a project-specific basis but also in all superordinate activities that define the framework on which these projects can be developed and implemented.

Summary of identified red flags

Most of the potential impacts of green hydrogen projects on environment and society can be avoided or mitigated through an adequate regulative framework that focuses on sensitive issues. Three main aspects have been identified as red flags (higher risks associated with them): Land use and changes on it, water resources and mining areas. The red flags are presented in the following table, where also initial mitigation measures are proposed.

Table 1: Red flags for environmental and social aspects

	Description	Overall risk classification	Remarks / Recommendations
Land use	▪ In the Central Hydrogen Valley, the current land use includes agricultural activities (grazing and cultivation) and freehold, large scale and customary small-scale activities. ▪ For project development current land use and potential changes have to be carefully assessed since international funding institutions (such as the International Funding Corporation, IFC) do not provide funding anymore if the land use is change from e.g., agriculture to energy production.	Medium / High	▪ Current land use and viability of project to change land use prior to project acceptance must be carefully evaluated. ▪ The implementation of renewable projects in agricultural areas should be evaluated and could still be feasible, if these projects can be integrated in the current land use or complement it (for example, agri-voltaics).
Hydrography	▪ Namibia is a country with already high water-stress. ▪ Recharge rates of most water resources are very low. ▪ Total available volumes are highly uncertain.	High	▪ Considering the high water-stress level already present in Namibia, current water resources should be prioritized for human consumption and environmental well-being, avoiding potential conflicts at local, regional, or national level. ▪ The development and implementation of green hydrogen and derivatives projects shall rely, exclusively, on water resources obtained through seawater desalination, in order to no further increase and, in the future, even decrease the current water-stress level. ▪ Specific safety distances (buffers) have to be kept to the watercourses.
Mining areas	▪ National Mining Legislation (ML) prohibits non-mining personal in mining licensed areas. ▪ Exclusive Prospecting Licenses (EPL) usually cover much larger areas and do not prevent access to the land for other industries.	Medium / High	▪ Consultations with the Ministry of Mines and Energy have to be performed to obtain up-to-date information for the mining licenses issued and restrictions for other activities to be implemented within these areas. ▪ Mining areas are not considered per se a strict exclusion criterion. Due to its abundance, it is necessary to find ways of alignment and even synergies between both sectors, mining and green hydrogen.

The conduction of detailed Environmental and Social Impact Assessments (ESIAs) for specific locations is essential due to the high amount and distribution of protected areas and relevant flora and fauna. The initial assessment presented above aims only at giving a first indication of the critical aspects that will be encountered by most project developers at any selected location and that should be duly addressed with proper regulations.

2.2 Renewable energies

As for the renewable energies in the Central Hydrogen Valley an evaluation with focus on wind and PV, has been performed, covering the following areas:

- GIS-based topographical desktop survey,
- Determination of the solar PV resource potential and the theoretical PV capacity and energy yield,
- Determination of the wind resource potential,
- Determination of suitable areas for the implementation of wind power plants,
- Determination of the theoretical wind energy capacity and energy yield per area.

2.2.1 White mapping

White mapping means the gathering of topographical data and information of exclusion and (environmental) constraint areas for a defined region. For the potential implementation of renewable energy projects, a series of features have to be considered and buffers (or safety distances) to these have to be determined specifically for wind and PV plants. These features include, among others, roads, dams, airports, lodges & camping, transmission lines, exclusion areas (e.g., Ramsar sites) and urban areas.

The respective features including the corresponding buffer areas were defined as exclusion areas and not suitable for the implementation of wind or PV power plants[1]. Additionally, restrictions on the maximum allowed slope for the terrain were also included in the analysis. The remaining theoretical areas potentially suitable for the implementation of PV and wind power plants after application of all relevant buffers and safety distances are presented in Figure 3 for PV power plants and Figure 4 for wind power plants.

[1] As already mentioned in the environmental and social aspects, protected areas such as national parks, community forests and communal conservancies are not automatically considered as exclusion areas.

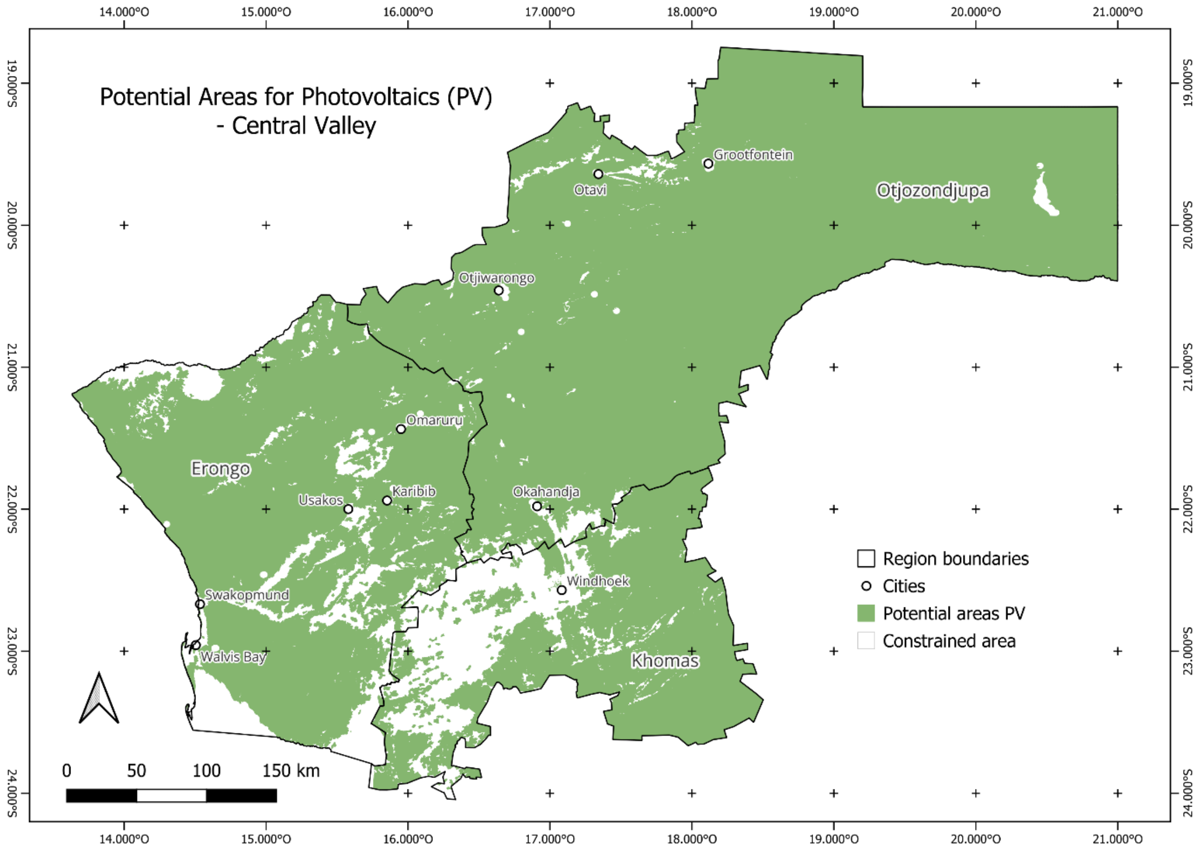


Figure 3: *Theoretical areas potentially suitable for the implementation of PV power plants (Source: Fichtner)*

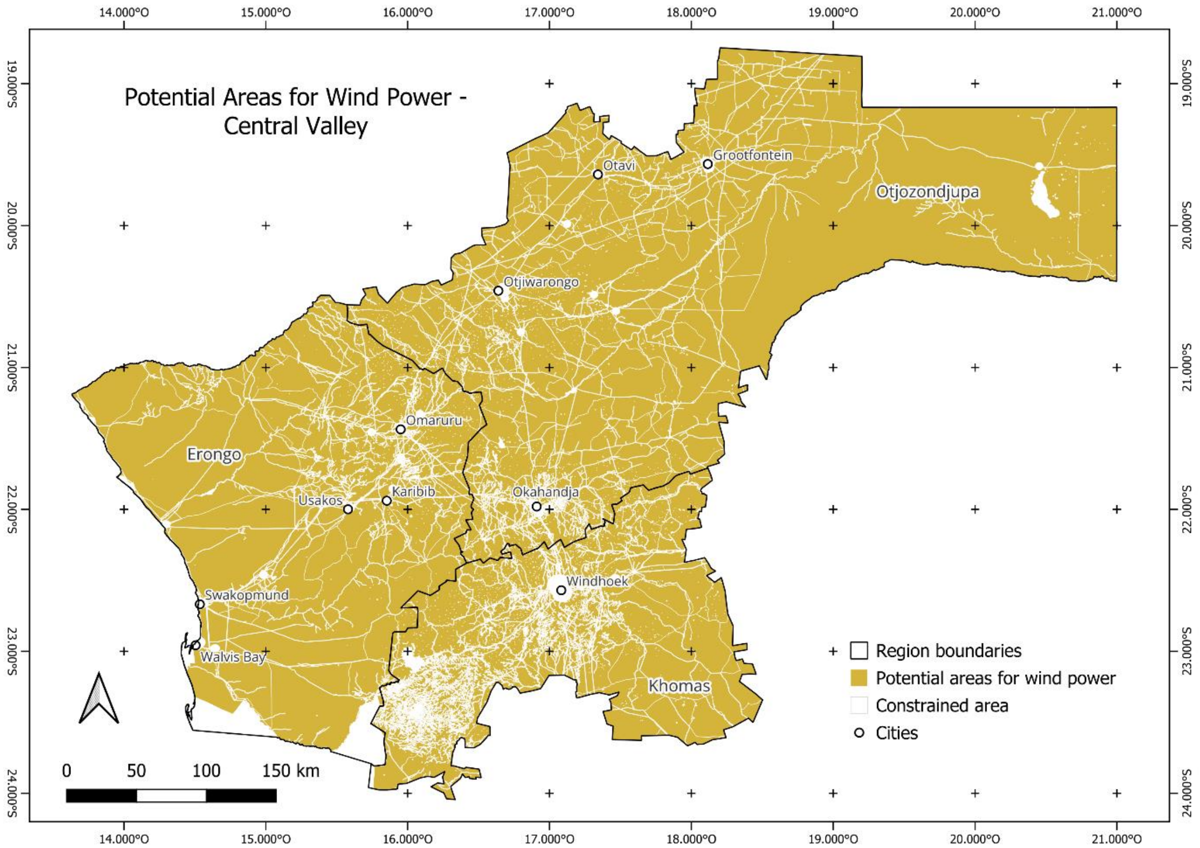


Figure 4: *Theoretical areas potentially suitable for the implementation of wind power plants (Source: Fichtner)*

2.2.2 Potential of renewable resources

Solar photovoltaic potential

To assess the solar irradiation and photovoltaic energy potential for the Central Hydrogen Valley, the data from the Global Solar Atlas (GSA)[2] was used. In general, the solar resource is well suitable for photovoltaic power plant implementation throughout Namibia. For the Central Hydrogen Valley, the global horizontal irradiation (GHI) boasts above 2,200 kWh/m² (Figure 5) resulting in a photovoltaic power production exceeding 1,900 kWh/kWp (Figure 6).

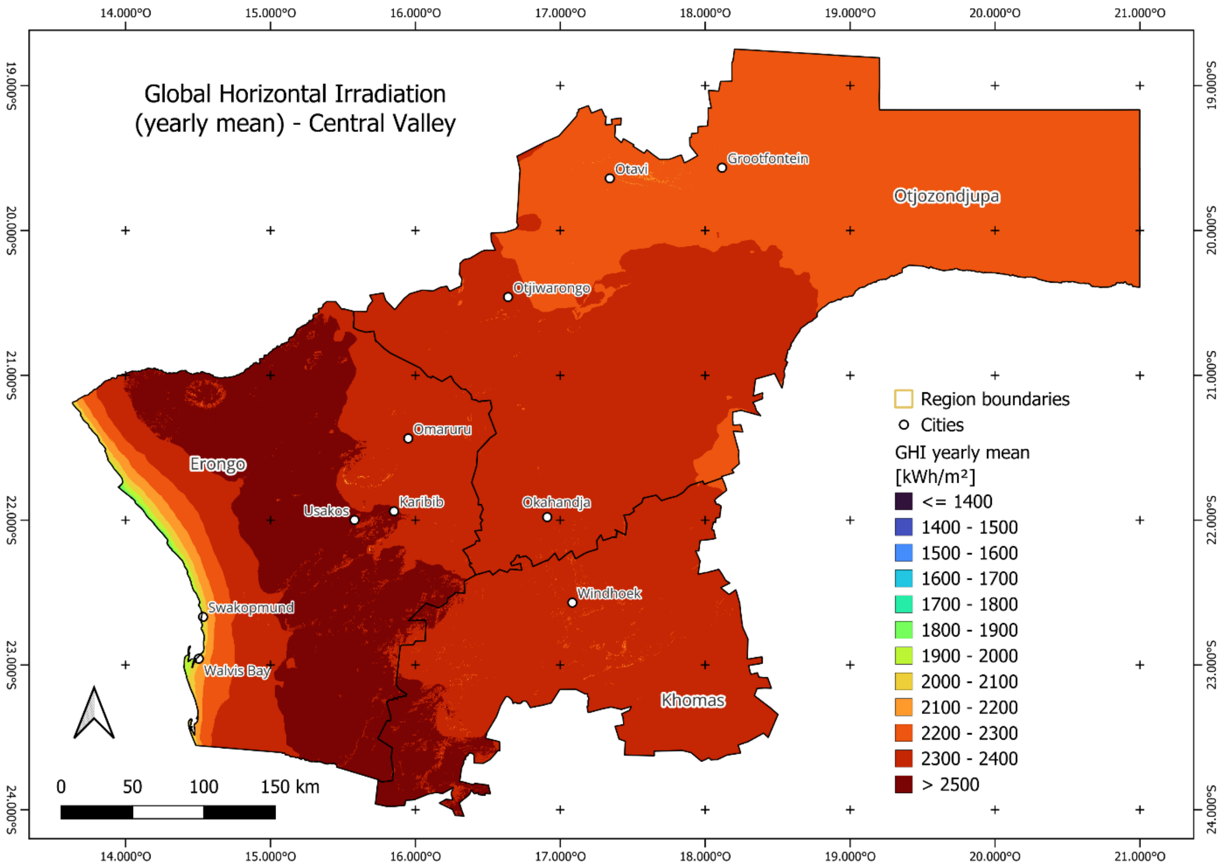


Figure 5: Global horizontal irradiation of the Central Hydrogen Valley (Source: GSA; modified by Fichtner)

[2] https://globalsolaratlas.info/

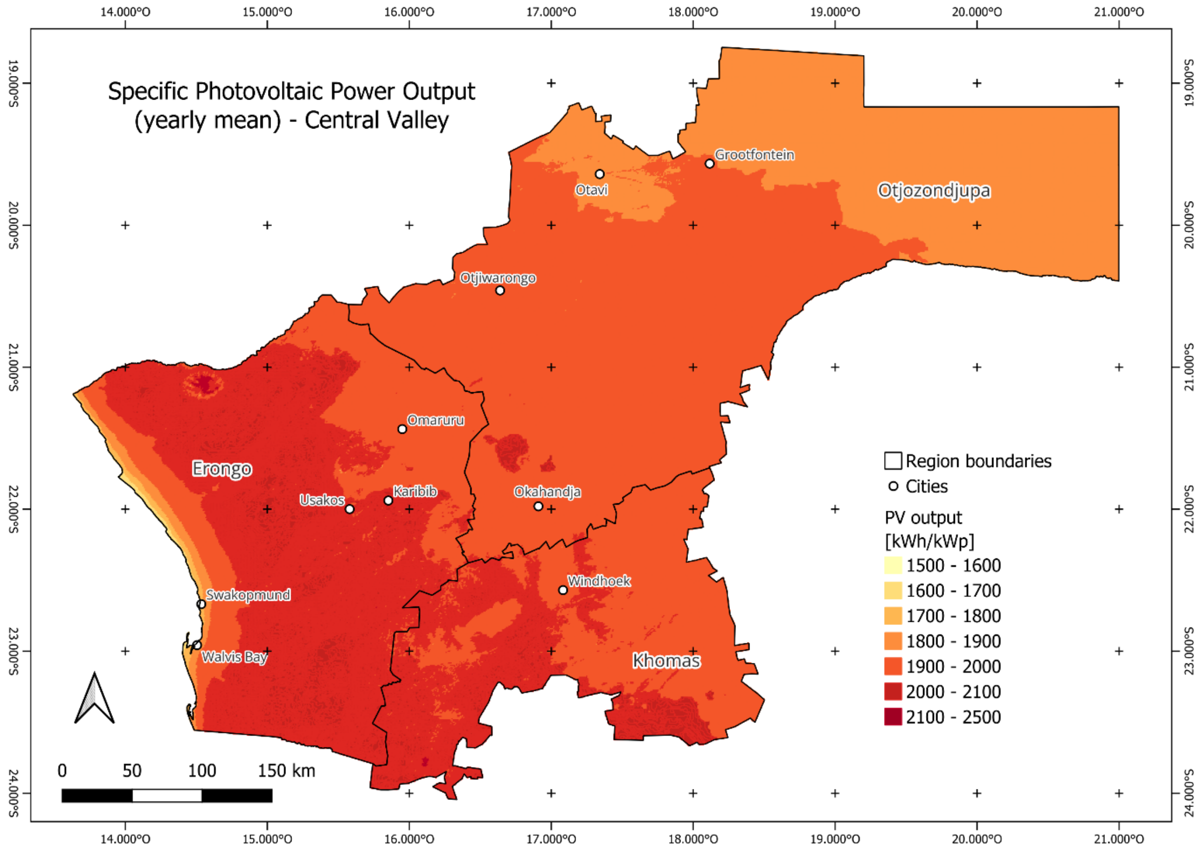


Figure 6: *Photovoltaic power potential of the Central Hydrogen Valley (Source: GSA; modified by Fichtner)*

Wind resource potential

The wind resource potential was assessed on publicly available data sources with Global Wind Atlas (GWA)[3] leading the way. The mean wind speed and wind power density distributions show a great variation across Namibia; the highest wind speeds are expected in the coastal regions in the southwest as well as the far northwest of the country. Mean wind speeds can reach extraordinary levels of >10 m/s as in the hotspot coastal zones but may also hardly scratch the 6 m/s-limit in vast areas across the country. Figure 7 and Figure 8 show the wind power density distribution and the mean wind speeds for a height of 100 m.

[3] https://globalwindatlas.info

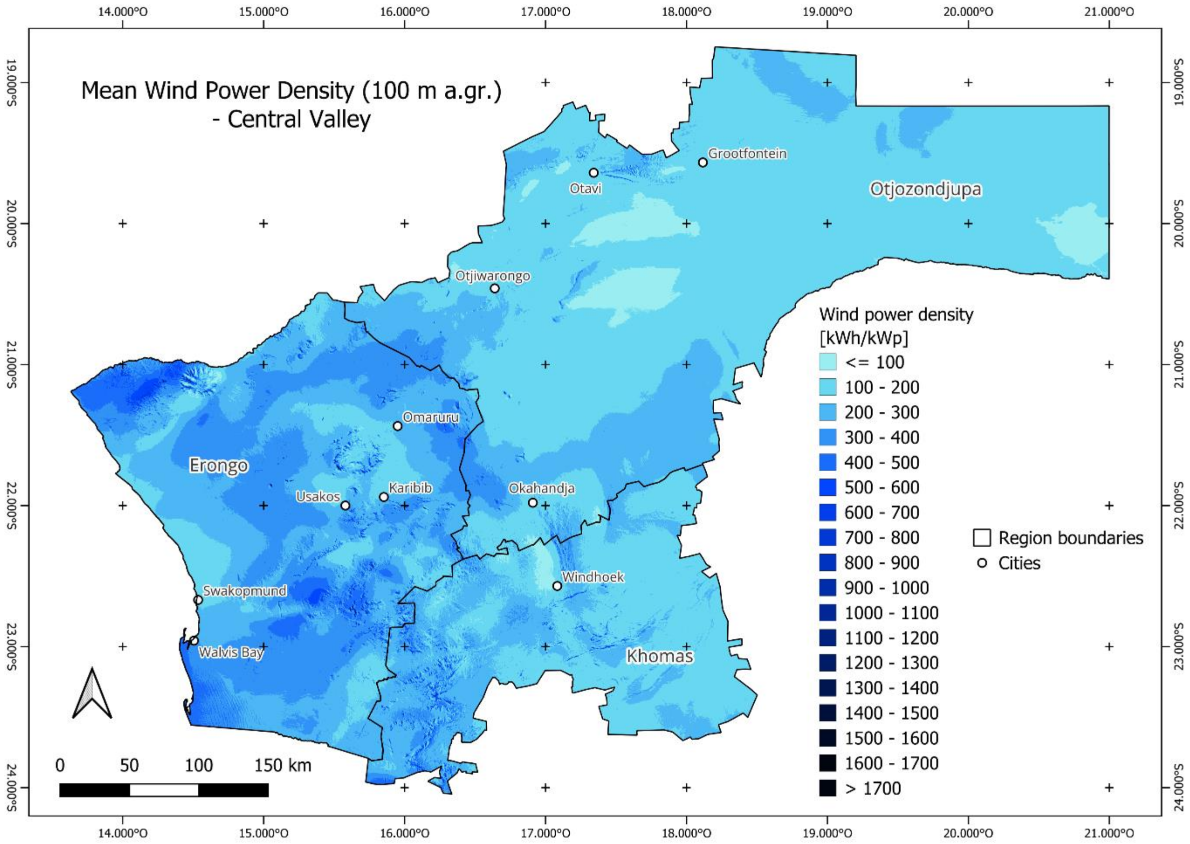


Figure 7: Wind power density at 100 m a.gr. for the Central Hydrogen Valley (Source: GWA; modified by Fichtner)

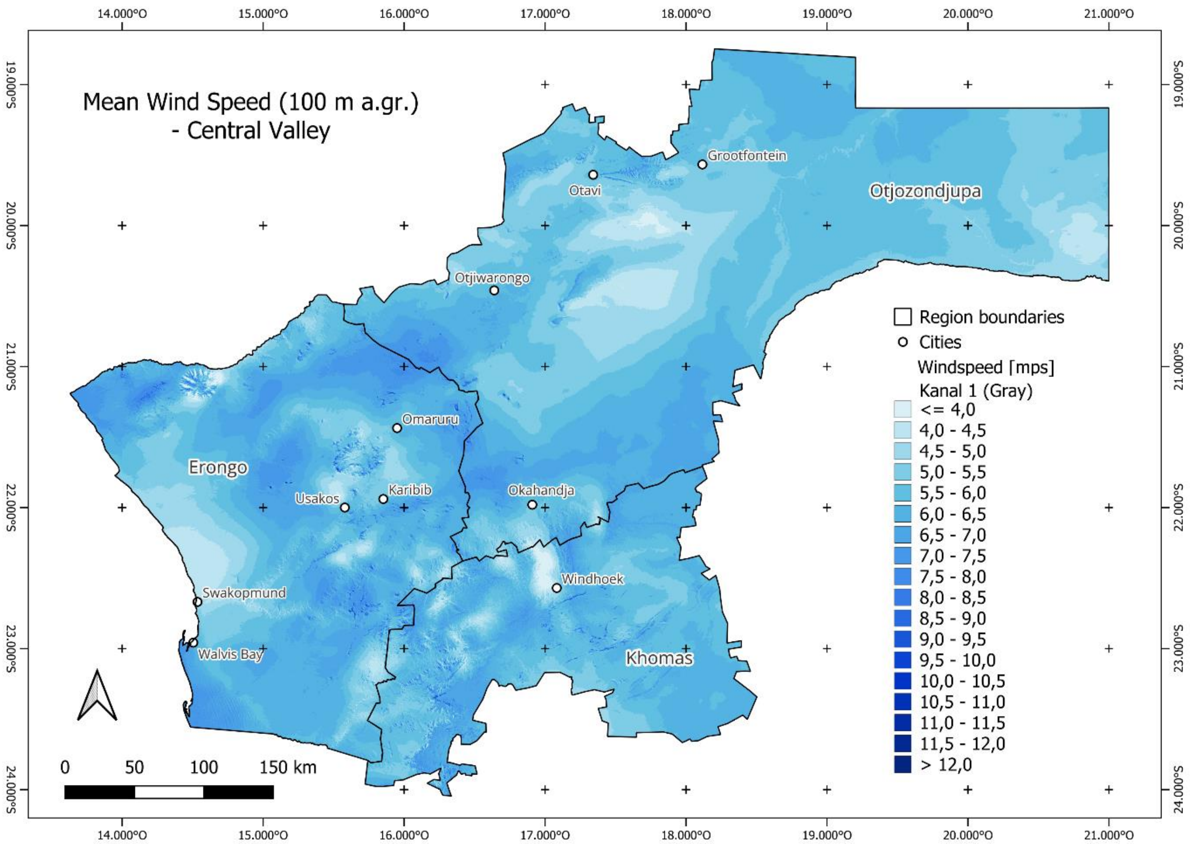


Figure 8: Mean wind speed at 100 m a.gr. for the Central Hydrogen Valley (Source: GWA; modified by Fichtner)

Differing to the solar resource potential the wind resource is not as consistent and evenly distributed over the area of interest. Thus, not the entire Central Hydrogen Valley can be considered suitable for the implementation of wind power but only separate areas within.

To select and differentiate between potentially suitable areas for wind plants implementation, parameters were defined for mean wind speeds and wind power density at different heights as specific minima for economically viable wind power implementation, taking into account that the objective is the maximum potential for green hydrogen production under different scenarios rather than the determination of the best spots for maximized wind energy production. The derived parameters are shown in the table below.

Table 2: Defining parameters for selection and determination of suitable wind power areas

	Minimum wind power density	Minimum mean wind speed
Core areas	500 W/m² @ 150 m a.gr.	>7.0 m/s @ 100 m a.gr.
Focus areas	300 W/m² @ 100 m a.gr.	>6.0 m/s @ 100 m a.gr.

The two defined areas (core and focus) are further divided into three categories:

- Category 1 (Core areas)- comprising the potentially most suitable sites in regard to wind resource and terrain conditions,
- Category 2 (Core areas) - similarly good wind resource expected, but more difficult implementation expected due to e.g., more complex terrain conditions.
- Category 3 (Focus areas) - comprising areas with lower wind range conditions.

Potentially suitable areas for implementation of PV and wind

According to the results of the white mapping, the PV output of the theoretical potential areas for photovoltaic implementation in the Central Hydrogen Valley is shown below.

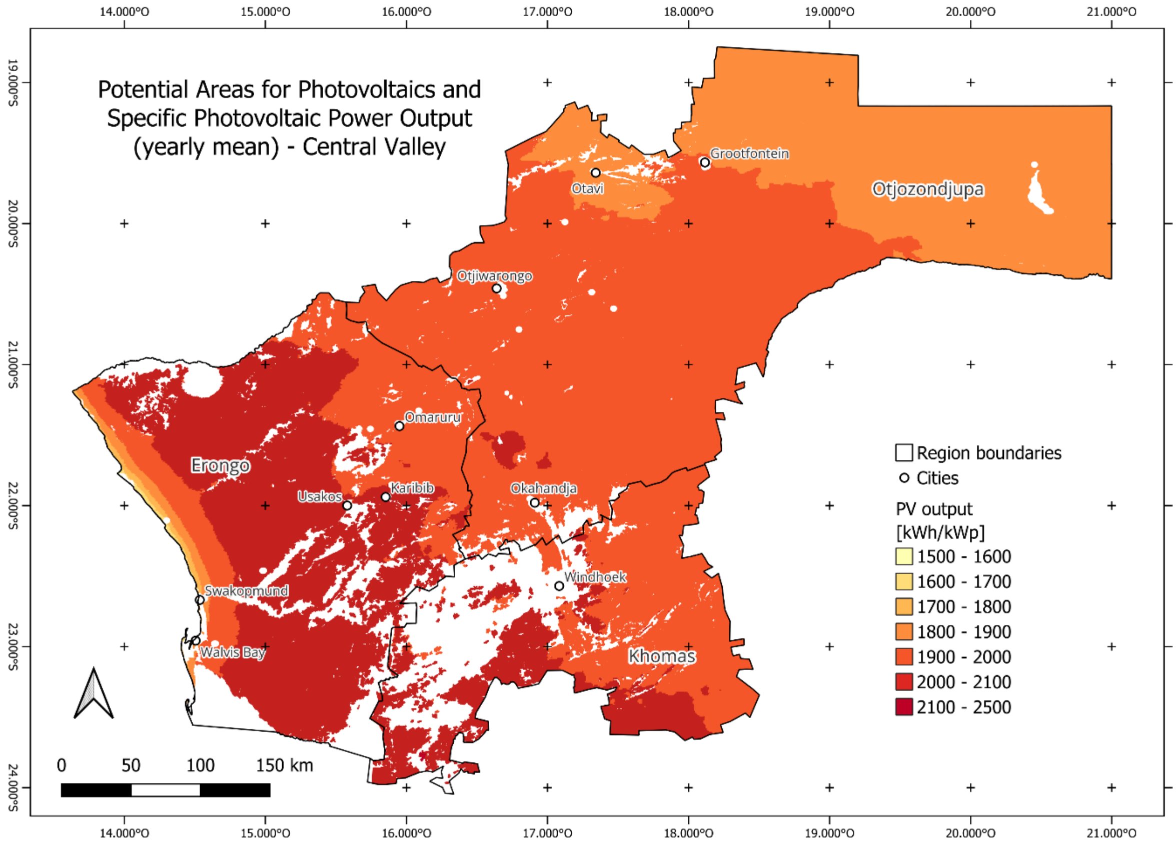


Figure 9: PV power output of the theoretical potential areas (Source: Fichtner)

For the implementation of wind power plants a total of 26 zones or areas (A-Z) were selected and considered generally suitable from a wind resource point of view as well in regard to the conducted topographical desktop analysis.

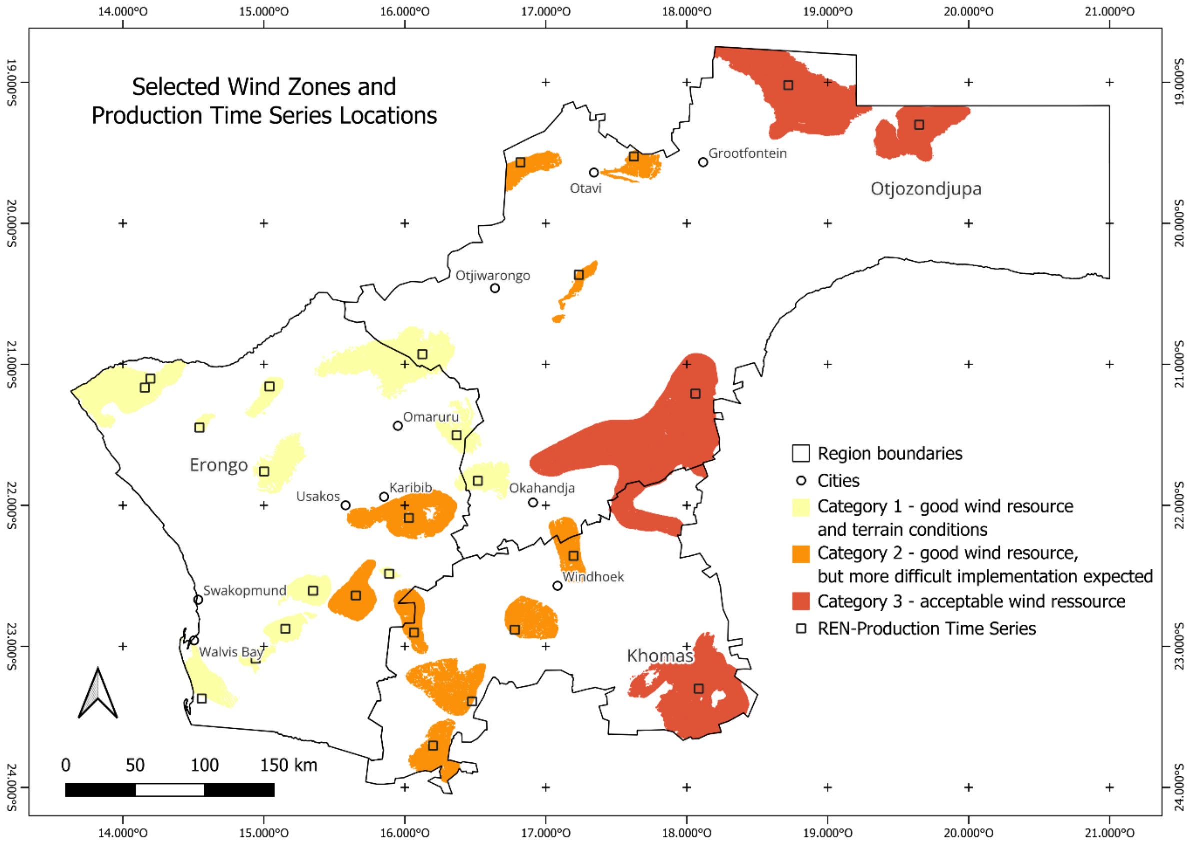


Figure 10: Selected 26 zones suitable for the implementation of wind power plants (Source: Fichtner)

According to the resources assessment performed for PV and wind, it can be concluded that PV is not a limiting factor in the Central Hydrogen Valley, but the wind resource is. Therefore, the wind potential is the factor that will narrow the sites for potential hydrogen production. As such, the pre-selected 26 zones for wind are the zones that will be further analyzed to assess their hydrogen production potential.

To give a better idea of potential interactions between protected areas (not per se exclusion areas), active mining activities and the selected 26 zones, Figure 11 shows a combination of all these features.

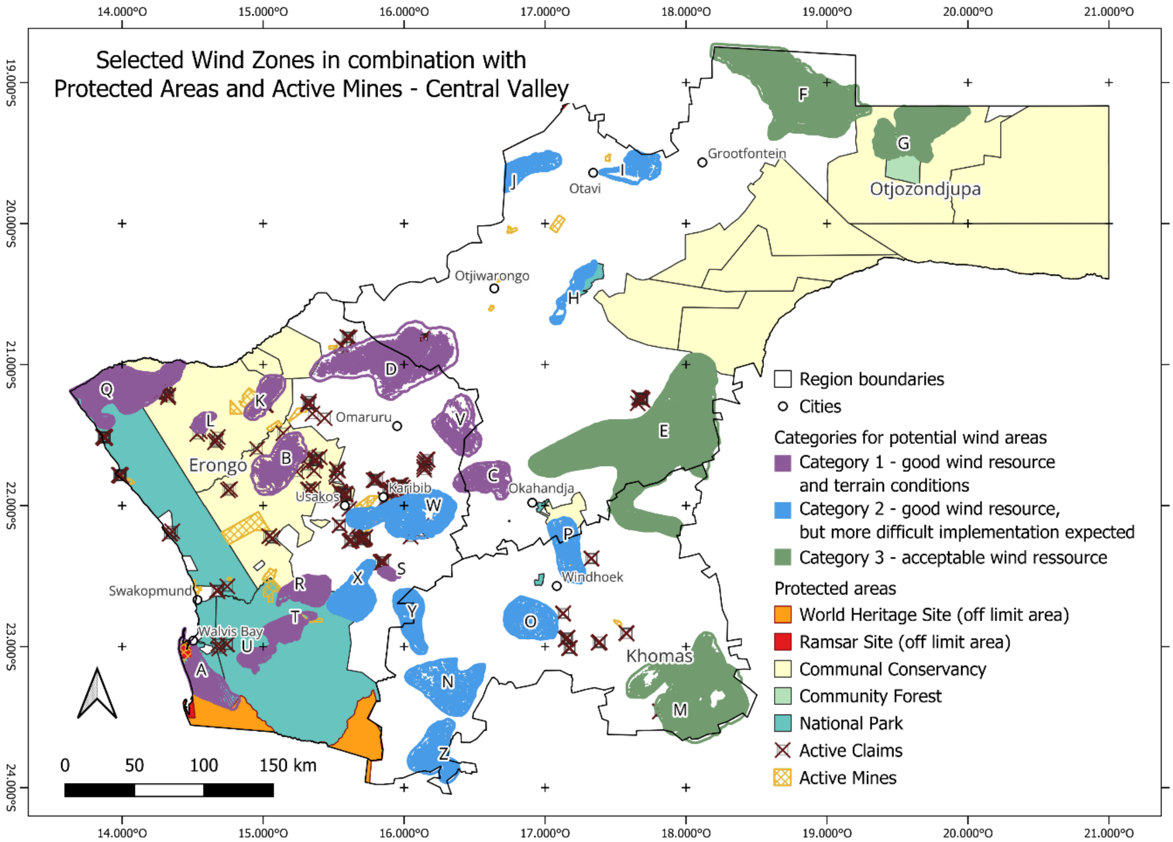


Figure 11: Selected wind zones in combination with protected areas and active mines (Source: Protected planet & Atlas of Namibia; modified by Fichtner)

Theoretical renewable power potential

The overall theoretical potential for the installation of solar PV and wind power in terms of installed capacity and power generation is shown in Table 3. While the theoretical wind power potential is based on and limited to the dedicated wind zones defined and discussed above, the theoretical potential for solar PV is based on the generally suitable area of the Central Hydrogen Valley considering topographical constraints only.

Table 3: Theoretical renewable power potential for the Central Hydrogen Valley

	Unit	Solar PV	Wind Power
Theoretical installed capacity	MW_{dc} / MW	12,212,673	167,586
Theoretical power generation	TWh	24,196.5	458.3

The theoretical potential shall not be misinterpreted with the actual capacity that will be feasible to install and operate in the Central Hydrogen Valley. The provided numbers are based on a set of assumptions and must be seen in connection with these assumptions.

The determined theoretical potential for solar PV would involve the coverage with PV modules of the entire area colored in green shown in Figure 3, i.e., an area of more than 159,000 km² - approximately 77% of the total land surface of the Central Hydrogen Valley - would be overbuilt with PV-modules. Such is eventually not considered feasible and the theoretical potential - only based on topographical constraints and general climatic conditions - must be further analyzed to determine the technical potential (e.g., under consideration of the terrain and environmental conditions on a site-specific level), the economic potential (not every PV or wind energy plant may be economic viable) and eventually the sustainable implementation potential.

2.3 Hydrogen potential and infrastructure

Based on the results obtained from the analyses on renewable energies, the following 26 zones are selected for the assessment of green hydrogen production, as illustrated in Figure 12.

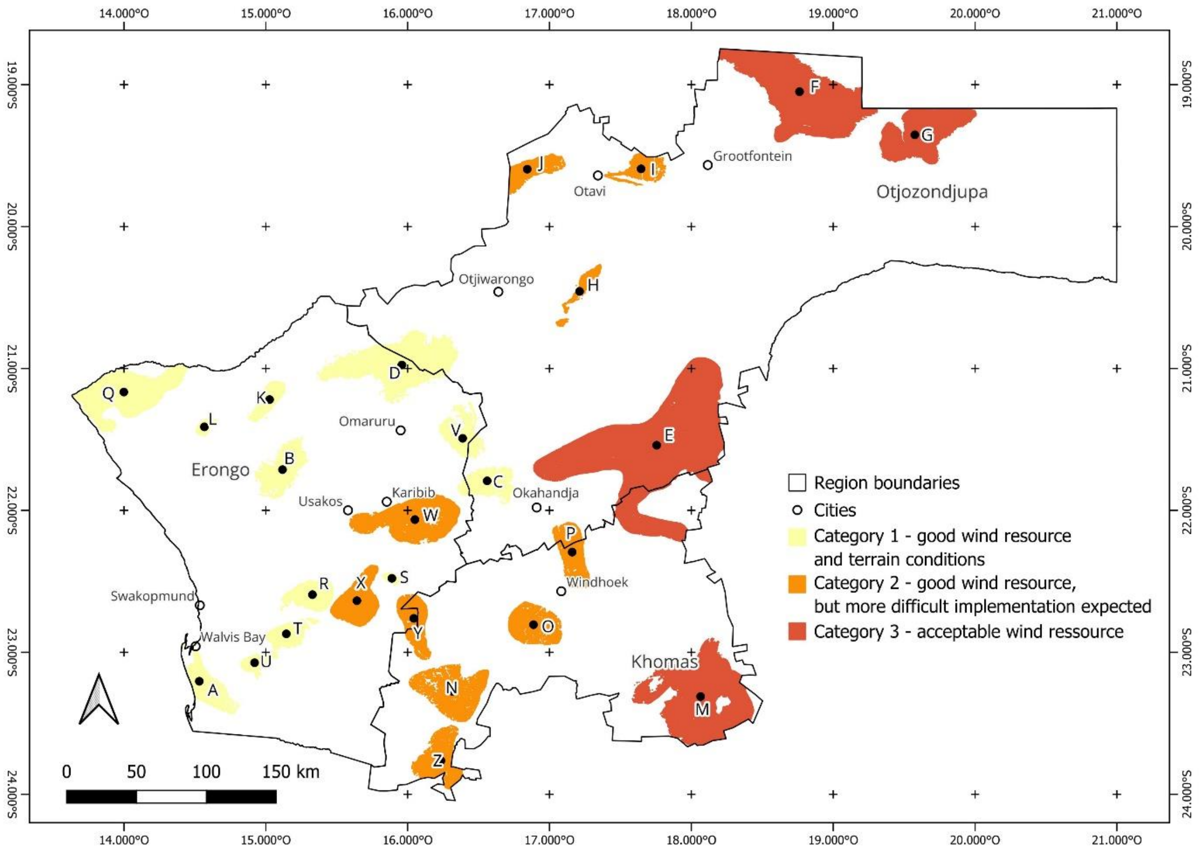


Figure 12: 26 identified locations (Zone A-Z) for green hydrogen production

As already mentioned, the wind resources have been identified as the limiting factor or primary driver that determines the potential and basis for zone selection of green hydrogen production in Namibia.

2.3.1 Levelized cost of hydrogen and production potential

The potential for production of green hydrogen in the Central Hydrogen Valley was assessed based on the two key measures: Levelized Cost of Hydrogen (LCOH), and the yearly production capacity.

Fichtner utilized its inhouse optimization tool (H_2-Optimizer) to generate a least-cost system of the green hydrogen production in the selected zones for a target hydrogen production of 90 kTPA considering:

- multiple locations of solar PV & wind and the fluctuating availability of these resources,
- electrical energy storage (battery),
- electrolyzer, and
- hydrogen storage.

As many technical details and project requirements are not yet available, assumptions have been made to ensure that an early-stage assessment of the green hydrogen potential in the Central Hydrogen Valley can be provided.

The levelized cost of hydrogen for every selected zone were calculated based on the mass and energy balance and system cost to provide a basis for the comparison of the economic attractiveness in each selected zone. Furthermore, sensitivity calculations are conducted to investigate the influence of changes on the LCOH of different parameters such as cost assumptions.

An overview of the results is presented in Table 4. The first column is the ranking of the zones according to their LCOH values starting with the least LCOH at rank 1. The third column is the LCOH of the optimal system design. The rows that are highlighted in blue are the top 5 zones with the lowest LCOH, whereas the row highlighted in grey is the zone with the highest LCOH. The yellow PV zone represents the areas with insufficient or no wind potential and thus reflects the cost of hydrogen production on a PV-only basis.

Table 4: Ranking of zones according to their specific LCOH

Ranking	Zones	LCOH (USD/t_{H2})
1	A	5,023
6	B	5,380
4	C	5,210
2	D	5,044
13	E	5,641
22	F	5,965
23	G	6,090
5	H	5,255
24	I	6,143
18	J	5,809
3	K	5,170
25	L	6,170
14	M	5,655
7	N	5,408
11	O	5,567
10	P	5,519
19	Q	5,879
26	R	6,222
9	S	5,499
20	T	5,894
16	U	5,692
8	V	5,471
12	W	5,637
15	X	5,668
21	Y	5,895
17	Z	5,785
27	PV	6,393

The zones with their respective LCOH are displayed in . The top 5 zones with the least LCOH in ascending order are zone A, zone D, zone K, zone C, and zone H. Zone R is identified as the zone with highest LCOH. The range for LCOH in all zones utilizing wind power is between 4,872 and 6,222 USD/tH2. For the other zones only utilizing PV (zone PV) the average LCOH is 6,393 USD/tH2.

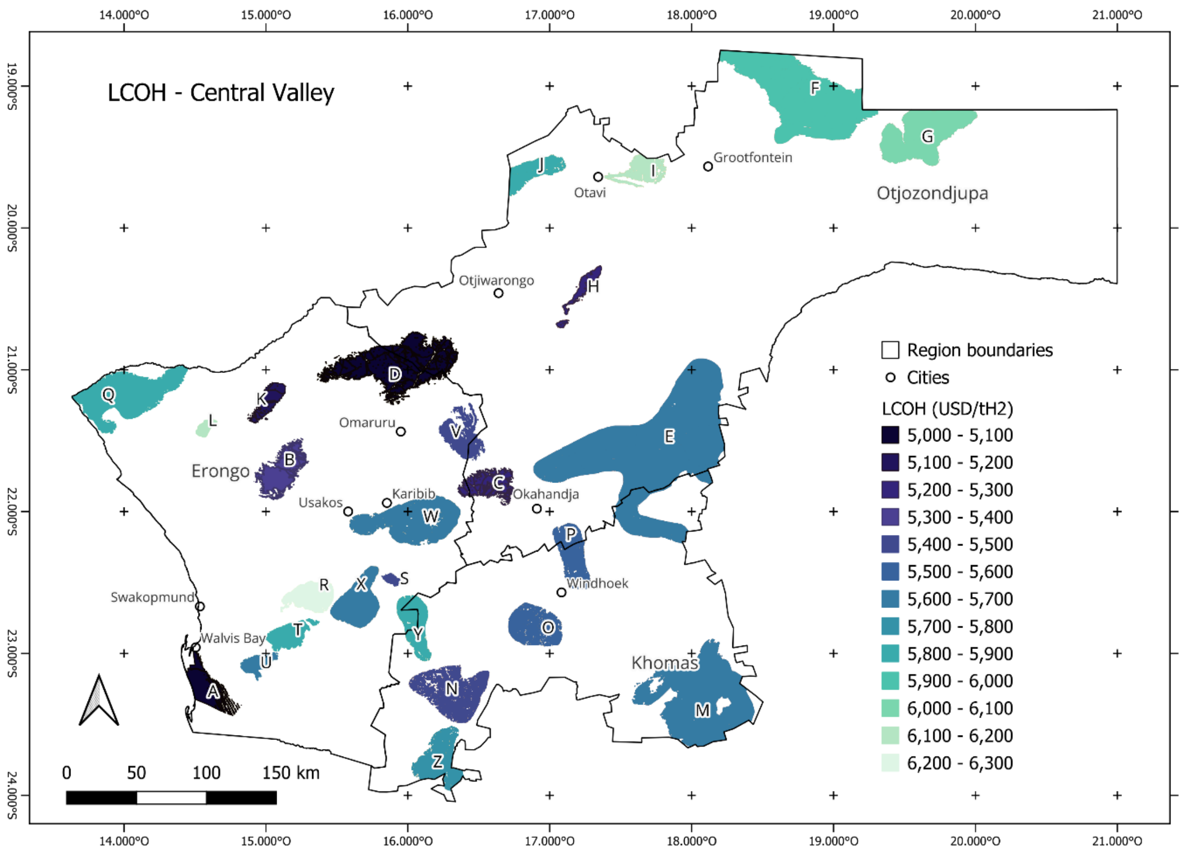


Figure 13: LCOH for the Identified locations (Zone A-Z)

Considering the individual technology sizing from the optimal system configuration for the selected top 5 zones as well as in the zone R and the PV only, the comparison shows that an even distribution of wind and PV is advantageous for system design, as the combination can provide a more constant power curve for the electrolyzer and limits the amount of storage and electrolyzer capacity to be build, as shown in Table 5.

Table 5: Summary of individual technology option sizing for selected zones

	Unit	Zone A	Zone D	Zone K	Zone C	Zone H	Zone R	Zone PV
Solar PV	MW_p	1,156	1,061	1,133	1,104	1,080	1,844	2,364
Wind	MW	1,080	1,141	1,117	1,158	1,268	566	-
Battery Power	MW	39	53	30	41	54	41	50
Battery Energy	MWh	152	165	157	192	200	193	260
Electrolyzer	MW	950	951	991	989	958	1,436	1,620
PV / Wind ratio	-	1.1	0.9	1.0	1.0	0.9	3.3	-
RE / Ely ratio	-	2.4	2.3	2.3	2.3	2.5	1.7	1.5

The solar PV and wind installed capacity ratio in the top 5 zones is between 0.9 and 1.1, whereas the renewable plants to electrolyzer ratio is between 2.3 and 2.5. In other words, roughly 2.5 MW of renewable generation capacity is required for 1 MW of electrolyzer, whereas the renewable generation capacity can be divided almost equally between solar PV and wind power generation.

To assess the total potential for hydrogen production of the different zones, the amount of wind required to produce 90 kTPA is interpolated using the maximum wind potential in each zone. This results in the maximum potential for hydrogen production over all zones utilizing a combination of PV and wind power of approx. 12.5 MTPA. As the PV zone does not have a defined area but is representative of all zones without available wind power, it is excluded from this analysis. The results obtained for each zone are presented in Table 6.

Table 6: Hydrogen production potential for each zone based on available wind potential

Zones	Wind potential (MW)	H_2 production potential (kTPA)
A	3,660	285
B	4,176	327
C	3,000	245
D	12,786	1,086
E	42,174	3,290
F	17,292	1,227
G	7,848	563
H	1,434	120
I	2,106	142
J	2,808	202
K	1,956	156
L	648	34
M	11,958	858
N	4,626	359
O	3,600	270
P	3,732	294
Q	10,842	726
R	3,408	166
S	354	27
T	2,508	171
U	1,326	92
V	3,096	234
W	9,216	664
X	5,208	389
Y	3,678	262
Z	4,146	294

Ranking the zones in ascending order by LCOH and considering their maximum hydrogen production potential, gives the diagram shown in Figure 14.

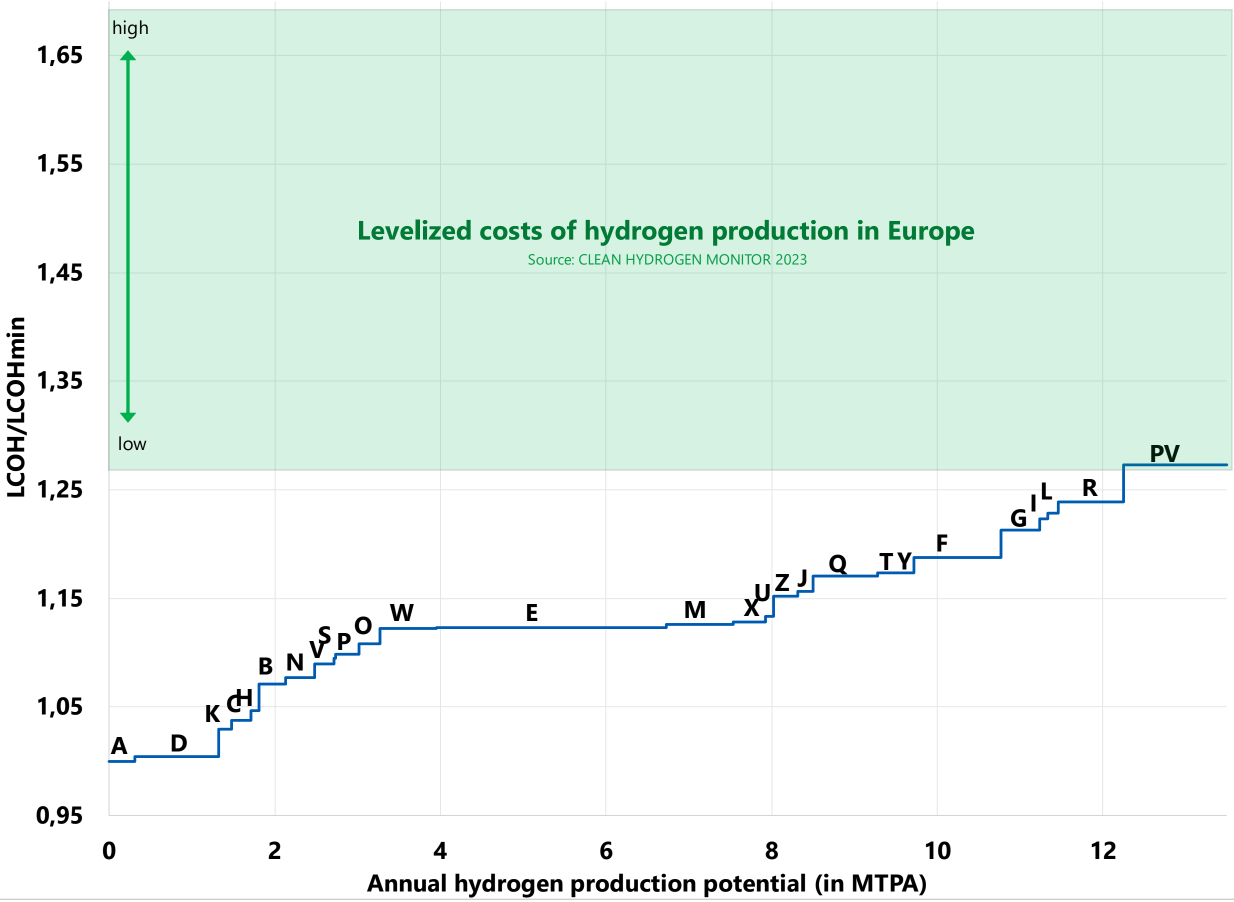


Figure 14: Annual hydrogen production potential for the zones ranked by LCOH and comparison of calculated LCOH with average LCOH in Europe for 2022

Due to the large differences in wind potential, the size of the potential in the individual zones varies greatly between 27 kTPA (zone S) and 3,290 kTPA (zone E). The top 5 regions in terms of LCOH have a hydrogen production potential of around 1,900 kTPA.

Compared to the production costs for green hydrogen in Europe[4] (between 6,300 and 8,500 USD/t $_{H2}$), the LCOHs in the Central Hydrogen Valley are relatively low. The zone with the lowest LCOH has about 1,300 USD/t$_{H2}$ lower costs for hydrogen production and all zones considered that take wind into account are below the lower value of the production costs in Europe. However, if wind is dispensed with and the aim is to produce hydrogen purely from PV, the costs could even achieve the low European level.

2.3.2 Water requirements

Namibia is an arid country with a high water-stress, which should not be further increased by implementation of green hydrogen and derivatives projects. For the development of a green hydrogen economy, an adequate management of water resources shall be implemented. In general, it is recommended that the water requirements for the production processes and cooling should be a) limited to its absolute minimum, and b) produced via seawater desalination at the coastal area and transported to green hydrogen production locations via water pipelines. It is therefore assumed that sufficient water can be provided for hydrogen production via desalination plants, without accessing existing water resources or

[4] CLEAN HYDROGEN MONITOR 2023.

infrastructure. The desalination plans are preferred next to existing ones to make an efficient use of available and shareable infrastructure.

Table 7 and Table 8 show the mass balance for the desalination and electrolyzation processes. For the desalination process the most common applied technology (Reserve Osmosis, RO) has been selected. The data presented are generic and will depend on the final selected technology provider and selected size. The mentioned electricity demand for desalination does not consider pumping.

Table 7: Mass balance for a generic RO desalination process

	Seawater (t)	Water (t)	Electricity (kWh)
SWRO desalination	-3.800	1.000	-0.005

Depending on the salinity level, the overall water quality, and other off-shore conditions (such as depth of the sea) the seawater intake of 3.8 t per ton of portable water can vary significantly.

Table 8: Mass balance for a generic electrolyzer plant

	Hydrogen (kg)	Electricity (kWh)	Water (kg)
Electrolysis	1.000	-55.000	-15.580

For the production of 12.5 MTPA of hydrogen, about 187 MTPA of potable water is needed (depending on salinity content of the seawater). With full load hours between 5,000 and 7,000 h/a some 26,700 to 37,400 m^3/h (or 0.64 to 0.90 million m^3/d) are necessary for the electrolyzers. Around 935 GWh of electricity is needed to produce this amount of water. For sustainability and certification reasons, it is important to ensure that the needed power is generated from renewable sources. If this constraint is considered, using only solar PV, this would result in about 30 MW_p per MTPA of hydrogen.

2.3.3 Green hydrogen derivatives

The local production of hydrogen in large quantities presents several challenges and opportunities that could make the conversion of hydrogen into derivatives useful, applying so-called Power-to-X processes (where X represents any product). Main drivers for the further processing of hydrogen lie within benefits for transport and storage as well as preferences of potential off-takers for direct use in existing infrastructures and technologies. In the following, an overview of main potential derivatives from green hydrogen is given: ammonia, methanol and green fertilizers. The data presented are generic and will vary depending on the final selected technology provider and selected size.

Ammonia

An overview of the mass balance for ammonia is given below. The mass balance does not consider cooling water yet as the final configuration (e.g., water cooling, air cooling) needs to be assessed for specific projects.

Table 9: Mass balance for a generic ammonia synthesis and upfront process steps

	Hydrogen (kg)	Nitrogen (kg)	Electricity (kWh)	Ammonia (kg)	Water (kg)
Desalination			-0.005		1.000
Electrolysis	1.000		-55.000		-15.580
Air separation		1.000	-0.559		-22.000
Haber-Bosch	-0.180	-0.820	-0.330	1.000	-77.000 *
Entire process	-0.180	-0.820	-10.710	1.000	-102.804

** sum of N_2 compression cooling water and NH_3 loop cooling*

If the total theoretical hydrogen production potential of the Central Hydrogen Valley of 12.5 MTPA would be converted into ammonia, this would allow a production of 66.7 MTPA of ammonia.

Methanol

An overview of the mass balance for methanol is given below. The mass balance does not consider cooling water yet as the final configuration (e.g., water cooling, air cooling) needs to be assessed for specific projects.

Table 10: Mass balance for a generic methanol synthesis and upfront process steps

	Hydrogen (kg)	Carbon dioxide (kg)	Electricity (kWh)	Methanol (kg)	Water (kg)
Desalination			-0.005		1.000
Electrolysis	1.000		-55.000		-15.580
DAC		1.000	-0.500		
Methanol synthesis	-0.189	-1.374	-0.147	1.000	0.562
Entire process	-0.189	-1.374	-7.808	1.000	2.519

If the total theoretical hydrogen production potential of the Central Hydrogen Valley of 12.5 MTPA would be converted into methanol, this would allow a production of 63.5 MTPA of methanol.

Green fertilizers

Another option for Namibia, with agriculture as an important economic sector in the country, is the further processing of ammonia into green fertilizers.

Today, Namibia does not produce any inorganic or chemical fertilizers, and imports 100% of them (mostly from South Africa), with an average annual consumption of about 20.000 tons of fertilizers between 2016 and 2019.[5] Fertilizer prices in Namibia are therefore heavily dependent on South African prices as its biggest supplier, which in turn is dependent on global market price volatilities. Because of this supply chain dependency, high import costs and prices, fertilizers are not commonly and widely used by Namibia's farmers, which makes the nations consumption of inorganic fertilizer one of the lowest worldwide with 4 kg

[5] Namibian Agronomic Board, 2022

per hectare of arable land, compared to Sub-Saharan Africa with 22 kg per hectare and the worldwide average of 150 kg per hectare.[6]

The main fertilizer types used in Namibia are nitrogen-based fertilizers as Urea, Limestone Ammonium Nitrate (LAN), phosphate-based fertilizers as Single Superphosphate (SSP) and compound fertilizers (Nitrogen + Phosphorus + Potassium - NPK).

Currently, most of the global ammonia production is natural gas based. This ammonia is then further processed into downstream products (e.g., urea, nitrates and chemicals like melamine) within the plant boundaries. In modern nitrogen fertilizer plants, natural gas is used as the major feedstock, with 80% of the gas used as feedstock, and 20% used for heat and electricity generation for the process.

Based on the two main end products from ammonia production, namely urea and ammonium nitrate, different fertilizer types are manufactured by mixing them with ingredients such as phosphorus and potassium (potash) to form NPKs, limestone/dolomite (Calcium Carbonate) to form CAN (Calcium Ammonium Nitrate), or by mixing urea and ammonium nitrate solution to make UAN (Urea Ammonium Nitrate).

While most fertilizer production is nitrate based and its major feedstock is ammonia (generated using natural gas), phosphate-based fertilizer producers tend to buy merchant (traded) ammonia, as they focus on own production of main resource input to the product which is phosphorus rock. Merchant ammonia makes up only about 10% of the entire world production volume, which is often transferred to other plants for downstream processes. As an example, Yara, one of the leading global ammonia and fertilizer production company, has a few dedicated large-scale ammonia production facilities, allowing further processing in the same facility and/or shipping to specialized fertilizer production facilities in certain markets across the globe. The material consumption per ton of fertilizer is exemplary shown in the table below.

Table 11: Material consumption per ton of fertilizer produced

Material consumption per ton	Ammonium nitrate	Urea	CAN	DAP	NPK (15-15-15)
Ammonia [t]	0.21	0.57		0.26	
Nitric acid [t]	0.79				
Ammonium nitrate (35-0-0) [t]			0.66		0.26
Phosphoric acid [t]				0.74	
Calcium carbonate [t]			0.41		
DAP (18-46-0) [t]					0.33
KCl (0-0-60) [t]					0.25
Carbon dioxide [t]		0.73			

Abbreviations: CAN - Calcium Ammonium Nitrate | DAP - Diammonium Phosphate | NPK - Fertilizer based on divers combinations of nitrogen, phosphorus and potassium

Considering the potential to produce green ammonia in large volumes, the deployment of a national industry for production of green fertilizers should be considered as a key driver for increasing food safety

[6] https://data.worldbank.org/indicator/AG.CON.FERT.ZS?locations=NA

in the country by strengthening, modernizing and making more sustainable the current agricultural system, with higher crop yields, and reducing the dependency of the country on imported products that are so interlinked with global geopolitical circumstances. Prospectively, the country could aim to become a net exporter of green fertilizers and green food for the regional and international markets.

The total green ammonia production potential of 66.7 MTPA could yield a green fertilizer production potential of about 240 MTPA[7] of Calcium Ammonium Nitrate (CAN) or about 117 MTPA of Urea, which would allow the country to cover its current annual consumption (approx. 20.000 tons) and increase its very low specific use.

2.3.4 Potential sources of biogenic carbon molecules

The further processing of green hydrogen in derivatives such as methanol or synthetic fuels requires additional carbon molecules. The main ways for obtaining the required carbon molecules for PtX processes include Direct Air Capture (DAC), capture from industrial processes and capture from transformation processes of sustainable biomass (e.g., from biogas generation or from thermal treatment).

The higher carbon concentration in biomass makes it the preferred carbon source where available. Taking into account that biomass encroachment is a critical problem throughout Namibia, the use of this bush biomass for hydrogen derivatives production processes offers the opportunity to reduce the problem and be a source for biogenic carbon molecules and was therefore closer examined.

If the estimated amount of bush biomass for the Central Hydrogen Valley (150 Mt[8]) shall be used within 20 years, assuming 3% growth per year of the remaining amount, about 10 Mt per year can be extracted[9]. One of the most efficient ways to process this biomass would be a gasification process, for which, the bush biomass will be previously torrefied to produce so-called black pellets. Considering some restrictions and the easiness of access to the sources, it is assumed that a share of 50% of the bush biomass is realistically usable for torrefaction. Therefore, the total amount of bush biomass available for torrefaction facilities would be approx. 5 Mt per year. By gasification of the torrefied bush biomass and assuming that 90% of the syngas is converted in a methanol synthesis, this results in about 3 MTPA of methanol. For this, a total of 0.38 MTPA of hydrogen are required, from which 0.15 MTPA are already contained in the syngas and only an additional 0.23 MTPA of hydrogen from electrolysis will be needed. Considering the total theoretical hydrogen production potential of 12.5 MTPA for the 26 pre-selected zones, the requirements for either methanol or synthetic fuel synthesis using bush biomass as carbon source would represent only around 2% of this total amount.

2.3.5 Infrastructure

For the deployment of a large-scale green economy, the development of new related infrastructure and the expansion of the existing one will be required. Among the main components that should be considered in infrastructure in a generic value chain of green hydrogen are:

- Transmission and distribution lines for electricity,

[7] including 0.27 tons of ammonia for nitric acid production.
[8] Total estimated of 450 Mt for Namibia. It is further assumed that approx. one third is located in the Central Hydrogen Valley.
[9] It must be underlined that after this period the supply of bush biomass would continuously decrease and bush biomass as a biogenic carbon source for hydrogen derivatives production would need to be replaced by other sources (e.g., DAC or sustainable sources to be implemented).

- Transport and distribution pipelines for water,
- Local small decentralized and large centralized storage of hydrogen (or derivatives),
- Infrastructure related to transport options of hydrogen and derivatives within the country,
- Roads for transport of equipment, products and for operation and maintenance of the plants,
- Port infrastructure for import of required technologies and components and for export of hydrogen and derivatives.

The infrastructure required for a specific region will depend mainly on local conditions regarding the current infrastructure available and on the selected approach for hydrogen and derivatives production (e.g. centralized vs. decentralized production sites).

Considering these infrastructure components, positioning green hydrogen production near to renewable power generation would have the advantage of avoiding long and large power transmission systems. Especially for large scale hydrogen production where GW-scale systems are involved, the cost for setting up a water and hydrogen transport infrastructure can be lower than investing in a new power transmission system. Therefore, producing green hydrogen close to renewable power generation and transporting green hydrogen via pipeline is taken as the base case for the current analysis.

For the Central Hydrogen Valley, the fundamental infrastructure necessary for green hydrogen production, situated near the renewable power sources, would comprise several key components:

- Firstly, seawater desalination plants will be needed to generate potable water. This water has to then be transported via a pumping station into a water pipeline. Additional pumping stations have to be placed along the pipeline to ensure a consistent water flow towards the electrolyzer sites.
- The produced hydrogen is compressed and introduced into a separate hydrogen pipeline for transportation from the electrolyzer sites to the harbor or to the facilities for further processing into derivatives. Supplementary compressors will need to be positioned along this pipeline to maintain the necessary pressure for efficient hydrogen transport.
- Furthermore, a basic road infrastructure is essential for the initial installation of these systems and for subsequent maintenance activities along the pipeline as well as potential local distribution of small volumes by trucks.

In the following subsections a general overview is given for main aspects to be considered for infrastructure development.

Hydrogen transport options within the Central Hydrogen Valley

When analyzing hydrogen transport from the production sites to the end users or conversion facilities for derivatives, several options can be considered regarding the means of transportation (e.g. by road in trucks or trains or via pipelines) and the transportation medium (e.g. compressed or liquified hydrogen or a hydrogen carrier such as ammonia). Figure 15 shows the different potential options that could be considered for transportation of green hydrogen within the Central Hydrogen Valley.

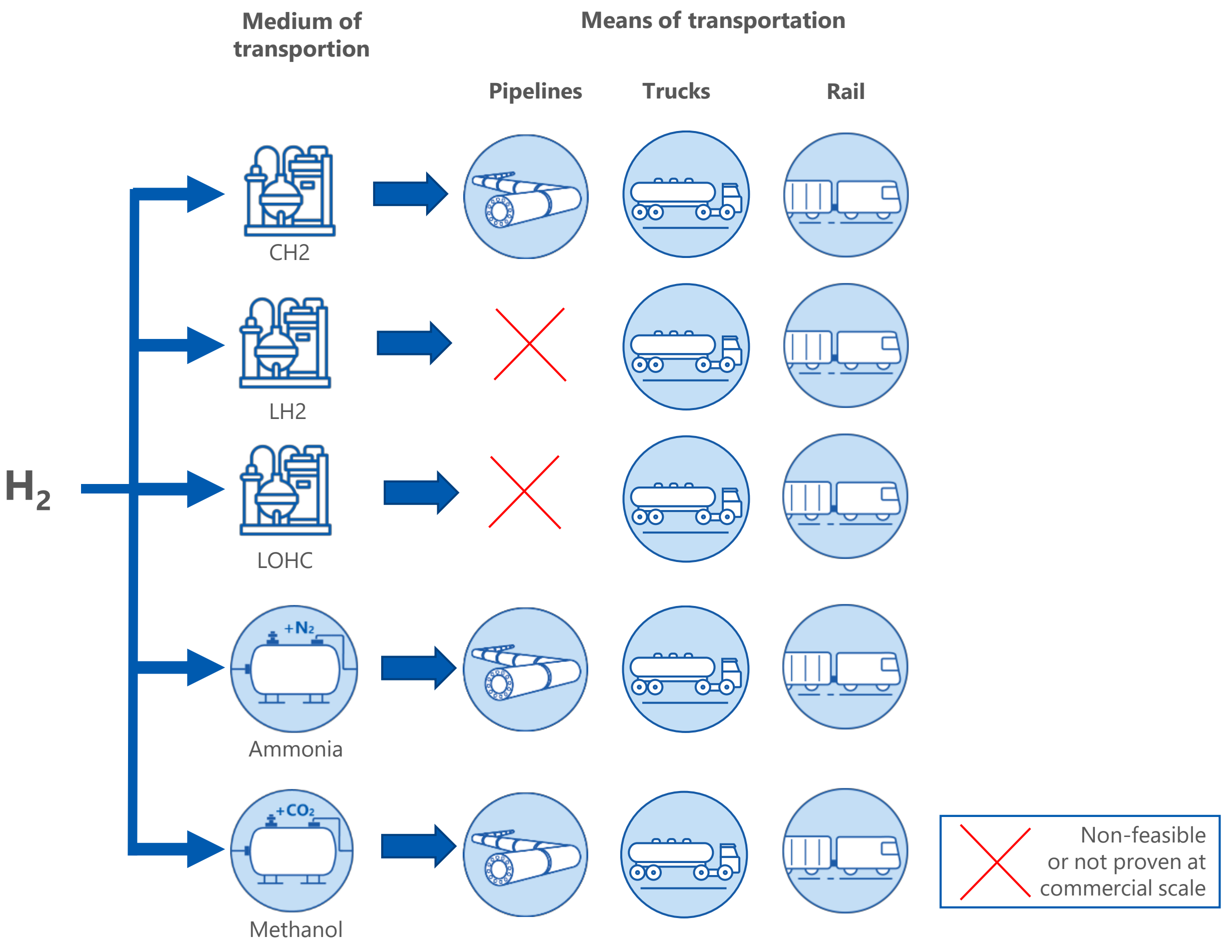


Figure 15: Potential transportation options for green hydrogen

It must be mentioned that the selection of the most adequate means of transportation will depend on different factors such as transport distances and volumes and potential end uses (i.e. if pure hydrogen is required). Table 12 gives an overview of the steps associated with every medium of transport presented in the figure above.

Table 12: Transport steps for different media

Transport medium	Transport steps	Remarks
Compressed hydrogen (CH2)	▪ Pipeline: hydrogen production, hydrogen compression, pipeline, hydrogen storage, hydrogen usage. ▪ Trucks or rails: hydrogen production, hydrogen compression, truck / rail tankers, hydrogen storage, hydrogen usage.	▪ Large volumes and medium to long distances. ▪ Small volumes and short to medium distances.
Liquefied hydrogen (LH2)	▪ Pipeline: hydrogen production, hydrogen liquefication (-253°C), hydrogen injection in cryo-pipeline, hydrogen vaporization, hydrogen usage. ▪ Trucks or rails: hydrogen production, hydrogen liquefication (-253°C), transport in cryo-tankers, hydrogen vaporization, hydrogen usage.	▪ Non-feasible (maintaining low temperatures throughout the transport pipeline would be very energy-intensive. ▪ Small volumes and short to medium distances.

Transport medium	Transport steps	Remarks
Liquid organic hydrogen carrier (LOHC)	▪ Pipeline: hydrogen production, hydrogenation, transport via pipeline (similar to oil pipelines), dehydrogenation, usage.	▪ Possible repurpose of oil pipelines, where available. It would be adequate for large volumes and medium to large distances, but it has not been proven at a commercial scale yet.
	▪ Trucks or rails: hydrogen production, hydrogenation, transport in conventional tankers, dehydrogenation, usage.	▪ Small volumes and short to medium distances.
Ammonia (NH_3)	▪ Pipeline: hydrogen production, ammonia synthesis, transport via pipeline, ammonia cracking, usage.	▪ Up to now only limited experience, mainly to connect industrial sites. But technically feasible and adequate for large volumes and medium to large distances.
	▪ Trucks or rails: hydrogen production, ammonia synthesis, transport via tankers, ammonia cracking, usage.	▪ Well proven at commercial scale. *NOTE: Ammonia cracking is considered the critical part of the process in case pure hydrogen is required at the end.*
Methanol (MeOH)	▪ Pipeline: hydrogen production, methanol synthesis, transport via pipeline, methanol cracking, usage.	▪ Up to now only limited experience, mainly to connect industrial sites. But technically feasible and adequate for large volumes and medium to large distances.
	▪ Trucks or rails: hydrogen production, methanol synthesis, transport via tankers, methanol cracking, usage.	▪ Well proven at commercial scale. *NOTE: Methanol cracking is considered the critical part of the process in case pure hydrogen is required at the end.*

From the presented options, the most adequate seems to be either the transport via compressed gaseous hydrogen or “storing” of hydrogen within a different chemical carrier (ammonia or methanol).

If ammonia and methanol are not considered as commodities as such but only as carriers of hydrogen molecules, its usage is linked with a series of advantages and disadvantages; specifically, both of these two products have an established global value chain, with proven processes and technologies. Nonetheless, in case that pure hydrogen is required, the processes of conversion (from hydrogen to the derivative) and reconversion (from the derivative to hydrogen) are energy intensive and the reconversion technologies are still not proven at commercial large scales, what makes it a rather inefficient option for the transport of hydrogen. The main properties of these carriers, are presented below.

- Methanol: Methanol is a liquid at ambient temperature, and therefore the evaporation losses during transport are negligible. Its volumetric energy density (approx. 4,600 kWh/m^3) is also almost twice as high as that of liquid hydrogen (approx. 2,360 kWh/m^3). As a result, almost twice the energy can be transported in the same volume, which makes it easy to transport methanol over long distances compared to hydrogen.

To produce methanol, a local source of biogenic CO2 is necessary. If the methanol is only needed for inland transportation and needs to be converted back to hydrogen later, it may not be feasible to establish a methanol transportation network. This is because not all locations may have the capacity or interest to produce methanol, necessitating a separate network. This would mean significant investments for a limited number of locations and restricted production volumes.

- Ammonia: At approx. 3,600 kWh/m^3, the volumetric energy density of liquid ammonia is between that of liquid hydrogen and methanol. However, ammonia can only be transported in liquid form at temperatures slightly below ambient conditions or under slight overpressure. Therefore, losses during transport are to be expected even if they are not of the same magnitude as cryogenic liquid hydrogen. Vessels for this purpose are already state of the art. In addition, the effort required for liquefaction or the creation of slight overpressure is much lower than the effort required for the liquefaction of hydrogen.

  Just like with methanol, establishing a separate transportation network for ammonia within the country is not advisable as not all developers aim to produce ammonia, implying the development of a dedicated ammonia network in parallel to the hydrogen network and the implementation of reconversion units. In addition, ammonia is significantly more harmful to the environment than hydrogen and therefore pipe-leakages much more critical. This usually results in higher regulatory requirements and restrictions for implementation in ecologically sensitive areas as well.

In conclusions, the transport of compressed hydrogen seems the most suitable transport option, as it can be produced anywhere and can be transported without high energy consumption for cooling and without losses related to conversion and reconversion processes. Depending on the potential off-takers, it may make sense to build ammonia or methanol pipelines over short distances, but this would have to be analysed in more detail on a case-by-case basis. Moreover, if the transport of small volumes of derivatives is envisaged, over short to medium distances, methanol and ammonia could also be efficiently transported by trucks.

Central / decentral production

In both cases, a centralized or a decentralized approach to produce derivates, the starting point is the decentralized production of green hydrogen (i.e. the preselected 26 zones). Several possible concepts could be considered for green hydrogen derivates production in the Central Hydrogen Valley.

One option is to establish centralized production hubs of derivatives near ports and desalination plants, leveraging infrastructure and economies of scale. These hubs would be supplied by connecting them to the hydrogen network and could be managed either by one single party (e.g. by the government or by private parties) or by several parties involved.

Another option is to produce green hydrogen derivatives in each zone in a decentralized way, utilizing local renewable electricity and serving local consumers. A separate pipeline for exports of these derivates could be considered in this case.

The general concept of centralized and decentralized derivatives production is displayed in Figure 16 and Figure 17.

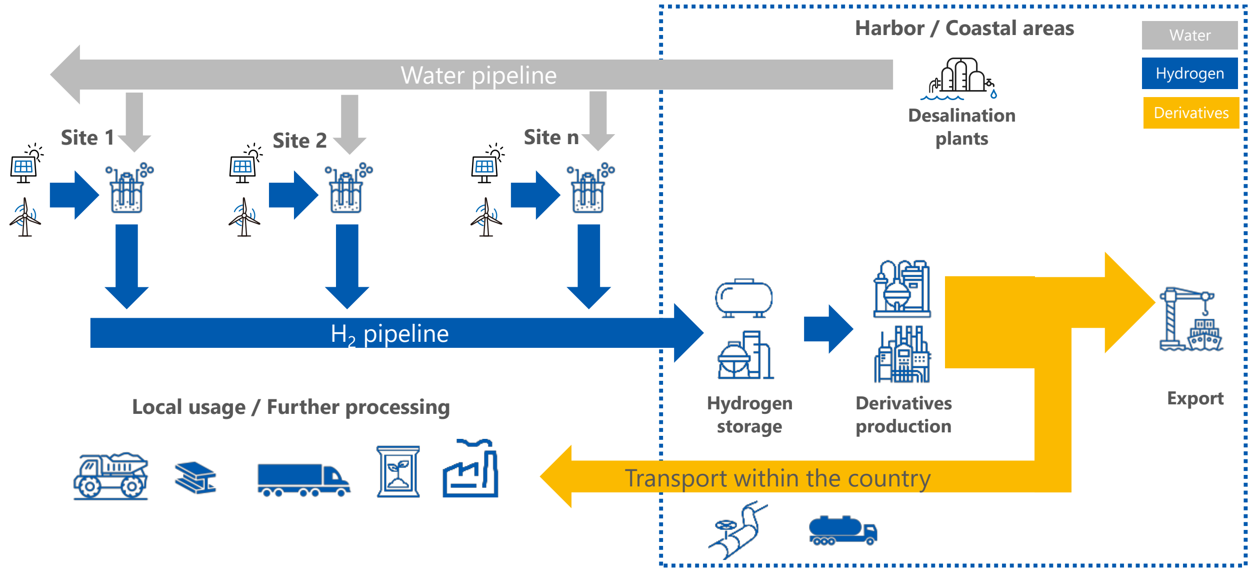


Figure 16: Centralized derivatives production

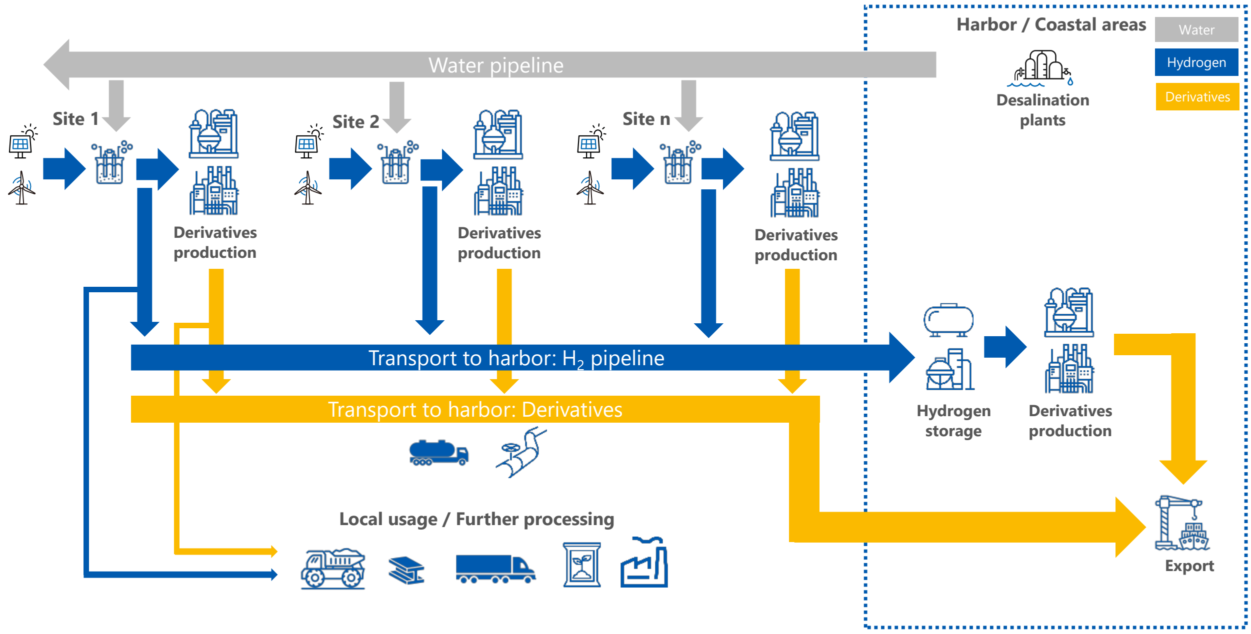


Figure 17: Decentralized derivatives production

Centralized production facilities, often located near harbors, benefit from proximity to major transportation routes, facilitating the efficient distribution of hydrogen derivatives. These facilities can leverage economies of scale, leading to lower production costs per unit. Additionally, centralized facilities can more easily capture and utilize waste heat and by-products, enhancing the overall efficiency of the processes. However, these facilities often face higher land costs and may pose higher environmental and safety risks due to the concentration of production activities. The centralized options would support a higher export share of the hydrogen derivatives as the local consumption would require additional transport systems.

On the other hand, decentralized hydrogen derivatives production facilities, which should be typically located near demand centers, can be strategically placed directly where the renewable energy sources, such as wind or solar farms, are available. This proximity allows for the direct use of renewable energy in the production process, thereby reducing the need for additional grid expansion. Decentralized facilities also promote local economic development and reduce transportation needs. However, these facilities may face challenges in terms of higher operational costs, lower production volumes, and complexities in distribution and storage.

Additionally, for derivatives requiring carbon molecules, the local availability of a biogenic source such as biomass is crucial. The processing of biomass through torrefaction plants (as presented in Section 2.3.4) could also follow a centralized or decentralized approach.

To make a reliable decision regarding the most suitable approach, factors like potential customers, volumes, export amounts, and user proximity need further analysis. Probably, the most adequate approach will be a combination of both options: A mix of a few decentralized derivatives production plants to cover a specific local demand (e.g., for green fertilizers or e-fuels) and large-scale centralized derivatives production plants close to the port for exports.

Hydrogen and water pipeline

With the maximum production potential at the sites known, and thus the maximum amount of hydrogen to be fed into a potential hydrogen network, a rough dimensioning of this network was carried out to give an indication of the expected pipeline length and diameter, as well as the resulting costs for such an infrastructure project. An initial design for a hydrogen network to connect the identified hydrogen production zones is shown in Figure 18. The initial pipeline route is designed to utilize the entire potential of the Central Hydrogen Valley. If the decision were made to utilize only part of the potential, a different route may be more suitable. Furthermore, it is most likely, that the network will be built up in different phases, as the implementation of large-scale projects progresses.

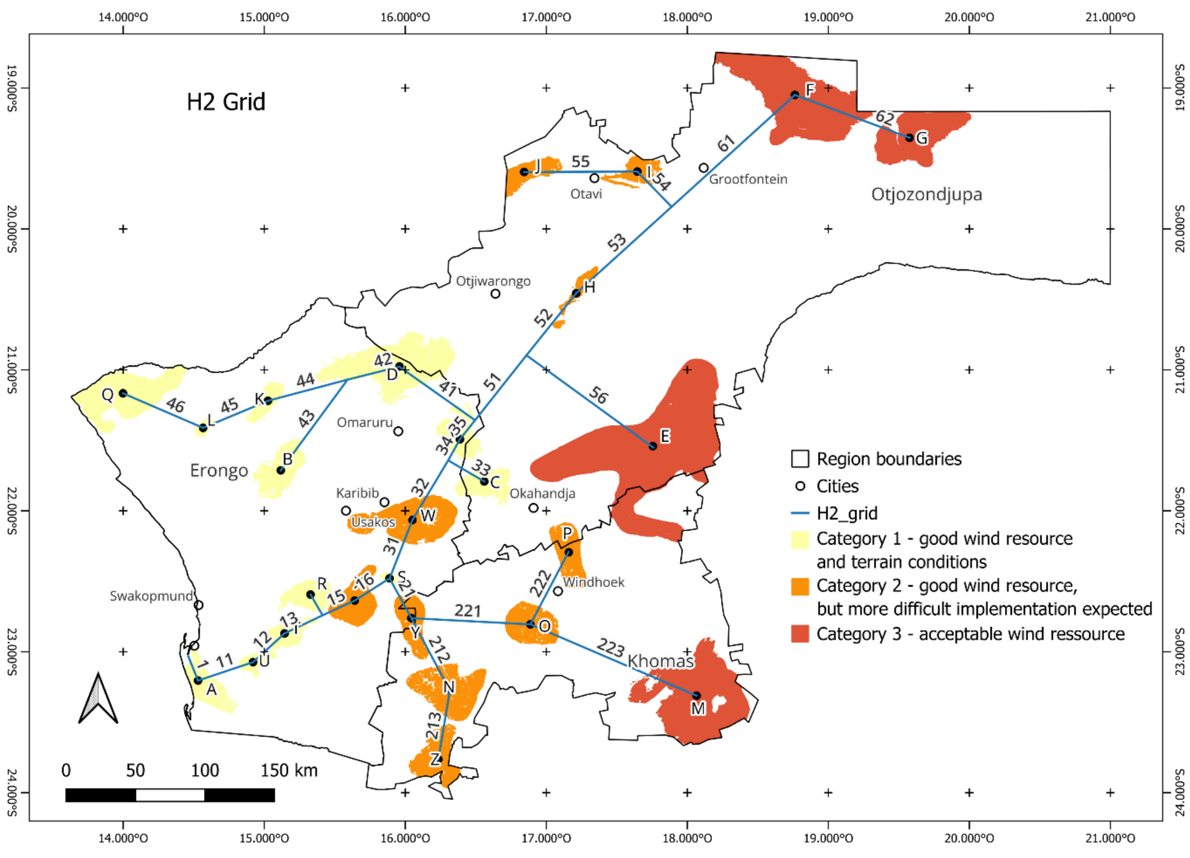


Figure 18: Initial high-level layout of the hydrogen grid

With a contingency of 40%, this gives an estimated pipeline length (without considering parallel laying of pipelines) of 2,610 km. The maximum flow rate at the port will be approximately 2,000 t_{H2}/h. Taking into account the multiple laying of 3 pipelines in some sections to handle the hydrogen volumes, the cumulative pipeline length is 5,015 km with an estimated cost of approx. 11.8 billion USD (incl. direct cost & planning).

A water pipeline is planned to transport the necessary water from the desalination plants to the electrolyzers. This will be laid parallel to the hydrogen pipeline, considering appropriate safety distances, in order to make the best possible use of any synergies during installation (e.g., route finding). In addition to the individual hydrogen production zones, the water pipeline should also supply the surrounding community areas or additional green industry infrastructure with water. Therefore, a slightly higher contingency of 50% is planned (compared to 40% contingency for the hydrogen pipeline) to cover these additional distribution lengths. This results in an estimated length of the water pipeline connecting all zones of 2,840 km, with the expected routing shown in Figure 19.

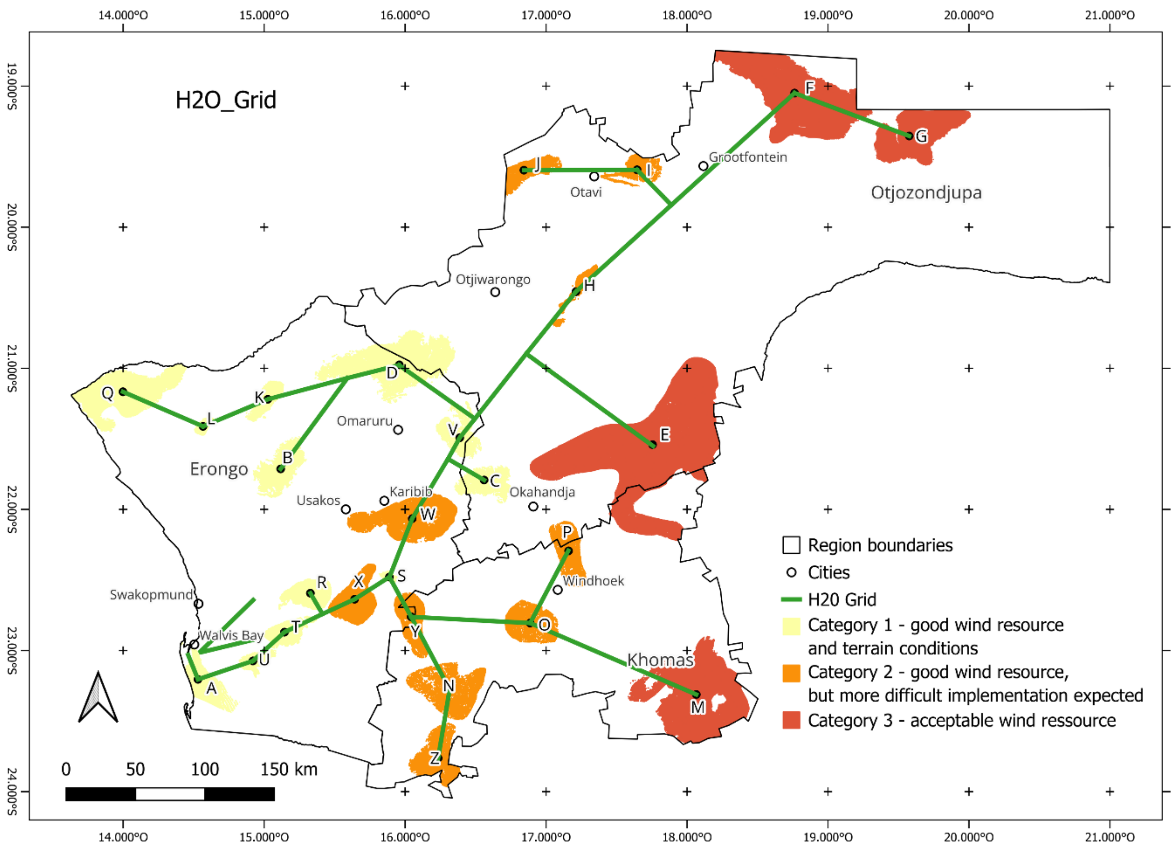


Figure 19: Initial high-level layout of the water grid

The development of such long hydrogen and water pipelines should follow a phased approach. It is neither recommended nor expected that the whole system will be developed in a single stage, partly because the system would be under-utilised in the early stages of deployment of large-scale projects. Figure 20 gives an overview of potential expansion stages of the hydrogen network. Strategically, the government could focus on developing a first section (e.g. Grid A in Figure 20), which can be further expanded at a later stage (Grid C).

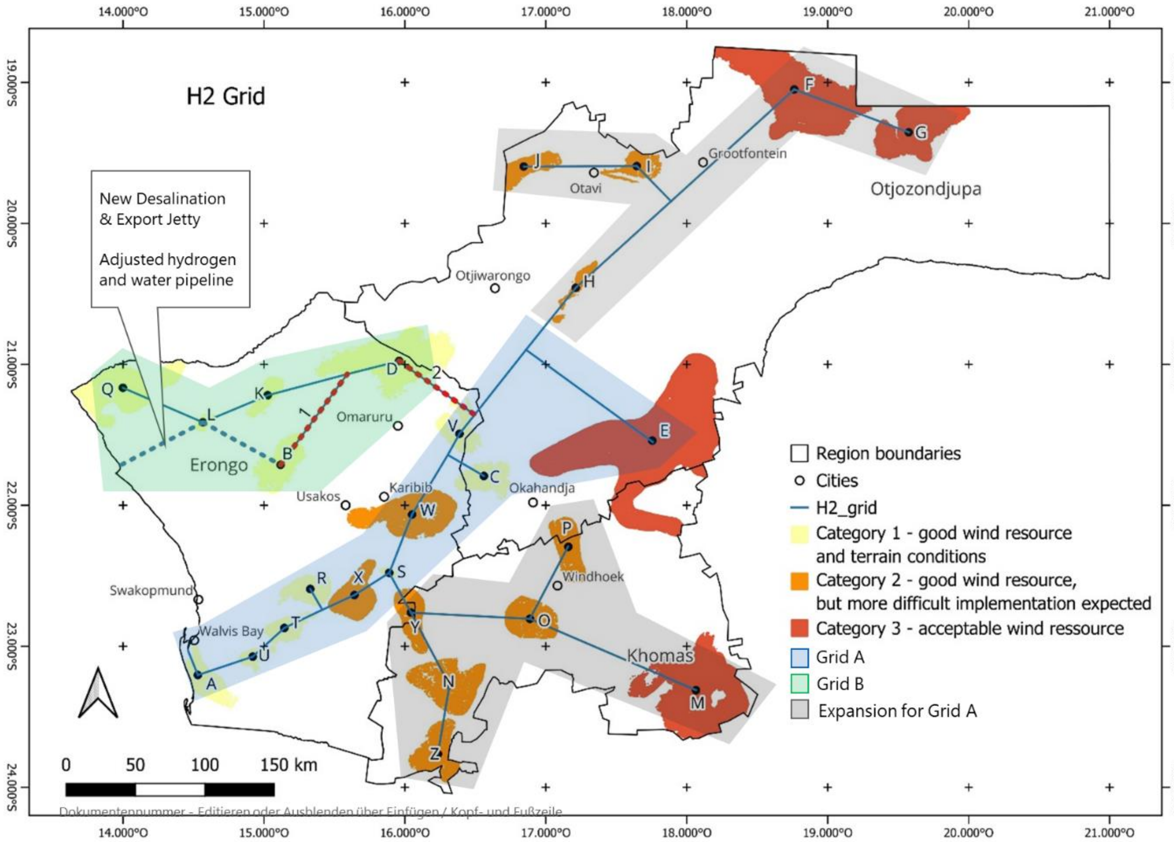


Figure 20: Potential expansion stages of the hydrogen network

Depending on the governmental ambitions and objectives, the connection between zones A and E in Grid A is suitable for the first stage of expansion (approx. 650 km without taking into account the parallel laying of pipelines) and enables a hydrogen production potential of 5,6 MTPA[10]. This will allow access to zone E, which has a high potential for hydrogen production and, correspondingly, also a high potential for job generation and local development.

If the government would decide to start with a more conservative approach for the Central Hydrogen Valley, e.g. under consideration of potential development plans for the South Hydrogen Valley, the first stage of expansion could be reduced to connect only zones A to X (also in Grid A). This would allow a potential hydrogen production of 1,1 MTPA[11] with approx. 240 km of pipeline.

Considering Grid B in Figure 20 (green area), the government could consider granting project developers rights for parallel private development of the hydrogen infrastructure in this area since they might be interested in these zones with a low LCOH. This might even consider the construction of a new desalination plant and an export jetty on the coast to make the area more accessible.

The Grid C (areas highlighted in grey) represents potential future expansion areas following the development of the originally planned hydrogen network.

[10] Adding the hydrogen potential for the zones A, U, T, R, X, S, W, C, V and E.
[11] Adding the hydrogen potential for the zones A, U, T, R, X.

Port infrastructure

The Port of Walvis Bay located in the Central Hydrogen Valley is the main port in Namibia and has already import infrastructure in place. The port should allow project developers to import required technologies and components and export its products (green hydrogen and its derivatives). In this later regard, the Port of Walvis Bay is working together with the Port of Antwerp and Brugges performing studies regarding required infrastructure and facilities and subsequently developing a roadmap for implementation. The port is also evaluating the feasibility of implementation of different facilities in the areas of the port, including desalination plants, electrolyzers, ASU units, ammonia production units, storage tanks and bunkering facilities. This would be part of the national wide shared infrastructure that could be controlled by the Port Authority or another entity still to be created.

One major issue that has been identified for implementation of these plans is the high investment required. This is why Namport cannot start developing infrastructure if certain volumes are not guaranteed by one or several project developers. One possible solution to this is for the project developers to bring in equity in order to de-risk the investments.

2.3.6 Potential prioritization of hydrogen production sites based on MCA

To expand the zone evaluation from a purely LCOH based assessment, an MCA was conducted to provide a more holistic assessment of the zones considering commercial, technical, site characteristics as well as environmental, social and regulatory criteria. In order to take into account the different priorities and perspectives of various interest groups in the location evaluation, the criteria were weighted from the perspectives of a developer, the government and an environmental agency.

The results for the 26 zones with their ranking from each perspective, as presented in Table 13, show a clear difference in the ranking of each zone depending on the perspective taken.

Table 13: Extract of MCA results considering different interest groups

Rank	Developer	Government	Environmental
	Zone	Zone	Zone
1	K	E	V
2	E	F	B
3	T	L	F
4	A	V	I
5	U	T	J
6	V	B	L
7	B	J	M
8	S	I	Q
9	L	U	K
10	D	Q	C
11	Q	R	E
12	M	M	O
13	C	G	W

Rank	Developer	Government	Environmental
	Zone	Zone	Zone
14	P	O	Y
15	O	K	Z
16	W	P	S
17	F	C	N
18	R	W	D
19	G	Z	P
20	J	Y	G
21	X	D	H
22	Z	S	X
23	N	X	T
24	H	A	U
25	Y	N	R
26	I	H	A

The multicriteria assessment provides a comprehensive and systematic approach for evaluating the suitability of different locations for implementation of green hydrogen projects. The methodology supports decision-makers in identifying the most suitable location for a green hydrogen project based on a range of defined criteria and its weighting.

The results presented above show a ranking of the best locations for the green hydrogen project from the perspective of the different interest groups but they do not represent a final assessment. Rather, the MCA methodology presented should serve as a preliminary basis for joint evaluation of potential production sites by the different interest groups; in this respect it should be continued and, if necessary, further developed to incorporate new findings into the evaluation (e.g., by adding criteria or adapting the weightings) to enable a well-founded comparison of zones based on current decision criteria in later project phases.

2.4 Enablers

The scale-up of the green hydrogen ecosystem in Namibia will depend on the solutions proposed to solve different barriers or risks identified along the green hydrogen value chain. Globally, the main barrier that has been identified relates to the high investment costs, which reflect the risks associated with a rather new and undeveloped value chain. Enablers aim at counteracting these barriers and risks and promoting the deployment of green hydrogen projects considering technical, economic, social, environmental and political aspects, as depicted in Figure 21.

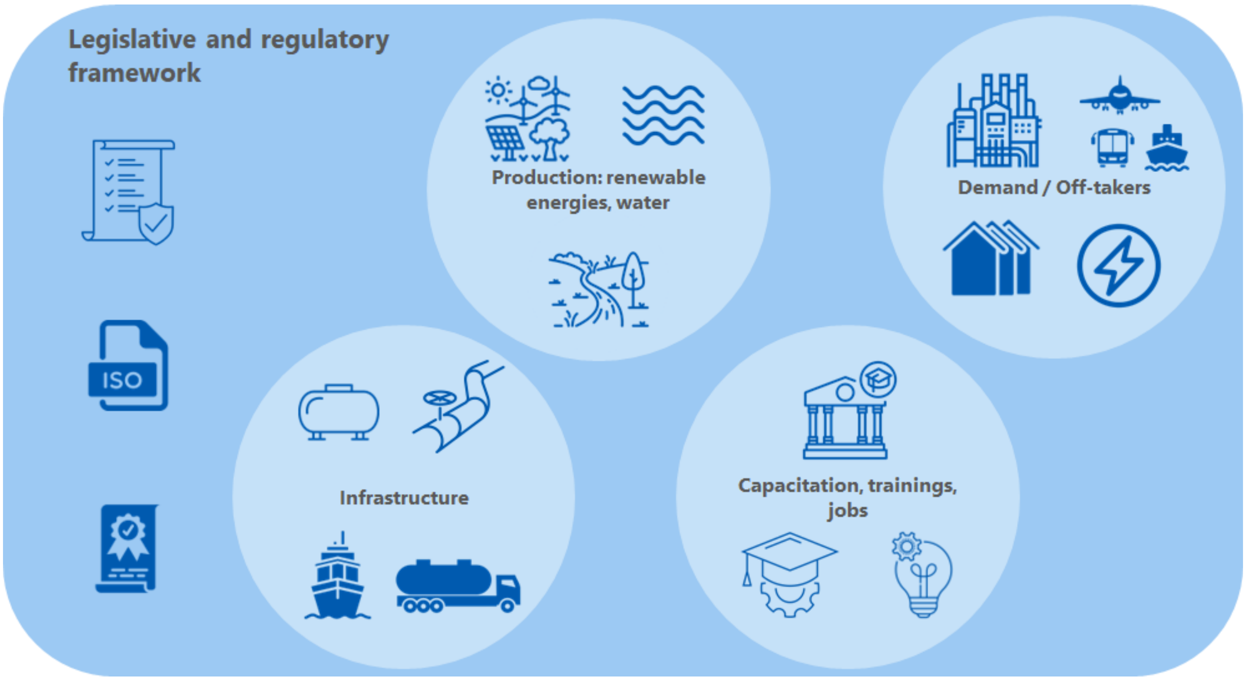


Figure 21: Aspects to be considered for the identification of enablers

2.4.1 Risks of green hydrogen development in Namibia

In the development of the green hydrogen value chain in Namibia, certain risks should be considered and where possible mitigated to ensure a safe deployment of the sector. In the followings tables the risks associated with the development of a green hydrogen value chain in Namibia are listed together with possible mitigation measures, sorted by technological (Table 14), social and environmental (Table 15), infrastructure and logistics (Table 16) and political risks (Table 17).

Table 14: Technological risks identified in the development of the green hydrogen value chain

Technological risk	Mitigation
Low level of research and development in solar, wind and electrolysis technologies.	▪ Promote development and research in academia and partnerships with producer countries by encouraging research and implementation of projects at local level.
Lower penetration of technologies causing low learning rates of green hydrogen value chain technologies.	▪ Promote the use of hydrogen in industrial and transportation applications through economic incentives, pilot projects, exemptions in mobility restrictions for vehicles that use green hydrogen or any of its derivatives, among others.
There is no cost reduction in innovative hydrogen derivatives such as synthetic fuels due to the lack of development and research in technologies.	▪ Develop partnerships with countries and companies that supply technologies to promote the development and installation of local production projects.
Global crises and unstable geopolitical context that interfere in supply chains affecting the prices and availability of technologies or raw materials.	▪ Develop political and economic alliances that allow more than one option for the supply of important components.

Table 15: Social and environmental risks identified in the development of the green hydrogen value chain

Social and environmental risk	Mitigation
Areas with wind potential that are located inside protected areas preventing the deployment of the technology.	▪ Establish dialogues between government entities, local communities and project developers to reach agreements on the feasibility of implementing projects in protected areas.
No availability of surface water resources.	▪ Promote seawater desalination and an efficient use of water resources.
Alteration of the quality of the water resource.	▪ Implement regulations on the quality and proper disposal of wastewater from desalination plants and green hydrogen and derivatives production plants , to reduce their impact on fresh or marine water sources.
Change in fauna communities (composition, structure, function, displacement, food chains) as a consequence of the implementation of the green hydrogen value chain.	▪ Generate environmental management plans to mitigate impacts on wildlife, as well as mitigation and compensation measures to be implemented by project developers.
Leaks or spills of hydrogen derivatives (ammonia, methanol, synthetic fuels).	▪ Develop clear regulations for their safe handling and manipulation, for example, setting minimum distances to drains, surface water and groundwater.
Modification in the use, suitability and access of the land as a consequence of the implementation and operation activities of renewable energy and hydrogen generation projects.	▪ Establish regulations regarding the location of hydrogen project facilities. ▪ Dissemination of relevant information to communities in the area of influence of hydrogen projects. ▪ Include in the development of the projects the supply of electricity and drinking water for the communities established in these territories. ▪ Establish mechanisms for the allocation of public land use for the implementation of hydrogen projects.
Generation of community conflicts due to changes in the use, distribution, and conservation of natural resources.	▪ Regulate the fair compensation to which the communities shall be entitled, which are affected by the implementation of green hydrogen generation projects.
Low acceptance of green hydrogen projects and derivatives.	▪ Conduct consultation and disclosure processes with communities established in the affected territories. ▪ Implement and enforce a clear safety regulatory framework (incl. compensation measures).
Inequity in employment generation due to lack of hiring and lack of qualified local labor in green hydrogen projects.	▪ Establish contracting quotas in the implementation of projects and establish certified training programs for the entire hydrogen value chain ideally linked to existing training certification bodies.
Lack of inclusion with a gender perspective.	▪ Establish incentives and differential actions in the training and hiring of women as technicians and in STEM areas (science, technology, engineering, and mathematics).

Table 16: Infrastructure and logistics risks identified in the development of the green hydrogen value chain

Infrastructure and logistics risk	Mitigation
Inadequate or insufficient existing infrastructure at e.g., airports, seaports and land routes for the import and transportation of technologies and components for renewable energy projects, green hydrogen and derivatives.	▪ Adequacy and specialization of airports, seaports and roads for the import of capital goods associated with renewable energy projects, green hydrogen or its derivatives.
Non-existence or poor condition of land roads.	▪ Establish a national plan for the construction or expansion of the infrastructure required.
Late development of industrial infrastructure for the production of derivatives that delays the penetration of hydrogen in a local level.	▪ Establish pilot derivative production projects with government support to demonstrate their technical feasibility and gain initial experience in their implementation and operation processes.

Table 17: Political risks identified in the development of the green hydrogen value chain

Political risk	Mitigation
Change of political priorities: New policies may lead to changes in regulatory and tax conditions or make it more difficult to apply for licenses and permits.	▪ Define long-term policies.
Country Risk: The high level of fiscal debt impacts the country risk rating and the project's cost of debt and equity.	▪ Development of financial instruments for interest rate hedging and access to non-reimbursable funds through public-private partnerships.
Financial risks associated with the stability of the financial system and exchange rates: Blockage of cross-border cash flows because of extreme exchange rate variations or governmental instructions.	▪ Development of financial instruments to hedge exchange rates and establishment of public-private partnerships.
Changes in foreign trade policies: Export or import restrictions that cause losses in commercial transactions.	▪ Definition of the country's economic priorities around green hydrogen and establishment of long-term commitments, e.g., installed electrolysis capacity, tons of hydrogen exported, among others.
No clear regulatory framework governing the implementation of projects, which generates uncertainty for their development and approval.	▪ Work jointly with government entities and the private sector to create a regulatory and normative framework that provides clarity on the steps, norms and laws to be followed for project implementation.
Failure to attract investors due to the total or partial lack of tax incentives.	▪ Work jointly with investors and the private sector to reach agreements and take actions regarding tax incentives that make large-scale projects viable.
Government entities are limited in their technical and regulatory capabilities.	▪ Establish training programs for government entities on regulatory and technical issues related to the green hydrogen value chain linked with existing certified training bodies.

2.4.2 Identification of enablers

Once the barriers and risks are identified, potential solutions or enablers have to be defined for counteracting these barriers. The previous tables included already mitigation measures for the identified risks, for complementing this analysis in the following table a compilation of main barriers and corresponding generic enablers are listed, grouped into different categories.

Table 18: Main enablers for identified barriers

Category	Main barriers	Remarks and main enablers
Global	▪ Rather low technological maturity and availability.	▪ This is a global issue with only limited influence by Namibia. ▪ A possible local enabler is the allocation of public and private funds for research, development and innovation (RDI).
Economic	▪ High investment costs. ▪ Macroeconomic factors affecting e.g., costs of capital and supply chains.	▪ These barriers are found at global level, but local enablers can improve the economic sustainability of the projects through e.g., tax benefits, incentives, credit facilities with reduced interest rates, among others.
Local development	▪ Chicken-and-egg challenge: No demand implies no production implies no demand. ▪ Easiness of integration of new processes into existing ones.	▪ Both sides of the challenge (offer and demand) will have to be developed in parallel. This could be enabled through mechanisms such as the definition of minimum quotas for local consumption of green hydrogen and derivatives or subsidies for technologies transition.
Environmental	▪ Potential regional differences in permitting processes. ▪ Changes of land use that put at risk sustainability of the project. ▪ High water-stress level in Namibia means that available resources have to be prioritized for human consumption, agriculture and nature. Industrialization cannot exacerbate this issue.	▪ Even if the environmental aspects will vary regionally (due to specific constraints such as protected flora or fauna), it is recommended to develop a regulatory framework that includes a standardized and simplified permitting process. ▪ The main barriers referring to environmental aspects can be counterbalanced through adequate regulations, emphasizing the two critical issues of current land use and water access.
Social	▪ Lack of communication with the communities resulting in potential objections to project development in specific areas. ▪ Lack of integration of local communities into the new productive processes.	▪ The long-term sustainability of a green hydrogen economy must benefit the communities. For enabling this goal, the national, regional and local authorities should lead the communication programs with the communities, in which project developers should regularly inform about their plans, benefits and potential risks associated with the projects. ▪ The government must ensure that the communities benefit from the project developments through e.g., participation in certified training programs and local job creation and improved access to basic

Category	Main barriers	Remarks and main enablers
		requirements (e.g. electricity and potable water)
Regulatory	▪ Lack of clear policy and regulatory framework. ▪ Potential discontinuity of energy policies.	▪ A clear and stable regulatory framework helps the project developers to reduce the risks associated to the high investments required.

At this point, the definition of an adequate regulatory framework is the superordinated aspect that will allow to specify enablers in each of the other categories. Taking a more detailed look at the categories listed in the previous Table 18, it is possible to identify several areas that call for the definition of specific enablers. The main areas and some remarks to them are listed in the following.

1. Regulatory framework:
   This comprises the regulatory elements that will have to be developed or adapted in order to promote the deployment of a green hydrogen economy, considering all steps of the value chain and guaranteeing, at the same time, a sustainable development in consideration of economic, social and environmental constraints, providing stability and security for project developers to invest.
2. Development and use of infrastructure:
   The deployment of a green hydrogen economy at large scale implies the expansion of existing infrastructure and the development of new one that is of public interest (consider, for example, the implementation of desalination projects for accessibility to required water resources) and whose use shall, therefore, not be restricted to specific project developers. The regulation of its use and development could therefore improve economic and social aspects: Economic aspects since several project developers could use a shared infrastructure reducing the specific investment costs and social since communities should be granted access to this basic infrastructure such as electricity and water.
3. Permitting:
   Permitting procedures for project implementation shall consider the direct environment where the production plants will be constructed and operated, this is why they might differ from one region to another and create potential difficulties for project development in specific areas. Without diminishing the relevance of site-specific constraints, e.g., regarding protected fauna or flora, aiming at a standardized and simplified process will ensure that the same high standards are adequately applied everywhere without project developers losing interest in implementing projects in specific zones.
4. Incentives and subsidies:
   The high investments required and other macroeconomic aspects affecting the cost of capital are still the main barrier for scaling up a green hydrogen economy. The sector requires governmental support that aims at diminishing these costs and the perceived risks that make banks still reluctant to financing projects in this sector.
   For example, tax incentives could include the reduction of tax rates through exemptions from tariffs, income taxes or other tax deductions. These are mechanisms to encourage the development of green hydrogen projects without affecting government budgets.

The incentives and subsidies that aim at decreasing these development costs will allow to transform a vicious circle in a virtuous circle: Fomenting the production and the end-use at the same time will allow to reduce production costs, further increasing the local demand and promoting further investments in production facilities.

5. Taxes:

Taxes could have an ambivalent view: From the point of view of a project developer, taxes applied to sustainable products might be considered rather a disabler, but from a governmental perspective, they represent a source of income. Still taking into account that most of the products might be foreseen for export, the taxation of green products (through royalties) could be used by the government for improvement of social conditions in the country. Additionally, the taxation of other traditional non-sustainable products through e.g., a carbon tax can also be used for social investment, while indirectly increasing the economic feasibility of sustainable processes.

6. Funding mechanisms:

As already mentioned for incentives and subsidies, the current difficulties to access investment due to the reserves of banks to finance these projects, call for government support, working together with financing institutions to specify investment programs that offer better conditions, which might also include the issuance of state guarantees.

7. Obligations for end use:

A solution of the chicken-egg-challenge, that should be reevaluated not as a sequence but as a parallel process, has to consider how to create a local demand, which can be reached through definition of minimum quota for local, regional or national consumption of e.g., green hydrogen or its derivatives. This together with decarbonization goals (maximum level of CO_2 emissions for specific sectors or products) reduces the risks associated with off-takers for project developers and promotes, at the same time, a local low-carbon development.

8. Mitigation obligations for unforeseeable events:

The development and management of relatively unknown processes or products at local level should be accompanied by strict requirements regarding health, safety and environment (HSE) that avoid or minimize the risks associated with unforeseeable events, such as extreme weather or accidental spillage of products. In the absence of these mitigation obligations, the adverse effects on human health and environment cannot be duly restrained and could result in a generalized opposition of the communities to the implementation of related projects.

9. Local personnel and services:

To ensure that the deployment of a new productive sector (green hydrogen and derivatives) results in economic and social benefits for the regions, it is necessary to define mechanisms for integration of local personnel and services, as much as possible, to ensure the social acceptance and sustainability of these projects.

10. Committed income:

This refers to the commitment of national, regional or local authorities to invest specific incomes resulting from e.g., taxes imposed by the government either as "royalties" on exported green products or from carbon taxes on other goods, in improving living standards throughout the country. This is therefore directly related to the taxes component already described (5).

11. Industrialization based on local goods:

The development of a green hydrogen economy represents an opportunity for Namibia to transform the national economy. The country shall aim for a green industrialization, which can be achieved in various stages:

1. Reduction of emissions from current processes and products. This includes tourism as a relevant source of income for the country.
2. Shift from primary to secondary sector, which also include the substitution of some imported goods by national production (e.g., ammonia and green fertilizers or synthetic fuels to replace oil products).

12. Localization of OEMs:

The localization of original equipment manufacturers (OEMs) (i.e. technology production plants operated directly in Namibia) goes in line with the aim for green industrialization, facilitating in addition technology and knowledge transfer and generating jobs. The security in the supply chain is also positively impacted by this aspect. The localization can follow a staged development, starting with e.g. renewable energy technologies such as PV and wind, and expanding to electrolyzers and other derivatives associated technologies at later stages.

13. Cooperation between public institutions and private actors (Public Private Partnerships, PPPs):

The cooperation between the public and private sectors through PPPs can play a fundamental role in the implementation of green hydrogen projects since the combination of different areas of expertise, e.g., regulatory, access to funding, capital, etc. can create synergies and better results for both sectors.

14. Capacitation of locals / Training:

Ideally, most of the jobs created by new projects can be covered by locals to increase the positive effects on local social development. Nonetheless, it must be noted that the involvement of local staff will be possible during construction and operation of projects only to the extent that they are duly trained (and certified) for the different required jobs:

- People and capability for construction should be available quite easily.
- For operation of hydrogen and hydrogen-derivate facilities the capabilities will have to be trained/made available.

Only with access to trained staff will project developers be able to comply with regulations regarding a specific quota for local staff and services. The training facilities and programs can be developed by both, private and public institutions, but the overall responsibility for fostering these activities should be undertaken by local authorities. The aim should be to link new trainings requirements to existing certified training centers.

15. Jobs creation:

The development of a new productive sector (green hydrogen and derivatives) will result in new jobs along the green hydrogen value chain. The likelihood that these jobs can be filled by local workers will depend on the (certified) training programs to be implemented in short- and medium-term, as mentioned above (14) and the accessibility of project developers to these human resources.

16. Technological maturity and availability:

Some technologies in the green hydrogen value chain are still in development, have not be proven at large scale, are not yet available or have limited availability.

Important technological improvements will result from global efforts with a limited influence by single countries. Nonetheless, all countries should contribute to these efforts through the support of research, development and innovation activities.

One relevant aspect worth to be mentioned here relates to the availability of data. It is recommended to develop a platform for open data that allows public and private actors to collect and share local data (e.g., GIS data, data of measurement campaigns, statistics).

The definition and application of specific enablers for the main identified areas will require the joint work of several public ministries and institutions as well as a coordinated exchange with other stakeholders, including project developers and communities, so that they better consider and tackle local conditions while focusing on primary areas and avoiding an overregulation of the sector.

2.5 Regional and international integration

Hydrogen is widely used around the world since many decades. Nonetheless, it has been restricted - up to now - mainly to on-site production (from natural gas or coal) and direct use, for example in refineries or in ammonia and methanol production plants. Green hydrogen has been identified as one of the main components to reach a carbon-neutral economy worldwide; nonetheless, there are major challenges that have to be overcome in order to establish a global value chain for green hydrogen.

Contrary to the current production of hydrogen, the production of green hydrogen via electrolysis requires good potentials for renewable energies. In a general way, it can be stated that, on the one hand, countries with a high demand for hydrogen (or its derivatives) have not enough potential on renewable energies for covering their demands and, on the other hand, the countries with high renewable energy potentials have up to now a limited demand for green hydrogen or its derivatives. The geographical split between potential consumers and producers is what makes it essential to establish a global value chain, requiring international cooperation and integration of markets.

The regional and international integration can help to create a more efficient and cost-effective hydrogen economy by enabling the sharing of resources, products and expertise.

Considering that the analyses under the current project are limited to the Central Hydrogen Valley, it must be noted that there are limited possibilities to support and/or integrate development with neighboring countries. Furthermore, it is important that the integration to other countries (directly in the region or in other continents) is promoted for Namibia as a whole (and not for specific areas within) through e.g. a strong international hydrogen diplomacy campaign led by government institutions. The implementation of several enablers described in the previous section 2.4 will create attractive conditions for international project developers and investors, promoting in this way Namibia's integration with other countries.

2.5.1 Regional integration

Starting from the three proposed hydrogen valleys in Namibia's Hydrogen Strategy (as presented in Figure 1), it results that the Central Hydrogen Valley borders only with Botswana, while the North Valley could be linked to Angola, and the South Valley to South Africa.

Due to the current limited energy needs of Botswana, the other two valleys seem to present a higher potential to be linked with neighboring countries for regional integration and jointly development of projects on green hydrogen and its derivatives.

The regional integration needs to be assessed considering the three hydrogen valleys and the integration among them. It is therefore necessary to knowledge that even regions of the country that are not included in these three valleys might be relevant for e.g. the supply of biogenic carbon sources (such as bush biomass) and that the benefits achieved through project implementation should be for all regions, in line with a sustainable national development.

Under current circumstances, the potential for regional integration is considered limited (and mainly to the larger market in South Africa), but this could change later on, depending on the energy politics implemented by other neighboring countries.

2.5.2 International integration

Even if potential restrictions are put into place that oblige project developers to keep a certain production share for local demand, due to the high hydrogen production potential, most of the volumes will be exported.

The international integration will be required with potential importing countries (access to markets) but should also consider cooperation with other potential exporter countries around the world, which would allow that the experiences gathered by the different countries are shared in order to move forward more efficiently in the implementation of projects and policies that promote the sector. The international integration is also fostered through cooperation with other specific regions or countries such as the partnership with Germany for green hydrogen or with the EU focused on green hydrogen and critical raw materials.

Besides that, for access to export markets an adequate port infrastructure is required. The Central Hydrogen Valley has the advantage of having the most important port in Namibia, which already has in place the infrastructure required for import of today’s and tomorrow’s technologies and components and which can be easily expanded to integrate export infrastructure such as new jetties for derivatives export.

On the other hand, the international integration of the North and South Hydrogen Valleys will depend on the development of local ports. For the South Hydrogen Valley, Hyphen is currently supporting the development of the Port of Lüderitz; for the North Hydrogen Valley a similar development is likely in the future.

Finally, it must be noted that also the development of large projects as Hyphen fosters the international integration through the technical and financial support and the access to foreign markets offered by international companies.

3 Opportunities for Namibia and the Central Hydrogen Valley with the implementation of a green hydrogen economy

The development of a green hydrogen value chain offers a series of opportunities and benefits at environmental, economic, and social levels. The following are the main opportunities that could result from the implementation of a green hydrogen economy at the national level.

3.1 Compliance with decarbonization commitments

Even if Namibia's greenhouse gas (GHG) emissions represent an almost negligible share of the global emissions, the country has demonstrated a strong commitment to reducing these emissions and acknowledges its overall responsibility in the fight against climate change. Recognizing the environmental and social challenges associated with rising emissions, the country has implemented several measures and made significant commitments to address this pressing issue.

Namibia is a signatory to the Paris Agreement, an international milestone that seeks to limit global warming to below 2°C and, preferably, to 1.5°C. As part of this agreement, Namibia has submitted updated Nationally Determined Contributions (NDCs) in which the country foresees to avoid 91% of the business-as-usual emissions by 2030 and, in case sufficient foreign funding and aid is obtained, aims to reach net-zero beyond 2030. In its NDC, Namibia recognizes two important factors:

- First, as a climate vulnerable country, adaptation remains a priority for Namibia. Namibia's NDC therefore has a strong adaptation component that describes what the country has already achieved on adaptation and what are the priorities for the future. In particular, the focus is on the significant improvement of the capacity for planning, implementation, and response of adaptation activities at local, regional and national levels.
- Second, Namibia is committed to taking a progressive approach to developing its economy on a low carbon pathway. In the updated NDC, Namibia has committed to reduce GHG emissions in the agriculture, energy, and transport sectors below 'business-as-usual' (BAU) GHG emissions by 2030 using only domestic resources under unconditional contribution, and even below BAU GHG emissions by 2030 if sufficient and appropriate support is received from developed countries under conditional contribution.

In order to support a continuous reduction of GHG emissions, developing a nationwide green hydrogen economy, which will contribute to the achievement of the targets through the massive use of renewable energy would be beneficial for the country's decarbonization plan.

3.2 Deployment of renewable energies

Namibia has a variety of renewable energy sources that allow it to diversify and, at the same time, decarbonize its energy matrix in an efficient manner. It should be considered, however, that the establishment of a green hydrogen economy drives the need for a massive deployment of these resources.

This means that the policies issued must ensure that the production of green hydrogen goes hand in hand with an increase in the installed capacity of renewable energies.

The hydrogen economy together with its derivatives expands the possibility of making the most of renewable energies by facilitating their integration into key sectors of the economy that are difficult to electrify, such as maritime and air transport.

In summary, the hydrogen economy provides a versatile and sustainable solution to drive the deployment of renewable energy by providing efficient storage and a way to harness clean energy in various sectors of the economy.

3.3 Boosting green industrialization and technological development

The deployment of a green hydrogen economy represents an opportunity for the industrialization and technological development of the country. Considering that the implementation of the different stages of the green hydrogen value chain will require joint work between public and private entities, this may allow the emergence of new productive areas that will boost Namibia's technological and industrial progress while meeting the established decarbonization goals.

Namibia, like other African countries, has historically had a production and export focus on the primary sector. The establishment of the hydrogen value chain and its derivatives on a commercial scale will facilitate a transition from a primary to a secondary economy, while, at the same time, promoting sustainable economic growth.

For best leveraging the country's green hydrogen production potential, several industries can be developed to meet global demand and capitalize on the country's strengths such as rich mineral and rare earth resources, strategic access to major sea routes, politic stability and vast landscapes with low population density. Nevertheless, it should also be considered that Namibia's industrial production is limited nowadays, and the corresponding trained workforce is also limited, therefore it is important to follow a staged approach to industrialization that allows to focus firstly on the most promising options (considering not only economic aspects but also the potentials for local development and high impact on local communities).

Industries that could potentially be developed in Namibia are those that produce components for the development of a green hydrogen supply, such as:

- Renewable energy equipment manufacturing: This includes the production of PV panels, wind turbines, and other renewable energy equipment. For the in-country production of components, the robust international market must be taken into account. PV panels are easy to transport and thus to import, whilst the manufacturing of wind turbines is quite complex with an established market of manufacturers. The first step should be to concentrate on setting up the essential industries for the management, operation and maintenance of these installations. Over time, smaller plants for component manufacturing can be established to accumulate knowledge in this field and scale up when necessary.
- Electrolyzer manufacturing: As the demand for green hydrogen increases, there will be a need for more electrolyzers, creating opportunities for local manufacturers or for the localization of OEMs. Demand is likely to increase in the short term as the number of international projects in the pipeline is growing

rapidly. Market pressure is therefore increasing, putting more pressure on OEMs and increasing the chances of Namibia finding OEMs willing to build capacity in the country.

- Hydrogen infrastructure: This includes the development and production of the infrastructure needed to transport and store hydrogen such as pipelines and compressors, but also other infrastructure required such as desalination plants

The advantage of establishing these supply chains lies in the local demand and the reduced dependence on component imports. This is particularly important in light of the increasing international expansion of renewable energies and hydrogen production and the resulting potential increase in competition for components. The establishment of these industrial sectors in Namibia will highly depend on the availability of trained local workforce in order to achieve the expected local social and economic development.

- Once the industry for green hydrogen production has been established, enabling the local manufacturing of components and facilitating the provision of services required, other related industries that benefit from local hydrogen production and thus have a competitive advantage over imported products should be developed in parallel with the ramp-up of hydrogen production. These include:Green chemicals and fertilizer production: Hydrogen can be used to produce green ammonia and methanol, which are used in various industries, including agriculture and plastics. Especially with the large agriculture sector in Namibia, in-country fertilizer production is a promising option.
- Green Mining and Steel/Metal Industry: The demand for green mining products such as green metals on the global market is increasing. Thanks to the combination of local hydrogen production and an established mining system for metal extraction as well as an existing export infrastructure, Namibia has good prerequisites to set up a value chain starting from green mining, using the green hydrogen and renewable power generation to decarbonize the mining supply chains, up to the production and export of green products such as green steel.
- Sustainable Aviation Fuel (SAF): Namibia's strategic location along major aviation routes between Africa, Europe, and South America could make it a potential location for the production and supply of SAF. Nevertheless, the production of SAF from green hydrogen is a relatively new and emerging field, and there are only a few pilot projects around the world. Therefore, while the potential is significant, it comes with the challenges and uncertainties of new technologies and emerging markets. As the market development is uncertain, it is recommended to closely look at the market and adjust the strategy accordingly. Therefore, SAF production is recommended to be aimed at as a mid or long-term target.
- Fuel Cell Manufacturing: Fuel cells convert hydrogen into electricity, and they are used in various applications, from powering vehicles to providing electricity for buildings. The growth of the green hydrogen industry could stimulate the development of the fuel cell industry. However, it is crucial to acknowledge that the trajectory of the global fuel cell market's growth remains uncertain. Consequently, the establishment of an industry within this domain necessitates careful alignment with anticipated market trends.
- Transport: Decarbonization of transport in country via trains and heavy trucks and for international trading via ship is a growing area of interest in the worldwide fight against climate change. To enable the decarbonization, certain technologies such as fuel cells, dual combustion engines etc. need to be developed together with a network of hydrogen refueling infrastructure. The production of synthetic fuels (not limited to SAF) is an option that should be considered at later stages, as it represents a

potential for decarbonization of internal transport and reduction of related imports as well as an additional high value product for exports.

In general, the industrial development associated with a green hydrogen economy brings with it new productive areas, implementation of sustainable energy systems and development of the associated infrastructure, including for example, land transportation networks, port infrastructure and large-scale storage systems.

In this way, a green hydrogen economy will allow Namibia to progress in line with the requirements of the energy transition and will allow it to expand its current export markets, in terms of destinations and products exported.

3.4 Generation of technical, technological, and RDI capabilities

The implementation of green hydrogen projects and its derivatives involves the establishment and operation of production, storage, transportation, distribution, and end-use infrastructure that require the development of specialized technical skills. This will drive, on the one hand, the generation of professional capabilities in different areas of engineering, such as chemical engineering, mechanical engineering, electrical engineering and project management. On the other hand, trained personnel should be available at all stages of the value chain; therefore, the development of basic technical capabilities at the production, maintenance, and construction levels, among others, will be promoted. In a complementary manner, the generation of capacities in the development of green hydrogen policies and regulations should be considered.

Furthermore, the constant evolution of hydrogen and renewable energy technologies requires research and development to improve the efficiency of generation processes, safe storage, and the application of hydrogen in different sectors. Investment in hydrogen-related research, development, and innovation (RDI) will enable the creation of research centers and specialized laboratories, where Namibian scientists and experts will be able to develop innovative technologies, components and solutions in this area. This will foster international collaboration between universities, companies and the government, and promote the transfer of knowledge and advanced technologies, thus strengthening Namibia's environmentally friendly innovation system.

First steps have already been taken to develop hydrogen technology and expertise in the country including the following projects[12] as displayed in Figure 22, four of which are located in the Central Hydrogen Valley.

[12] For detailed information see: https://gh2namibia.com/h2-projects/

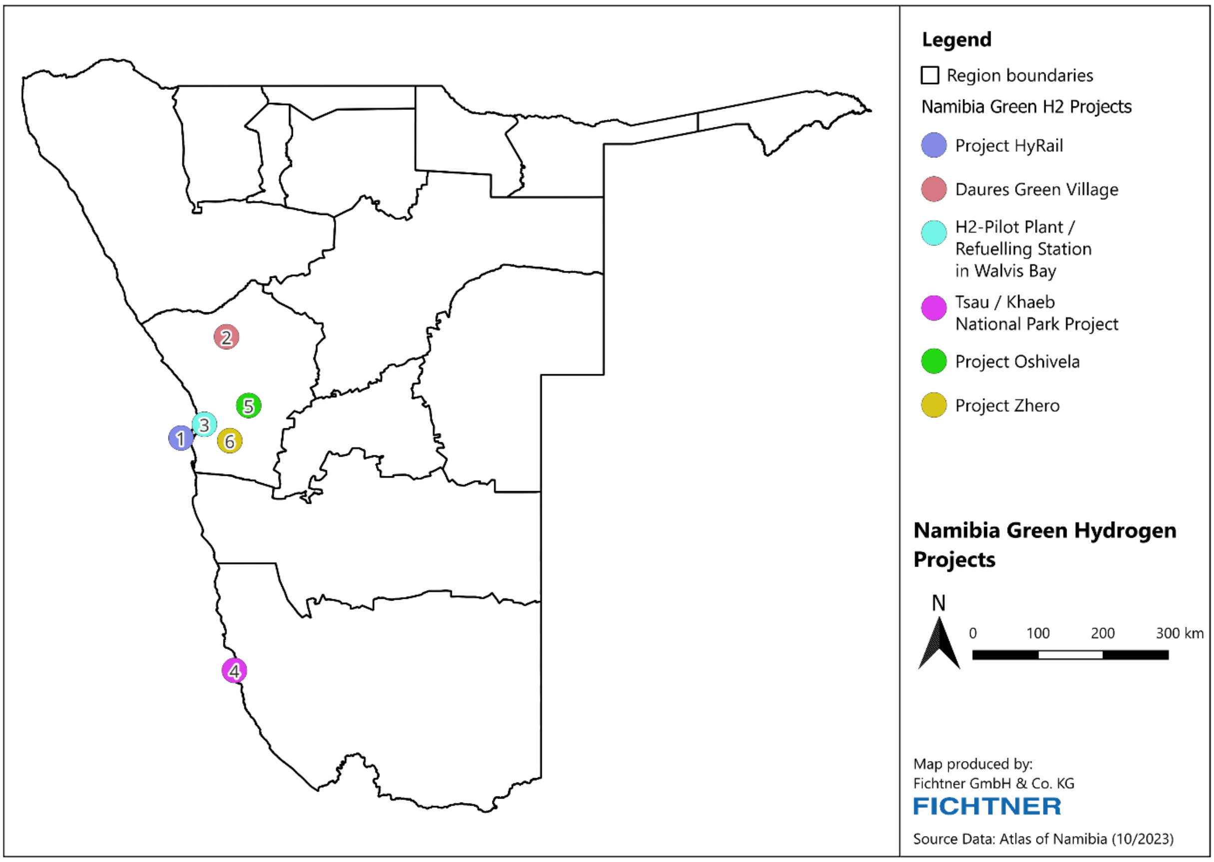


Figure 22: Ongoing green hydrogen projects in Namibia

HyRail - Hydrogen-Diesel Dual Fuel Locomotive Project (1)

Namibia's railway sector, which consumes nearly 11 million liters of diesel annually, is planning to implement a hydrogen off-take development project. The project aims to develop Africa's first H_2 Dual Fuel Locomotive (diesel-H_2), using locally produced green hydrogen. The project will involve converting two locomotives for hydrogen use, developing a hydrogen fuel tender wagon, and creating the necessary infrastructure for hydrogen storage and transport. This initiative will create local off-take for the green hydrogen produced in the country.

Daures Green Village (2)

The project aims to develop Africa's first Green Village in Uis, Erongo region, Namibia, focusing on hydrogen use cases. The phased approach includes proof of concept for green hydrogen and Anhydrous Ammonia production, and industrial-level production for local consumption and export. The village will serve as a research center and have its own training facilities, ensuring skill transfer and the development of a Namibian hydrogen value chain. The project includes sustainable green hydrogen production, establishment of a green scheme program, storage and transport of green hydrogen, and integrated application technologies for green hydrogen utilization. The village will be powered by solar and fuel cells.

H_2-Pilot Plant / Refuelling Station in Walvis Bay (3)

CMB.TECH and Ohlthaver & List have partnered to develop the PV2Fuel project, aiming to produce gigawatt-scale ammonia in Namibia. The project involves converting solar energy into hydrogen and ammonia for export and use as clean fuel. A joint venture, Cleanergy Namibia, has been established and secured land at the Port of Walvis Bay to develop an ammonia factory. The project will start with a pilot plant near Walvis Bay airport, featuring a 5 MW photovoltaic solar system, a 5 MW electrolyzer, and a hydrogen refuelling station. A larger commercial plant is planned for the second phase.

Tsau / Khaeb National Park (Hyphen SCDI) Project (4)

The Southern Corridor Development Initiative (SCDI) was conceived for Namibia's first gigawatt-scale green hydrogen project. Hyphen Hydrogen Energy was selected as the preferred bidder for the first project in November 2021. The project, estimated at USD 9.4 billion is planned to be developed in phases, at full development targeting 350,000 metric tons of green hydrogen production a year from ~7 GW of renewable generation capacity and ~3 GW electrolyzer. First production is foreseen in 2026.

Project Oshivela (5)

Project Oshivela in Namibia aims to produce the first industrial iron with net zero emissions using HyIron technology. The project, starting in late 2024, plans to produce 15,000 tons of Direct Reduced Iron annually, making it one of the largest green iron production sites globally. It's expected to reduce CO2 emissions by 27,000 tons per year. The modularity of HyIron technology allows for potential expansion, with a feasibility study underway to increase production to 1 million tons annually.

Project Zhero (6)

Zhero is a development company that aims to expedite the global energy transition through the development of large-scale renewable energy projects. The company has set a target to reach a Final Investment Decision on 5GW of low-cost energy projects by 2026. These projects span across various regions including the US, Europe, MENA, Australia, and notably, Africa[14]. Zhero is also planning to develop a project in Namibia aiming at 2000MW - 100000tH2/a either as GH_2 or NH_3 with production start in 2029[15].

3.5 Social and environmental benefits

3.5.1 General

The deployment of a green hydrogen economy seeks sustainable development that includes economic and productivity growth with an innovative and environmental-friendly character. This economy will foster job creation in the different sectors related to the value chain, which in turn will create conditions that ensure widespread access of communities to basic services and build an adequate basis for the reduction of inequality and the improvement of the population's quality of life.

Complementing these social benefits, the sustainable production of green hydrogen and its derivatives brings environmental benefits by reducing GHG emissions and promoting clean production processes, allowing the population to have access to clean energy instead of using, conventional fuels (incl. traditional use of biomass) that have serious effects on human health.

These benefits could be maximized, if the required regulations implement a circular economy approach that focuses on sustainability through the efficient use of resources through utilization, reuse and recycling,

[14] For detailed information see: https://www.zhero.net/press-release
[15] Information provided by client

resulting in an extension of their useful life and lower negative impacts to the environment and communities.

3.5.2 Jobs creation

In the green hydrogen industry, the distribution of job creation across different skill levels is influenced by various factors, including technological complexity, the stage of industry development, and existing local educational infrastructure. The precise percentages of job creation between high-skilled and low-skilled jobs varies based on these and other factors. Nevertheless, a general overview of the jobs created and elaboration on the skill levels required can be drawn:

High-skilled jobs

High-skilled jobs typically require advanced education, master's degree, or PhD, and often extensive experience or specialized training. These jobs are concentrated in areas like engineering, research and development, management, and specialized technical roles such as:

- Engineers and scientists: Developing and optimizing green hydrogen production, including renewable energy integration.
- Research and development Professionals: Innovating in electrolysis technology, fuel cell efficiency, and hydrogen storage solutions.
- Management and strategic roles: Including project managers, business development managers, and policy advisors who require a deep understanding of both the technology and market dynamics.
- IT and data analysts: Managing the complex data systems that monitor and control production and distribution processes.

Medium to low-skilled jobs

Medium- to low-skilled jobs may require less formal education, possibly vocational training or on-the-job training. These roles are crucial for the operation, maintenance, and support of green hydrogen production and its applications such as:

- Technicians and operators: For maintenance of renewable energy systems, electrolyzers, and hydrogen infrastructure.
- Construction and manufacturing workers: Building the infrastructure for hydrogen production and the manufacturing of related components.
- Logistics and transportation workers: Managing the distribution of hydrogen and its derivatives.
- Support and administrative staff: Handling the day-to-day operations of businesses within the hydrogen economy.

The precise split of job creation between high-skilled and low-skilled is not finally predictable, as it will also depend on the localization and type of OEMs that can be achieved. Nevertheless, given the large workforce requirements for several construction sites in the initial setting up of a hydrogen infrastructure, it is expected that, after an initial strategic phase before starting the actual construction, the share of mid to low-skilled workforce required is much higher. As the industry matures, a shift towards more high-skilled jobs is expected, particularly as technology evolves and systems become more efficient and complex and construction sites become less. In general, it is important to notice, that the operation of hydrogen production facilities requires less workforce than the maintenance and operation of the renewable energy generation technologies.

For electrolyzers, Table 19 provides an overview of the latest expectations on jobs creation expressed in full time equivalents per million USD of investment. Over time the number of FTE decreases based on gained experience in operation and maintenance as well as larger sizes of electrolyzers.

Table 19: FTE's per million USD investment for electrolyzers

FTE/ Million USD investment	2030	2040	2050
Electrolyzer[16]	4.0 - 5.1	2.8-3.1	2.6-2.7

For PV and wind, Table 20 shows estimates for jobs creation based on different data sources. It must be noticed that these estimates have an inherent uncertainty as they consider different aspects such as direct jobs only, indirect or induced jobs. The indirect and induced jobs are typically significantly higher than the direct jobs but will highly depend on the country of interest.

Table 20: FTE's per million USD investment for PV and wind

FTE/ Million UDS investment	IEA (2020)	UNIDO/GGGI (Brazil)	UNIDO/GGGI (Brazil)
PV[17]	12.1	25.7	55.6
Wind[18]	1.7	29.2	60.5

As the data sources vary significantly, such kind of details can be considered as indicative only and are not a reliable basis for an estimation of the workforce needed. A more reliable estimate would require an in-depth study that takes into account specific local conditions when the projects have further progressed.

3.6 Institutional strengthening

The development of green hydrogen projects requires the strengthening of public and private sector capabilities. The implementation of a governance model to define a regulatory, normative, and promotional framework allows the responsible institutions to expand and adapt their competencies and capacities to embrace global developments with local implications and keep pace with global energy transition processes. For this, the governmental institutions should act in coordinated manner to make an efficient use of the available capabilities.

The purpose of developing a green hydrogen economy in Namibia is framed within the objectives of energy transition and decarbonization and should be supported by institutional experience in the definition of competencies by the different entities, in the development of innovative regulatory models to promote emerging technologies and in the adaptation of technical regulations to enable new strategic projects, without overregulating the sector.

[16] With an average investment cost of 1 million USD/MW electrolyzer this would lead to a 4.0 - 5.1 FTE / MW in 2030.
[17] With an average investment cost of 0.6 million USD/MW PV this would lead to a 7 - 33 FTE/MW in 2030.
[18] With an average investment cost of 0.9 million USD/MW Wind this would lead to a 1,5 - 54 FTE/MW in 2030.

4 Roadmap for development

Considering the complete value chain for green hydrogen and its derivatives, a great opportunity is given for a green industrialization of Namibia and the reduction of its current dependence on fossil fuels and imports of products, which promotes economic and social development in harmony with the environment. This sustainable development will also allow Namibia to access new international markets by exporting products with high added value. All of this will be reflected, among other aspects, in access to a better infrastructure, the creation of jobs throughout the production chain and in the generation of new technical, technological and research and development capabilities in the country.

The speed of this development will depend, however, largely on the creation of a regulatory, normative, and promotional framework that incentivizes the implementation of projects along the hydrogen value chain and attracts national and international investments.

After recognizing the fundamental role that green infrastructure will play in the future, the necessary strategic steps and key milestones for developing green infrastructure in the Central Hydrogen Valley need to be taken. The following roadmap gives recommendations and identifies prioritized actions and milestones that shall enable a structured development of the green infrastructure in Central Hydrogen Valley.

The goals and prioritized actions defined in this roadmap are summarized in the following Figure 23.

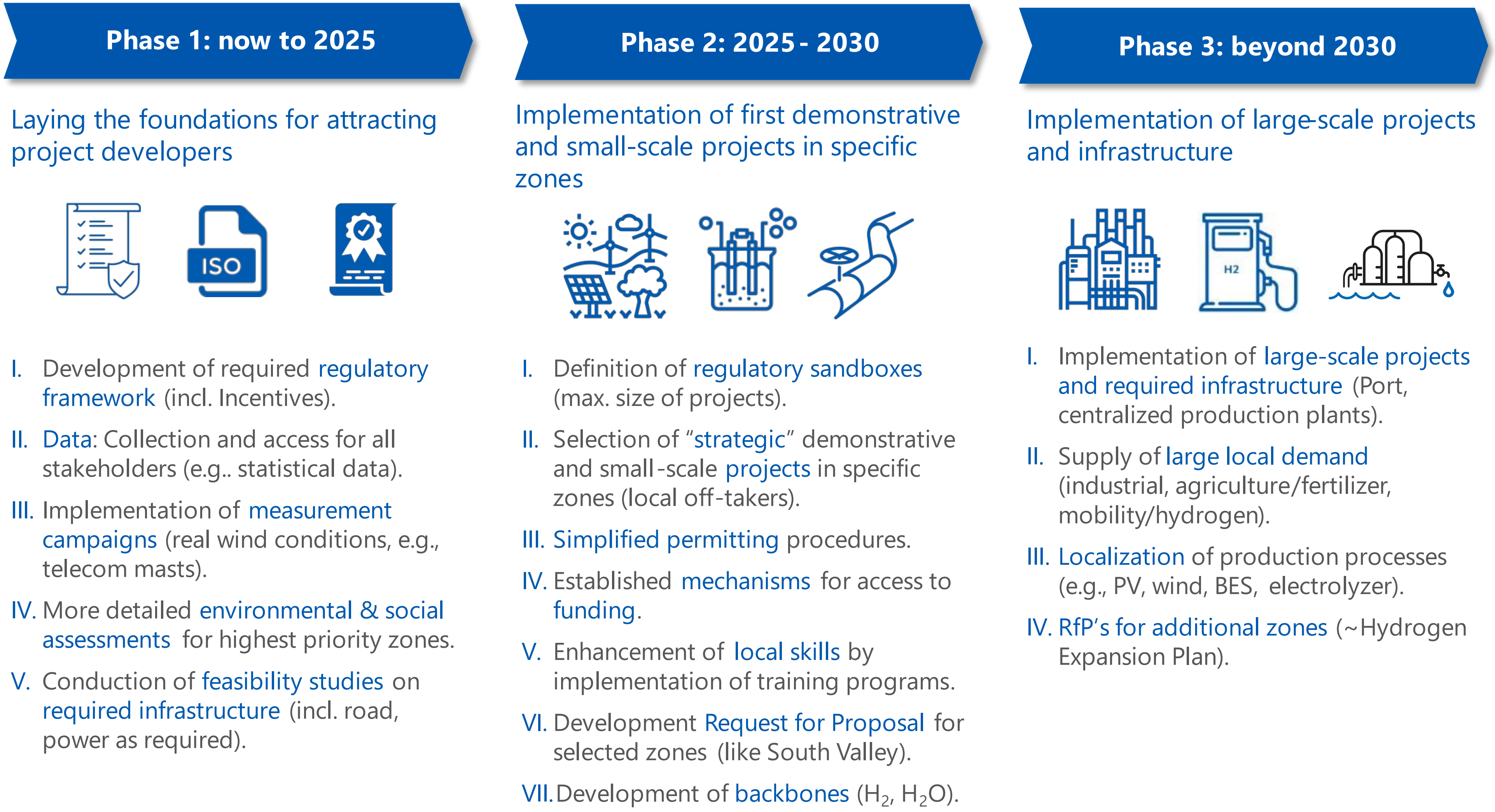


Figure 23: Roadmap for development of the Central Hydrogen Valley

The development is structured in three successive phases. The measures proposed in the individual phases to reach the key milestones are described in more detail below, followed by a list of specific measures for the development of green infrastructure in the Central Hydrogen Valley.

4.1 Phase 1 (now until 2025)

The first phase is time-critical and should be implemented as soon as possible. Against the background of the large-scale international development of the hydrogen infrastructure, it is essential to offer potential developers, manufacturers and suppliers a structured and attractive framework in order to maintain their interest despite the growing number of alternatives and to enable a rapid investment decision. To this end, the following measures are recommended:

Development of required regulatory framework (incl. Incentives)

The development of a required regulatory framework is a critical step in the roadmap for green infrastructure projects. This involves creating clear rules, regulations, and guidelines that govern the planning, construction, and maintenance of green infrastructure.

- Setting standards and regulations:

  Definition of technical and environmental standards for green infrastructure projects. These standards ensure that all projects are designed and implemented in a way that maximizes their environmental benefits while minimizing any potential negative impacts and they give developers the necessary guideline for system design. These regulations should also be enablers for sustainable and value-adding development in the country.

- Incentives and subsidies:

  To encourage investment in green infrastructure projects, the government can provide various incentives such as tax breaks, grants, or subsidies. These incentives can help offset the high initial costs of setting up green infrastructure and make it more financially attractive for businesses and local authorities to invest in these projects. An analysis of which incentives would be the most beneficial and would have the highest impact should be done as a next step.

- Design enabling market rules:

  Design enabling market rules for the deployment of green hydrogen, including removing barriers (typical barriers are listed in Section 2.4, Table 18) for efficient hydrogen infrastructure development, and ensure access to liquid markets for hydrogen producers and customers. Typical market rules, that might need to be adapted are regulations that allow for the trading of hydrogen in energy markets, or policies that promote the use of hydrogen in sectors like transportation, industry, and power generation. A standard for the permitting procedure for such plants needs to be implemented and safety standards for the production, storage, and use of hydrogen established. Furthermore, the market rules should encourage the development of necessary infrastructure for hydrogen production, storage, and distribution. This could be facilitated through public-private partnerships or government funding for infrastructure projects.

- Zoning and land use policies:

  The regulatory framework should also include zoning and land use policies that encourage the development of green infrastructure. This could involve designating certain areas for green infrastructure or requiring that a certain percentage of new developments include green infrastructure elements.

- Public Private Partnerships:

  Encourage the private sector to invest in green infrastructure through public private partnerships. These partnerships can leverage private sector expertise and funding to deliver public infrastructure projects.

- Research and development support:

  Support research and development in green infrastructure technologies through funding and partnerships with academic and research institutions at national, regional and international level. This can lead to advancements in technology that make green infrastructure more efficient and cost-effective and bring knowledge and educated workforce in the country.

- Public awareness and education:

  Increase public awareness and understanding of green infrastructure and its benefits to get the publics backing for the projects. This can be achieved through educational campaigns and initiatives.

By developing a comprehensive regulatory framework that includes these elements, an environment that is conducive to the growth and success of green infrastructure projects can be created.

Data: Collection and access for all stakeholders

It is important that all stakeholders (e.g., government agencies, private sector companies, non-profit organizations, researchers, and the general public) have access to a central set of data so that they have the same basis for further consideration or an informed investment decision. This can be achieved through a centralized data portal or platform. The necessary data includes information on the location, type, and size of existing green infrastructure, as well as data on environmental factors such as air and water quality, biodiversity, and climate conditions. It should also include statistical data and data on social and economic factors, such as community needs, land use, and property values.

Implementation of measurement campaigns

In order to provide reliable and up-to-date data, it is necessary to analyse what data is already available and in what form, and to process it accordingly. Where data is missing or outdated, it should be updated as soon as possible. In the context of green infrastructure, this includes, for example, the collection of wind and weather data. Existing telecom masts in Namibia, due to their height and location, often experience strong and consistent wind conditions and could therefore be used as platforms for wind measurement equipment, providing valuable data for assessing wind energy potential.

Detailed environmental & social assessments for highest priority zones

With the first high priority zones for green hydrogen identified within the study, these should be further evaluated with site specific studies to being able to narrow down the identified theoretical potential to a feasible implementable one and to estimate the environmental and social impacts and give potential investors more security when investing in a certain zone and allow a faster progress.

Conduction of feasibility studies on required infrastructure (incl. road, power as required)

It is necessary to have an overview of the infrastructure required for the projects along the value chain for green infrastructure projects and to develop a strategy for the implementation and operation of the infrastructure assets. Therefore, it is necessary to determine what kind of assets the government wants to invest in and what kind of services should be offered to developers. For example, it is likely that the government will need to establish a national hydrogen backbone network, but certain sections of the pipeline that are not part of the main network could be privately established by developers to enable faster implementation. Further it is required to set a strategic target for the region to determine i.e. the amount of green hydrogen or its derivates to be exported to enable better planning and sizing of infrastructure assets.

4.2 Phase 2 (2025 - 2030)

After laying the foundations for attracting project developers and setting the basic rules to enable a sustainable and fast paced development of green infrastructure, the implementation of first projects is recommended as a second step to get familiar with the technologies and project structures, gain trust of developers and train Namibian workforce, among others.

Regulatory sandboxes:

The phase begins with the definition of regulatory sandboxes, to have a controlled environment for testing new technologies or business models. The maximum size of projects within these sandboxes should be defined by governmental authorities to ensure manageable testing and evaluation.

Strategic project selection:

The roadmap then involves the selection of strategic demonstrative and small-scale projects in specific zones, providing tangible evidence of the technology's potential to local consumers and investors. Zones close to existing off-takers and desalination plants or zones close to the future hydrogen backbone would be beneficial as they would require less investment in hydrogen and water pipelines.

Simplified permitting procedures:

Simplify and standardize permitting procedures to expedite the development and implementation of the projects using the knowledge gained from the small-scale sandbox projects. Permitting procedures that take too long or are not clearly defined from the beginning will drive away project developers.

Funding access:

Establish mechanisms for accessing funding, providing clear and accessible pathways for project developers to secure necessary financing at beneficial conditions (e.g., with reduced interest rates).

Skills enhancement:

Establish certified training programs to enhance local skills and build capacity needed for the development and maintenance of the projects.

Request for proposal development:

Elaborate a Request for Proposal (RFP) for selected zones, inviting bids for project development and ensuring the selection of competent developers, for which the experience collected in the South Hydrogen Valley might be helpful in reference to lessons learned and potential improvements.

Infrastructure development:

Based on the results of the feasibility studies conducted in Phase 1, start developing infrastructure required to enable large scale project implementation. This includes a hydrogen and water pipeline and desalination plants. It is important to consider the timing of the future development of the major projects in each zone in Phase 3 to ensure that the infrastructure is designed to a sufficient scale (e.g., appropriate pipe diameters) and that all the necessary media are available when the future major plants are commissioned.

4.3 Phase 3 (beyond 2030)

In Phase 3 a scaling up of the green industry is foreseen with the implementation of large-scale projects and infrastructure based on the lessons learned and basics established in Phases 1 and 2.

Large-scale projects and infrastructure:

The implementation of large-scale projects and the simultaneously continuous development of the necessary required infrastructure will involve moving beyond the initial small-scale and demonstrative projects to more substantial, impactful initiatives. As a lot of material and workforce is required for these tasks, it is recommended to have an overview of the available capacities and structure the project implementation schedule accordingly.

Localization of production processes:

Localize production processes for components such as PV modules, batteries and electrolyzers, to ensure that the technologies and processes used in the green industry are locally sourced or produced, fostering local industry and reducing reliance on imports.

Supply of growing local demand:

If the right framework conditions are created in Phase 1 and appropriate incentives are provided for the development of a local green infrastructure, an increasing share of local hydrogen consumption can be expected to be met by local producers. Potential local users of hydrogen are industrial production, agriculture and fertilizer production, mobility and producers of hydrogen derivatives. It is important to ensure that this demand can be met, as the local processing and use of hydrogen offers enormous potential for the economic development and decarbonization of the country. For example, the local production of green fertilizers would allow Namibia to reduce its dependency on imported fertilizers (at corresponding high costs) and to promote the use of local produced fertilizers to increase crop yields and food safety.

RFPs for additional zones:

Considering the available capacity of resources, it is unlikely, that the maximum potential for green hydrogen will be met with the first large scale projects. After 2030 a successive development is expected that will require the issuance of further RfPs to development of green industry projects and their related infrastructure in new areas, expanding the reach and impact of the initiatives.

4.4 Additional specific considerations

Based on the results of the previous study, and considering the measures to boost green industrialization as elaborated in section 3.3 in this report, a series of concrete measures are recommended that can contribute to the decarbonization goals of the country and a faster ramp-up of the green infrastructure.

Potential for sustainable tourism:

The comparatively high purchasing power of tourists, who come predominantly from developed countries, opens up different opportunities and challenges for future tourism in Namibia. For example, affluent tourists place more emphasis on the sustainability of their trips and are potentially willing to pay more for low carbon alternatives. For Namibia, this creates a need to enable sustainable tourism and the opportunity for covering the additional corresponding costs through tourists. Possible measures in this direction could include the use of hydrogen or biodiesel as a substitute for conventional diesel for mobility in national parks. In addition, air traffic in the country could be switched from kerosene to locally produced sustainable aviation fuels.

Setting regulations for the integration of renewable energies and hydrogen in mining processes:

Driven by the prospect of reducing environmental impact, integrating renewables into the system and reducing costs, it would be conceivable to set a green electricity quota for mining and other industries, in addition to the existing regulations on the import and export of mining products, in order to gradually drive the expansion of renewable energy. Existing fuel-based generators could be cost-effectively replaced with photovoltaic systems to save fuel during the day and reduce CO_2 emissions. Optionally the diesel generators that are currently used for off-grid mining sites could be replaced with local generated hydrogen.

Furthermore, the diesel consumption related to the transportation in mines (a major share of energy consumption in open pit and underground mining) due to heavy machines (such as trucks, excavators and tractors) can be replaced by hydrogen or derivatives. In an early stage even the dualization of current transport machinery by using mixtures of diesel and hydrogen can already deliver major emissions reductions and has already been successfully implemented in other countries.

Using hydrogen in industrial transportation:

To further generate local off-take and benefits using hydrogen, an option would be to use the existing rail system with upgraded trains using hydrogen as fuel and a further developed railway network to transport imported products from the harbour directly to Botswana (e.g. to transport diesel tankers for exporting diesel), thereby decarbonizing the transport system and having an added benefit for road safety in the country as trucks are shifted to rail.