HYAFRICA

15 AUGUST 2022 – 14 AUGUST 2025

LEAP-RE

Long-Term Joint EU-AU Research
and Innovation Partnership on Renewable Energy

Pillar-1 project

The LEAP-RE project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

HyAfrica

LEAP-RE

Consortium

One SME (coordinator), 2 research institutes, 5 universities and 1 governamental regulatory body.

Aim of the project

- Map **natural hydrogen resources** in promising regions of Morocco, Mozambique South Africa, Togo and assess its **potential for being applied in standalone energy systems** for isolated communities.

Relevance vs MAR#3 and MAR#4

- Local source of energy to isolated communities in stand-alone and off-grid systems
- Natural hydrogen is a constant energy source – reliability of power supply
- Reduces energy costs and develops local economies by creating job opportunities.
- No GHG – water is the only by-product. Unlike green H_2, natural H_2 reduces energy-water competition.

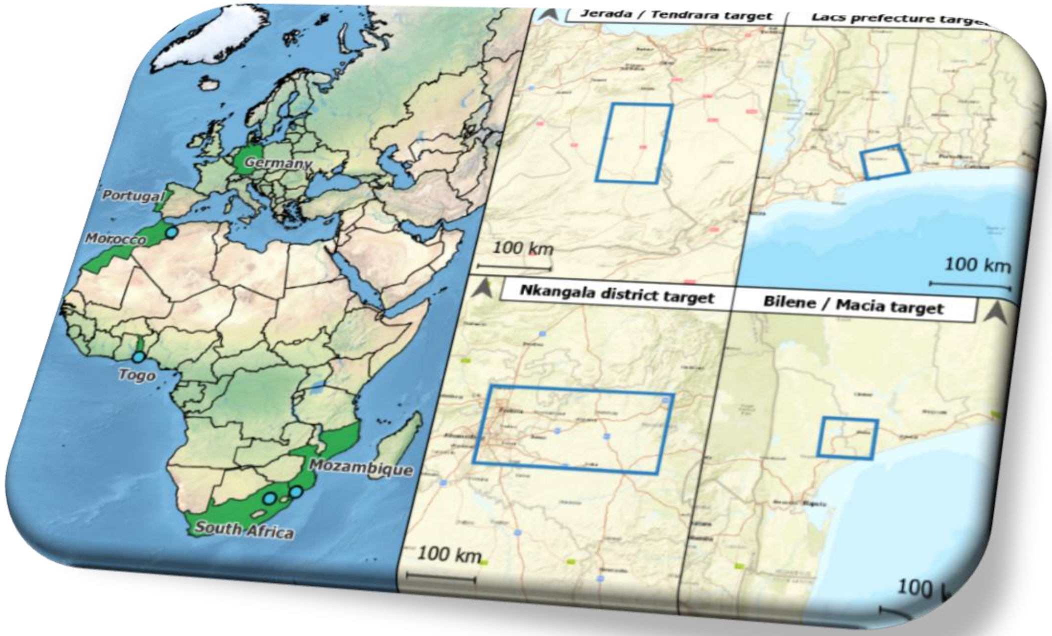
Specific Objectives

SO1 - **identify and map existing resources** and increase knowledge about the controlling geological conditions

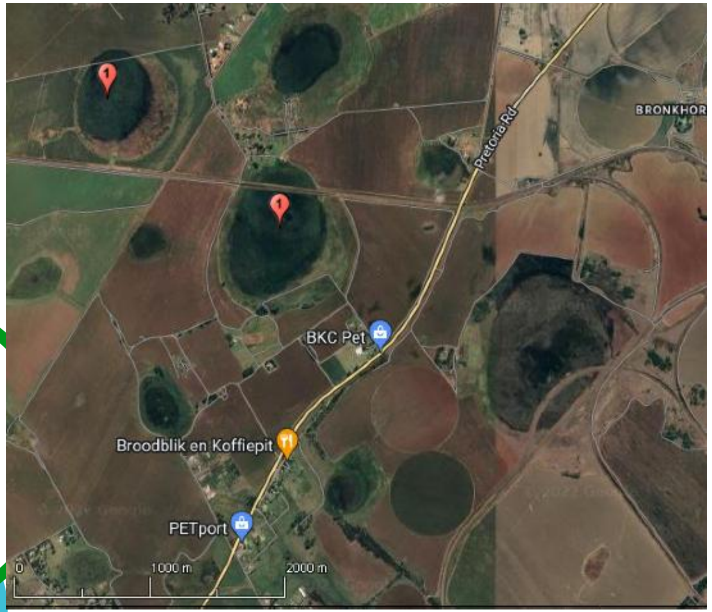
SO2 - develop **roadmaps for natural hydrogen exploration** and exploitation in the target countries.

SO3 - assess the **socio-economic impact and develop business models** for standalone, off-grid and mini-grid systems based on H_2.

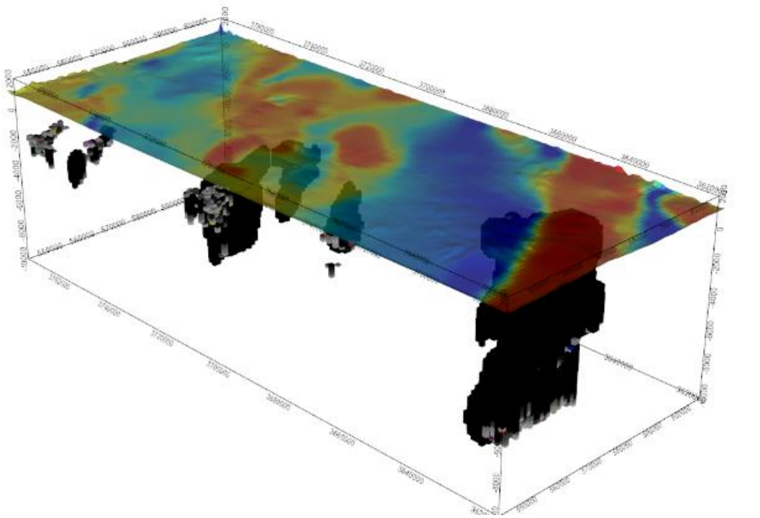
SO4 - **build awareness and capacity** on natural hydrogen application in standalone and mini-grid systems among the academic community and institutional stakeholders.



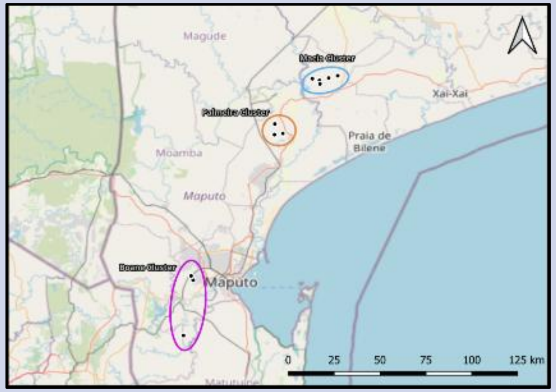
SO1 - Identify and map existing resources

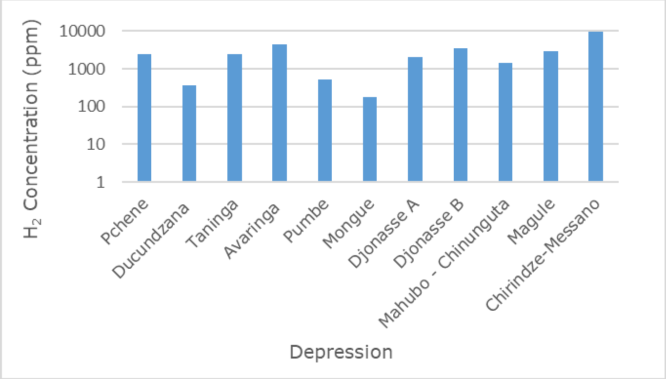
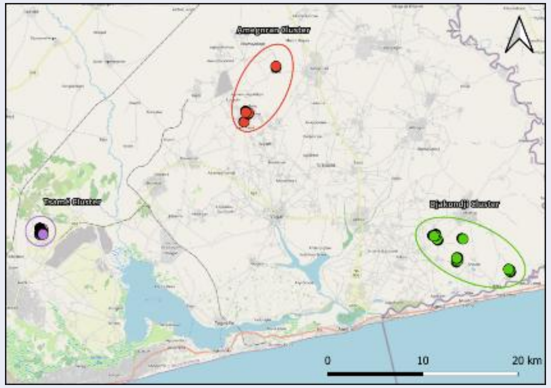


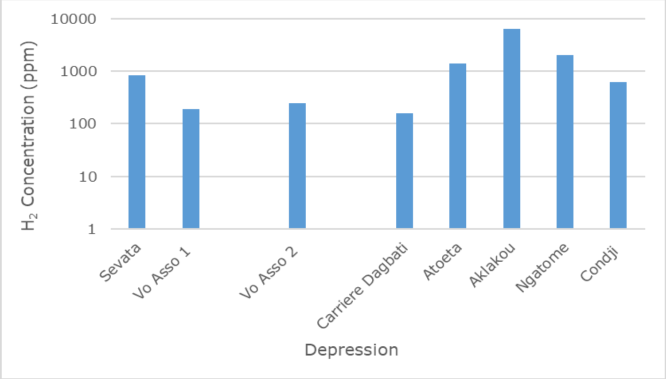
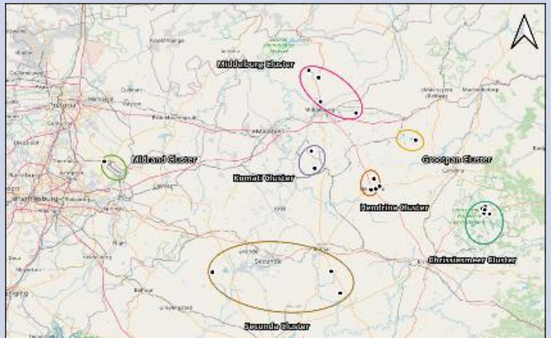
- Remote sensing: Depressions as proxies for seeps;
- Surface geochemistry: *in situ* H_2 measurements (and radon)
- Geophysics: gamma spect. and existing magnetic/ gravimetric / seismic data
- Laboratory analysis: soil gas composition
- Structural geology: regional discontinuities and deep faults
- Magnetic / gravimetric anomalies: 3D modelling and H_2 origin
- **Definition of hydrogen system**

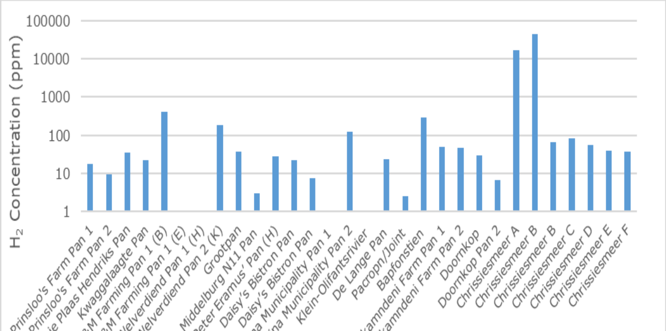


SO1 - Identify and map existing resources

<table>
<tr><th>Country</th><th>Clusters</th><th>measurements and samples</th><th>H2 concentration (ppm)</th><th>Max H2 conc. (ppm)</th></tr>
<tr><td>Mozambique</td><td>
</td><td>511 measurements, 17 samples

</td><td>
</td><td>9 500 ppm (0.95%)</td></tr>
<tr><td>Togo</td><td>
</td><td>168 measurements, 13 samples

</td><td>
</td><td>6 500 ppm</td></tr>
<tr><td>South Africa</td><td></td><td>1733 measurements, 25 samples

</td><td>
</td><td>44 000 ppm (4.4%)</td></tr>
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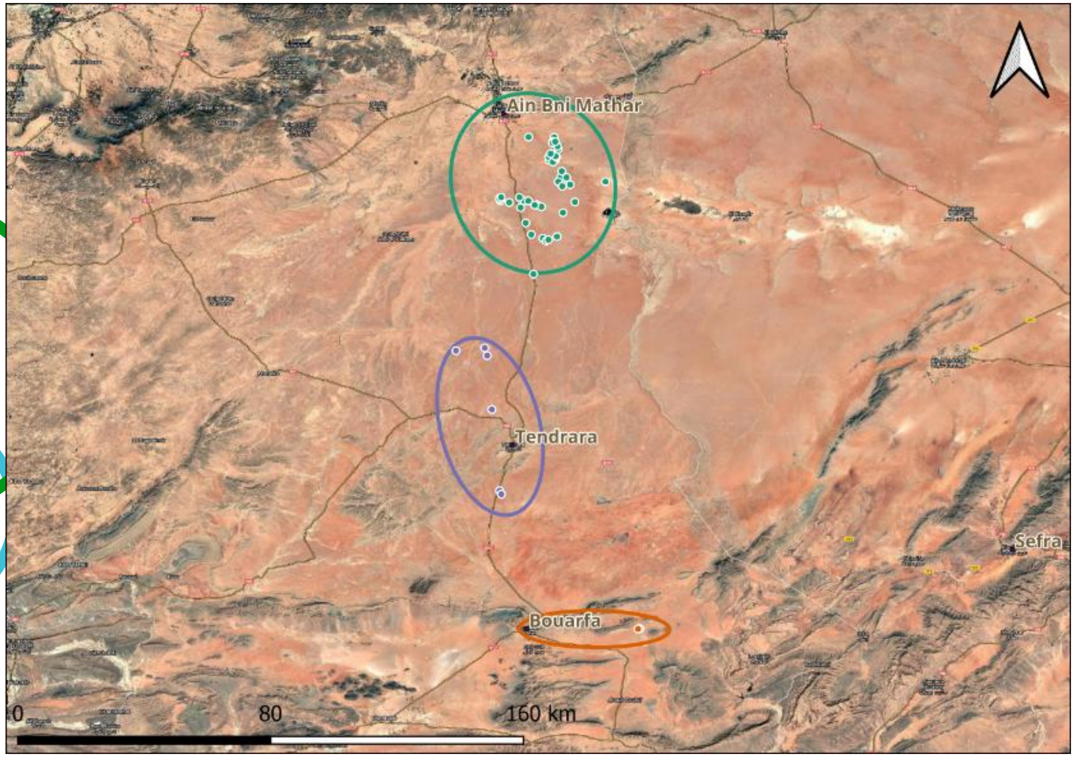
What about Morocco?

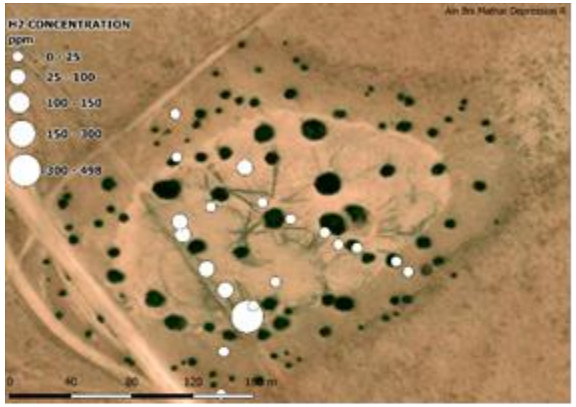


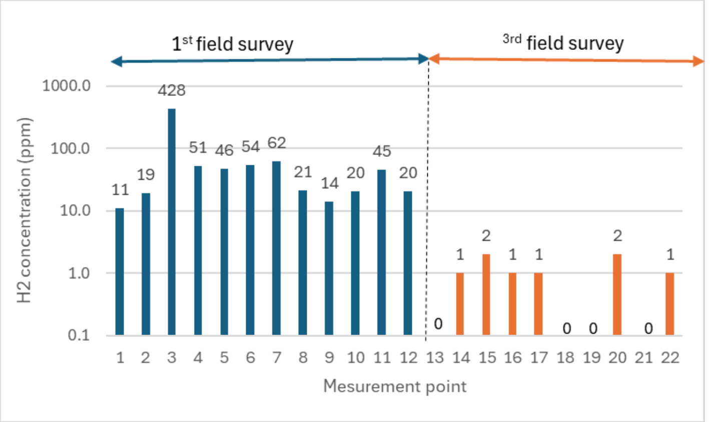
683 points measured. Three field surveys

1^{st} and 2^{nd} field survey- high H_2 concentrations, up to 450 ppm

3^{rd} field survey – different methodology – H_2 on background values.

Artifacts - H_2 originated by measurement process.





Moroccan team pursuing with measurements in another Area - **Khemisset**.

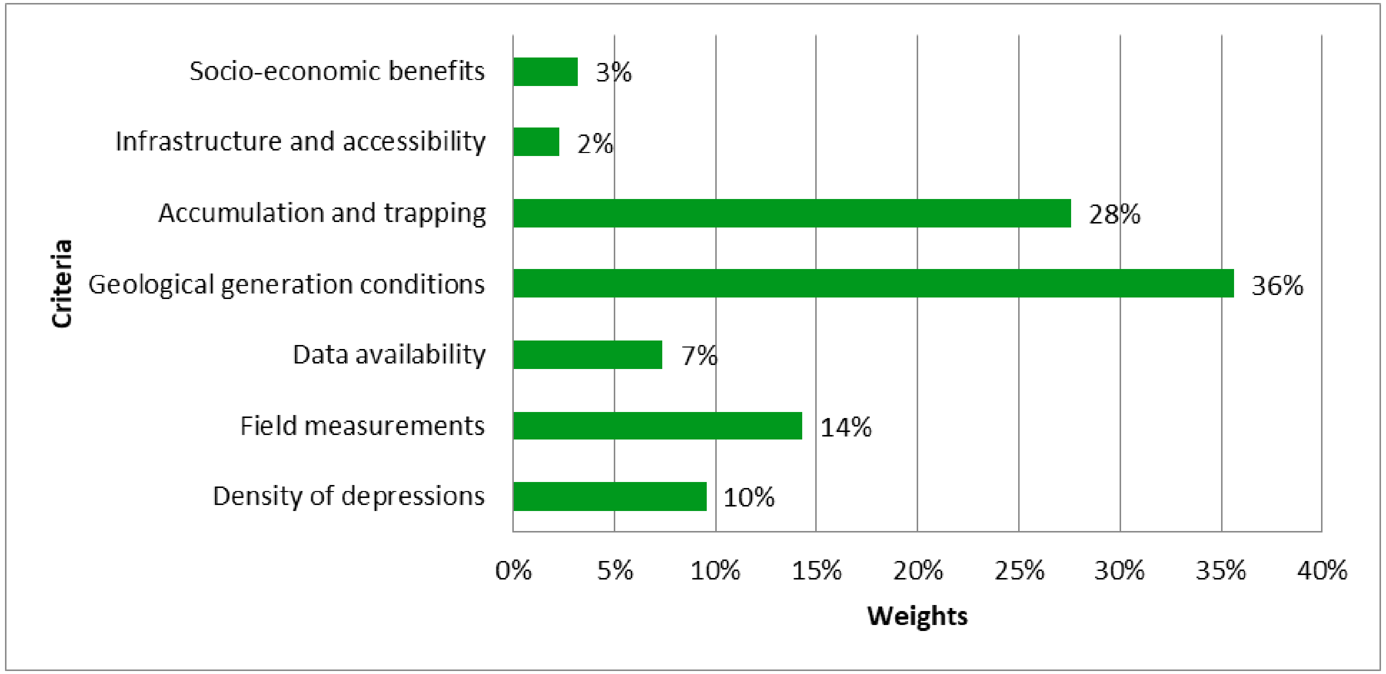
SO1 - Identify and map existing resources

Ranking of target zones

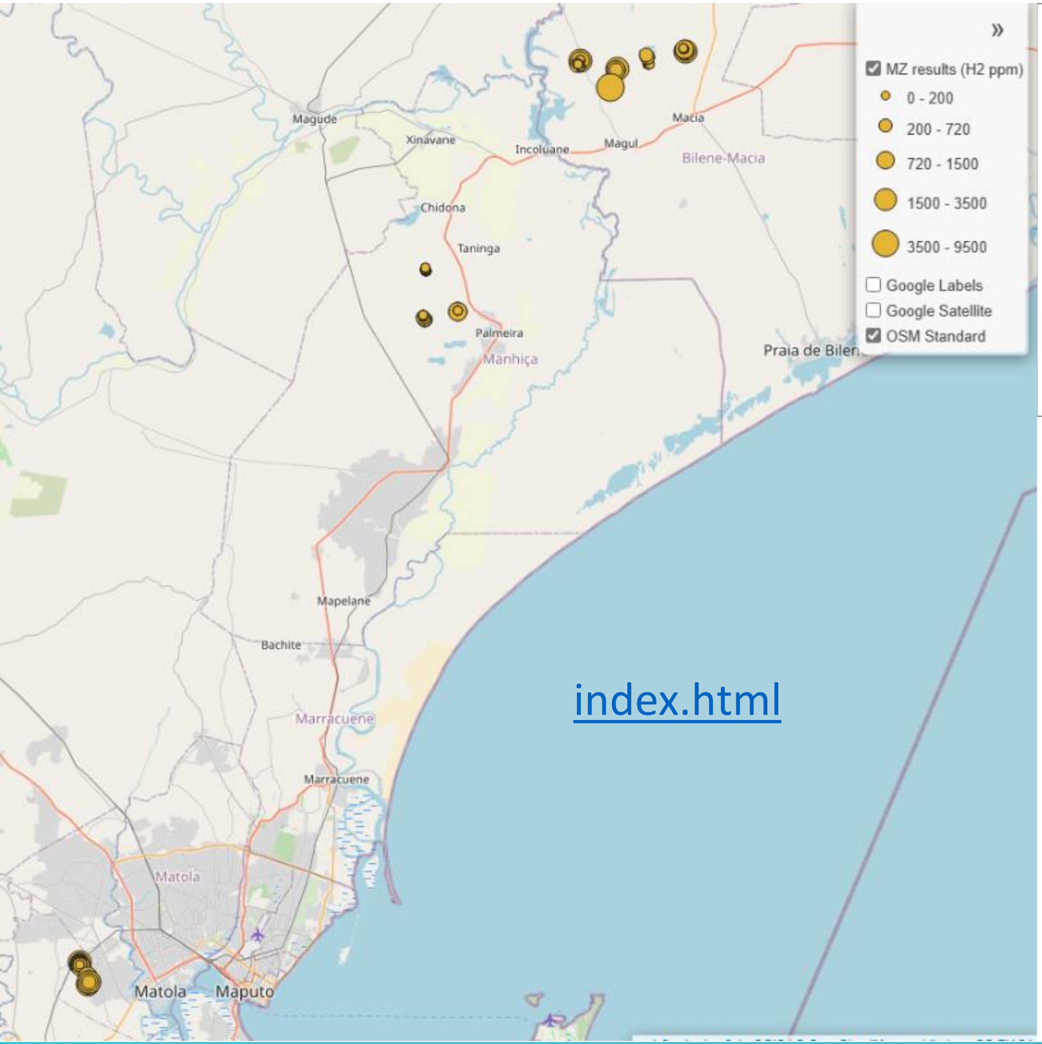
Analytic Hierarchy Proccess (AHP) – implemented with 7 criteria (technical, socio-economic)

Saaty's scale of relative importance (Saaty, 2005)

SCALE	NUMERICAL RATING	RECIPROCAL
Extremely Preferred	**9**	**1/9**
Very strong to extremely	8	1/8
Very strongly preferred	**7**	**1/7**
Strongly to very strongly	6	1/6
Strongly preferred	**5**	**1/5**
Moderately to strongly	4	¼
Moderately preferred	**3**	**1/3**
Equally to moderately	2	½
Equally preferred	**1**	**1**



SO1 - Identify and map existing resources



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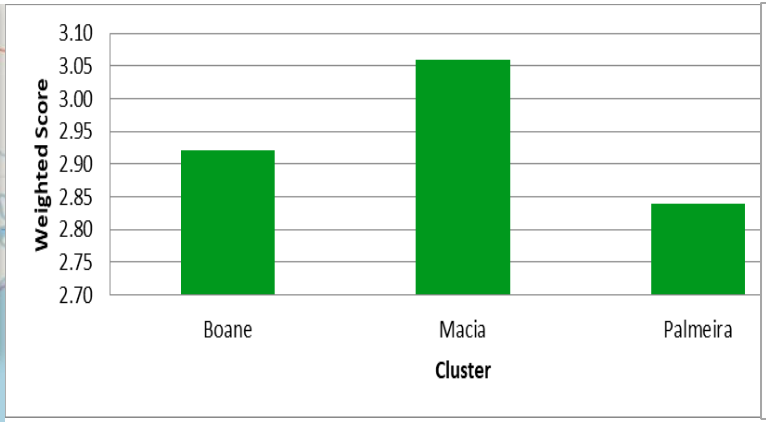
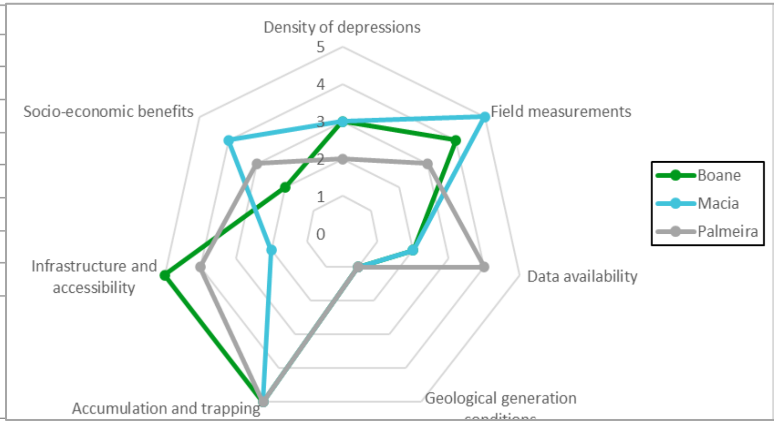




The Macia and Boane areas stand out, with **several depressions yielding peak field readings above 1000 ppm and up to 9500 ppm**.

Potential generation mechanisms include water-rock reactions in mafic or ultramafic basement lithologies and structural control by graben-bound faults.

Macia and Boane warrant prioritization for follow-up surveys, flux monitoring, and shallow borehole investigations.

SO1 - Identify and map existing resources

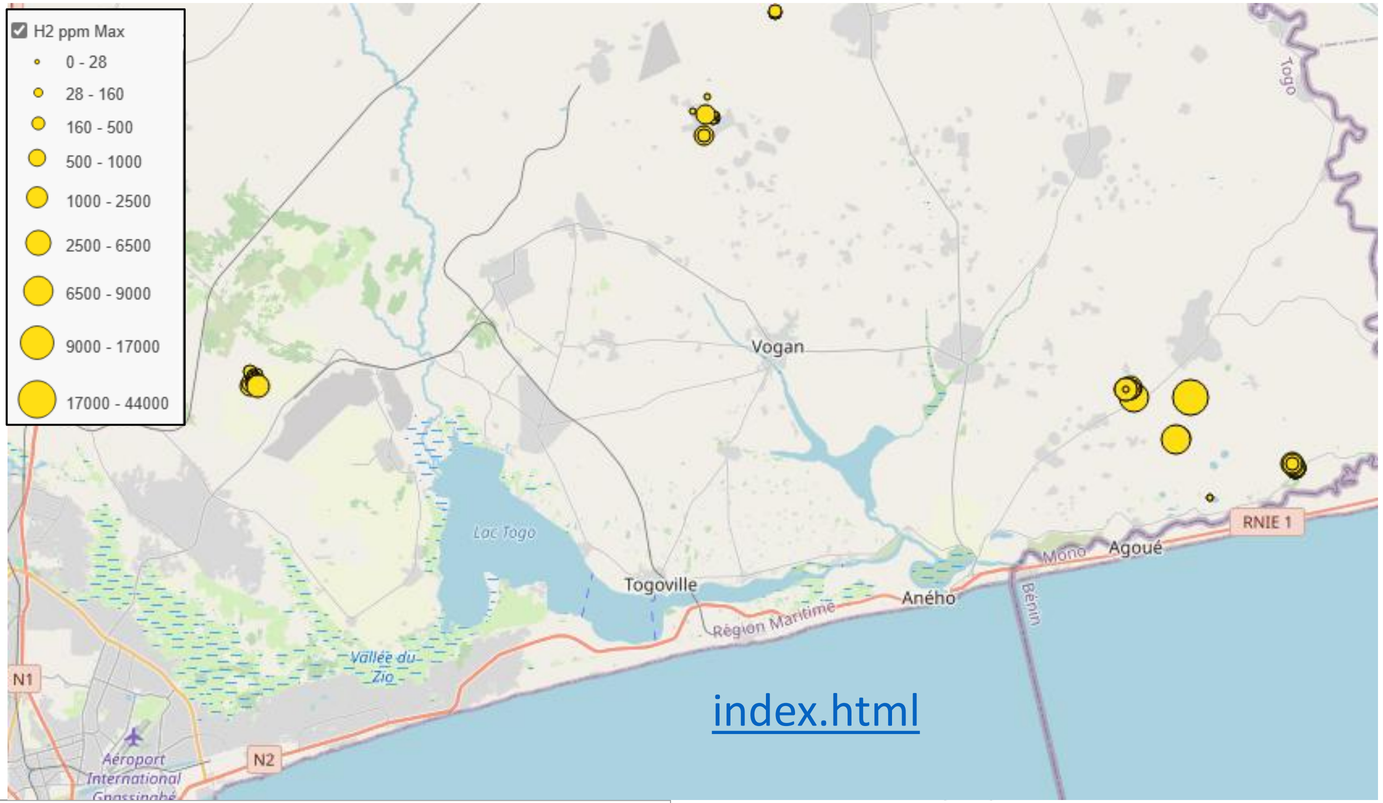
Ranking of target zones

Togo priority areas

Dakondji cluster revealed stronger anomalies, with field peaks reaching 6500 ppm and multiple laboratory-confirmed values above 200 ppm.

Complex faulting, Pan-African basement reactivation, and sedimentary cover—may facilitate hydrogen migration. Possibility of radiolytic origin.

Dakondji emerges as a promising candidate for continued exploration- integration of fault mapping, shallow coring, and long-duration gas monitoring could be essential for evaluating its potential.



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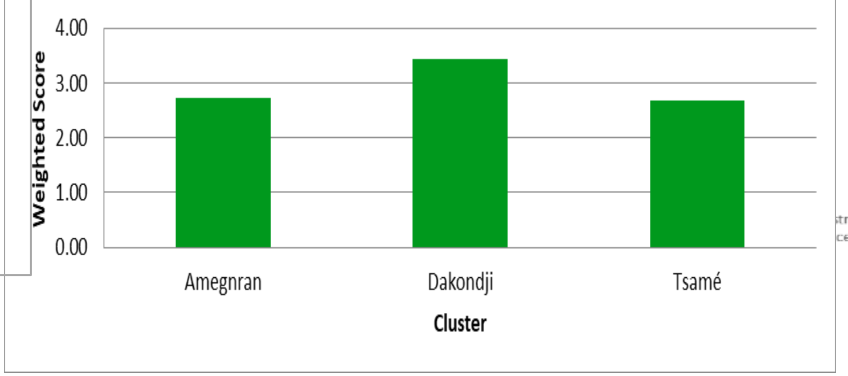
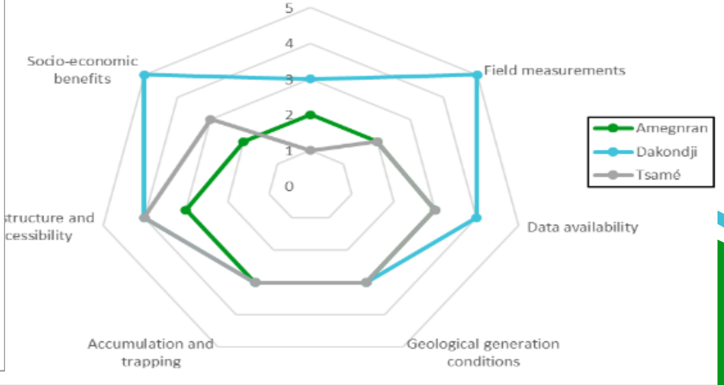
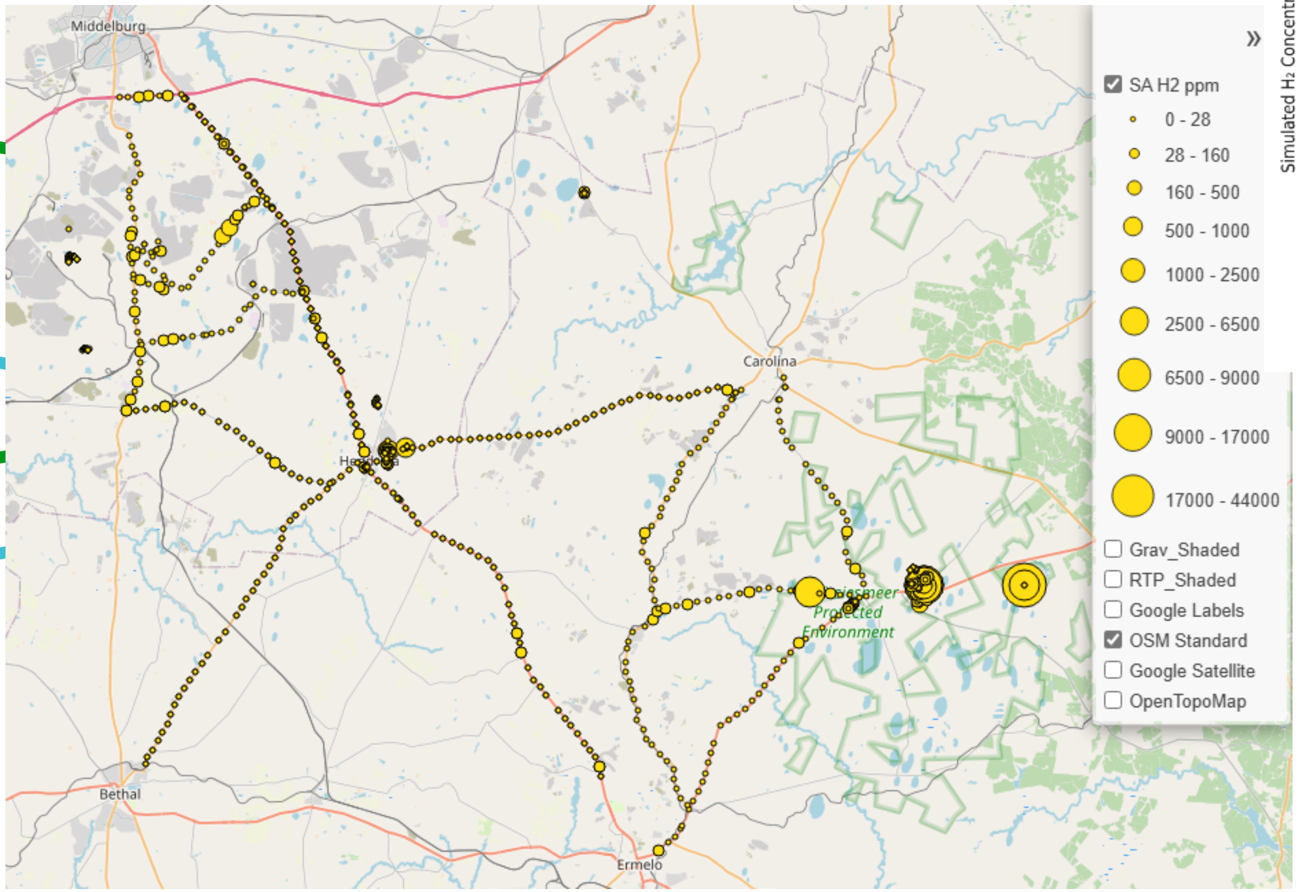
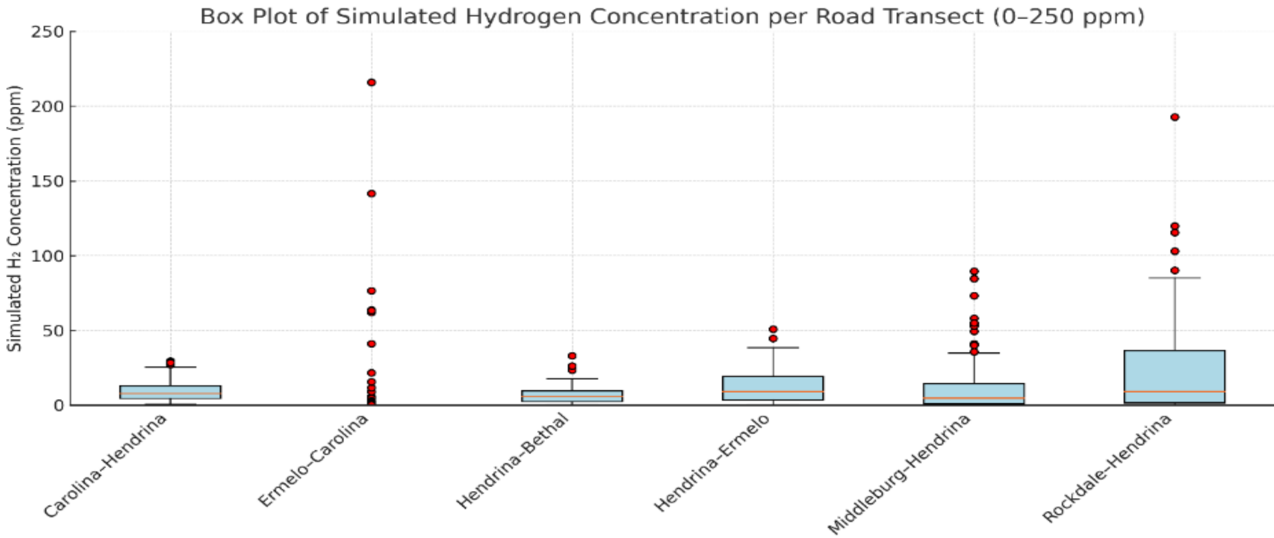




Ranking of target zones

South Africa priority areas





Komati and Hendrina clusters - multiple field peaks of 1,000–2,500 ppm, and the Chrissiesmeer cluster delivered **exceptional values—up to 44,000 ppm (4.4%)** in the field and **16,700 ppm in the laboratory.**

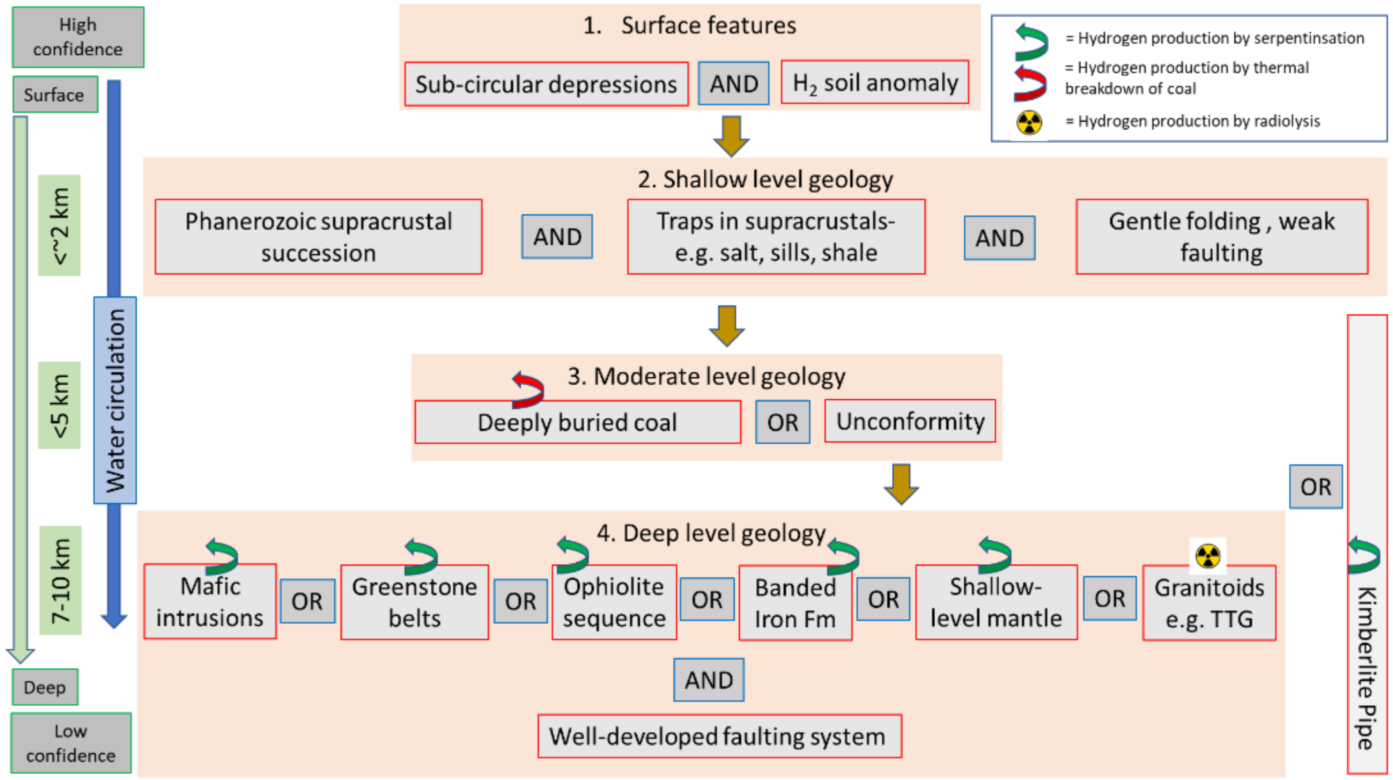
Complex Precambrian cratonic crust overlain by Paleozoic strata

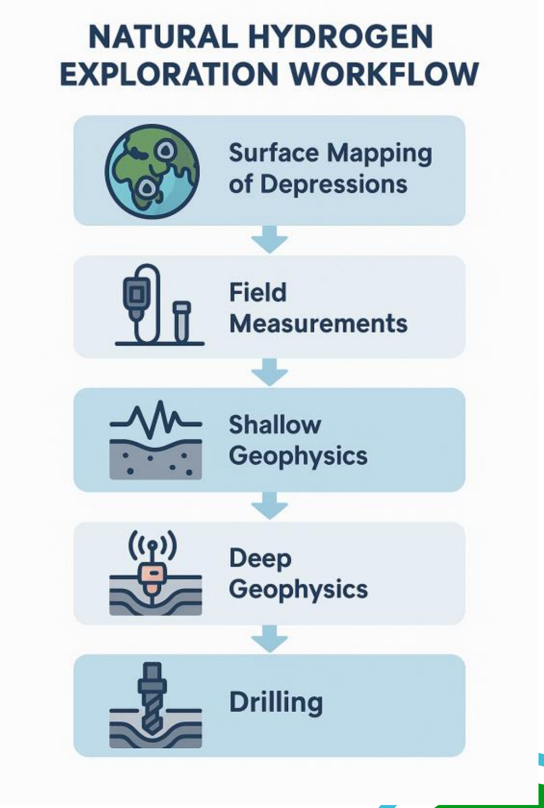
These sites merit:

- Continuous gas monitoring
- Shallow borehole drilling for vertical gas profiling
- Integration of field data, remote sensing and geophysical
- Assessment of temporal variability and recharge dynamics

Providing authorities with systematic workflows for exploration 1/3

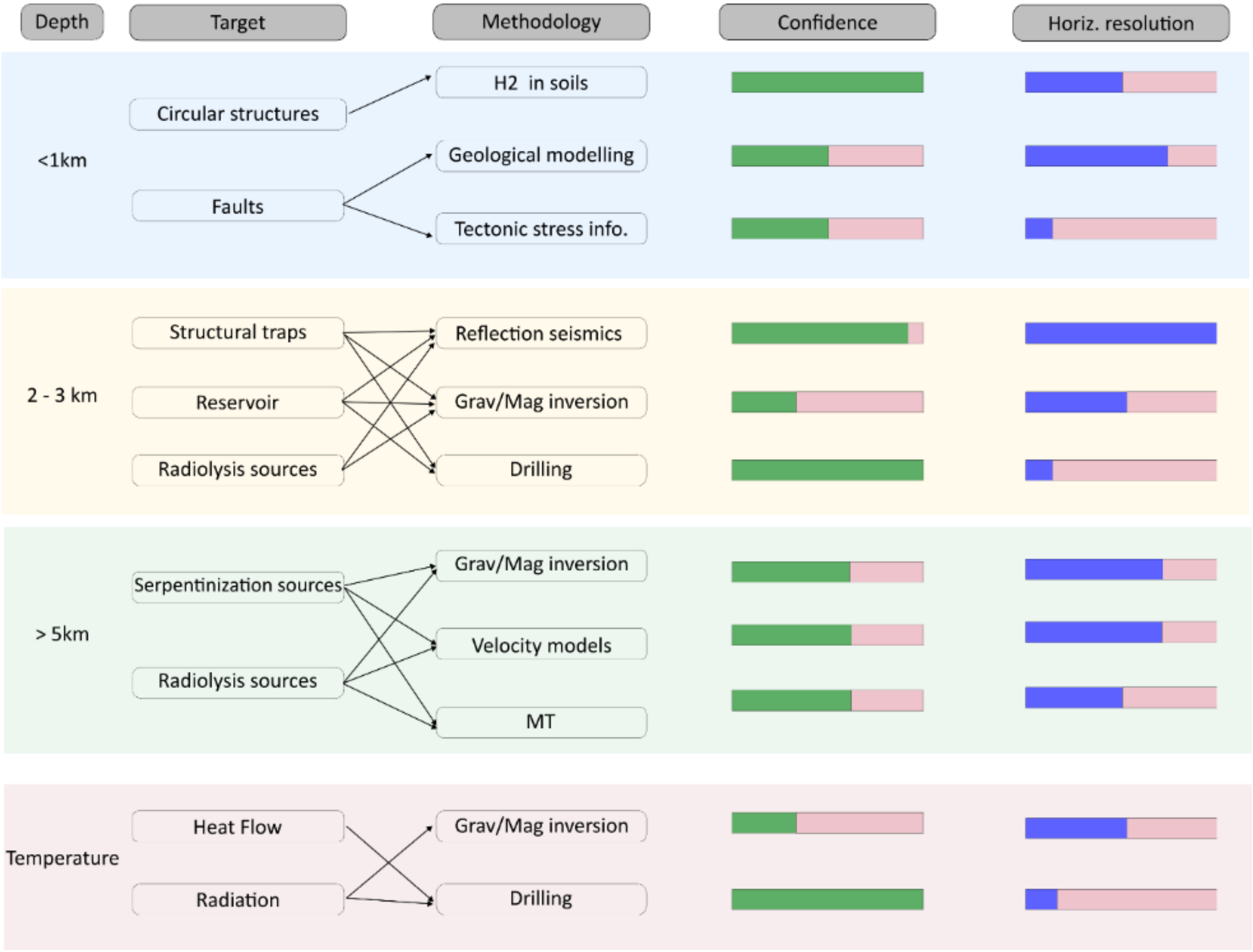
Stage 1 - Geology, structural geology and the origin of hydrogen

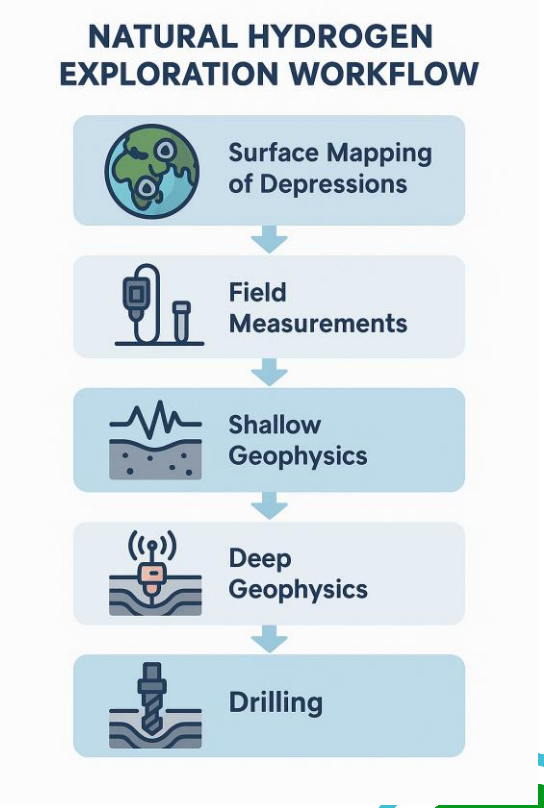




Providing authorities with systematic workflows for exploration 2/3

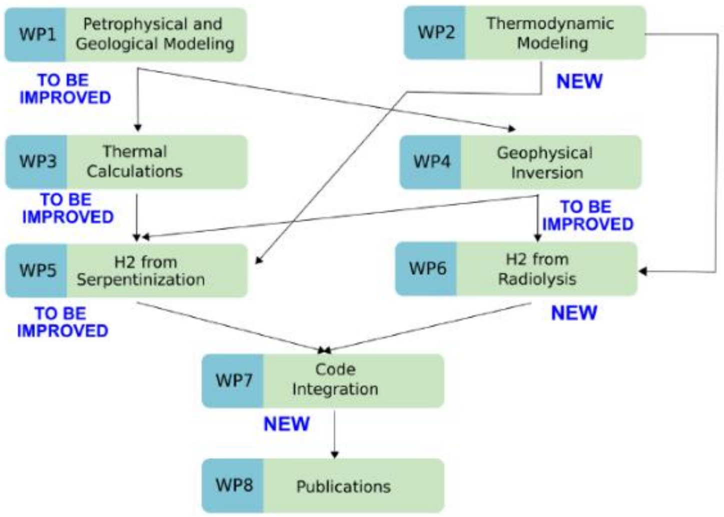
Stage 2 - Deep geological conditions – geophysics and drilling





Providing authorities with systematic workflows for exploration 3/3

Stage 3 - Tools to quantify the hydrogen generation and consumption rates



Present: H2 generation from serpentinization

Future: H2 from radiolysis

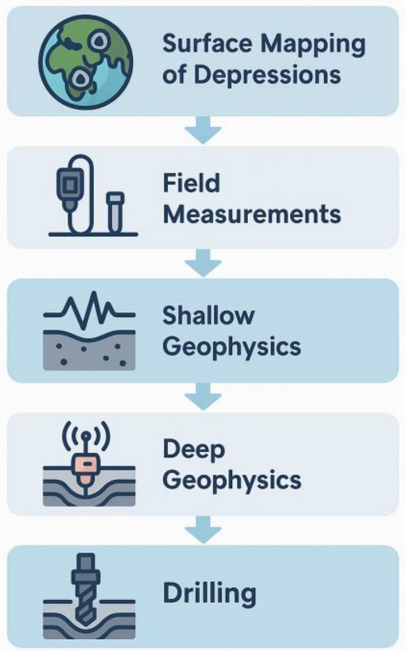
PoNHy: "Potential for Natural Hydrogen"

```python
import os
import sys
import numpy as np
import matplotlib.pyplot as plt
import discretize
from discretize.utils import active_from_xyz
import time
import seaborn as sns
from scipy.interpolate import griddata
import pandas as pd
import warnings
from scipy.stats import gaussian_kde
from datetime import datetime
import xarray as xr
from matplotlib.lines import Line2D
from tqdm import tqdm

warnings.filterwarnings('ignore')

# Begin of time
start_time = time.time()
current_time = datetime.now().strftime("%Y%m%d_%H%M%S")

dir_path = r"/home/christiansen/Python/HyAfrica" + os.path.sep

# Define the folder name with date and time
folder_name = f"Results_{current_time}"
results_path = os.path.join(dir_path, folder_name)

# Create the folder if it doesn't exist
if not os.path.exists(results_path):
    os.makedirs(results_path)
    print(f"\nResults will be saved in folder: {results_path}\n")

# Define the CustomPrint class for redirecting stdout
class CustomPrint:
    def __init__(self, file_path):
```

Type: open source

Owner: IAG

NATURAL HYDROGEN EXPLORATION WORKFLOW



SO2 - Develop roadmaps for natural H_2 exploration

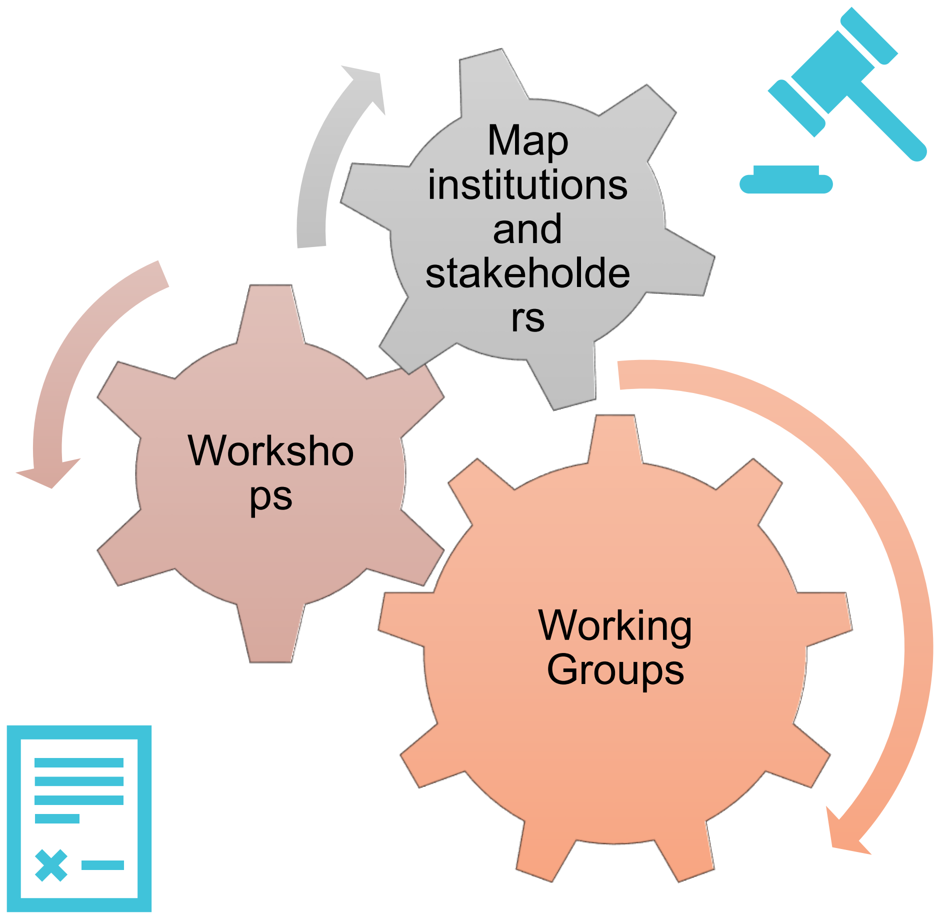
Providing authorities with a regulatory framework 1/2

Assess **legislation and regulatory gaps** in target countries

Engage with local policy makers

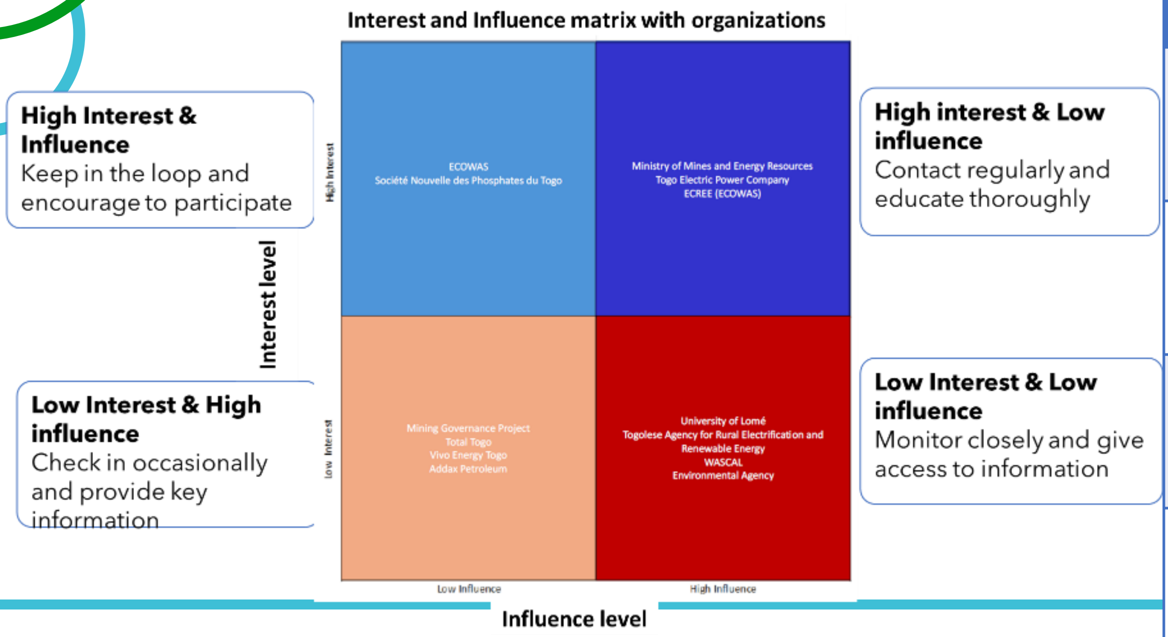
Develop mechanisms to **include natural H_2 in the Energy or Mining Laws** of target countries

Develop roadmaps in target countries for for **natural H_2 strategies**



SO2 - Develop roadmaps for natural H_2 exploration

Providing authorities with a regulatory framework 2/2

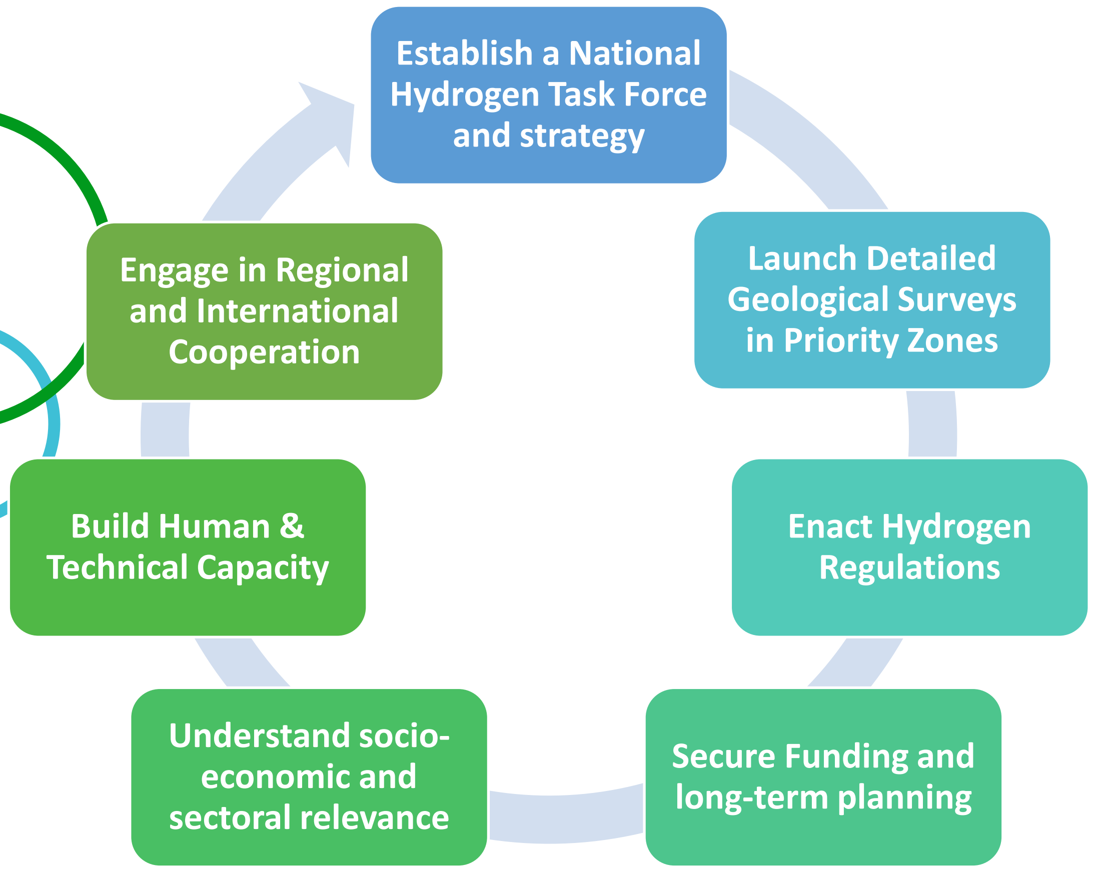


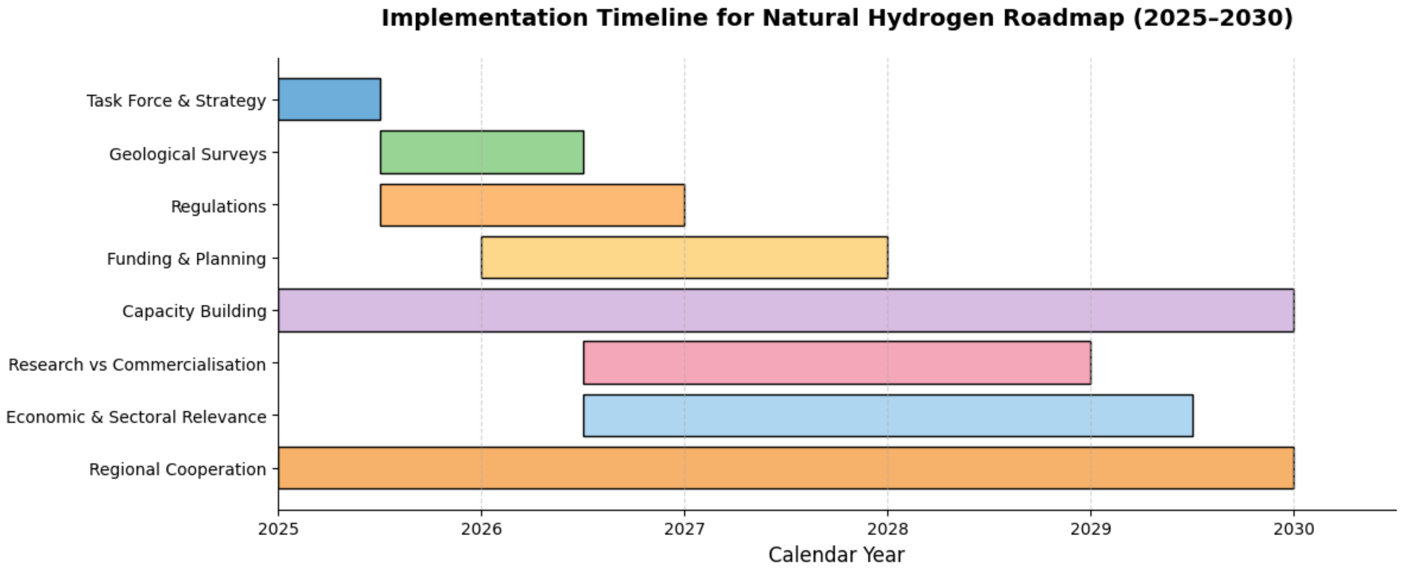
Natural Hydrogen in National Energy Laws

Country	Current legal status	Suggested approach
South Africa	No dedicated law; natural H_2 implicitly treated as petroleum; licences via PASA.	Treat under petroleum law; issue guidelines; align with green H_2 roadmap.
Morocco	No specific legislation; mining & hydrocarbons laws provide entry points; ONHYM exploring.	Integrate into mining law; choose regulator (METSD/ONHYM); dual-institutional model.
Mozambique	No H_2 law; Mining & Petroleum laws exist; MIREME/INP & ARENE oversee energy sector.	Incorporate into Mining or Petroleum laws; develop renewable energy strategy.
Togo	Mining & hydrocarbons codes exclude H_2; definitions need revision.	Amend mining or hydrocarbon code to include H_2; clarify licensing and regulation.

SO2 - Develop roadmaps for natural H_2 exploration

Providing authorities with a roadmap and action plan 1/2

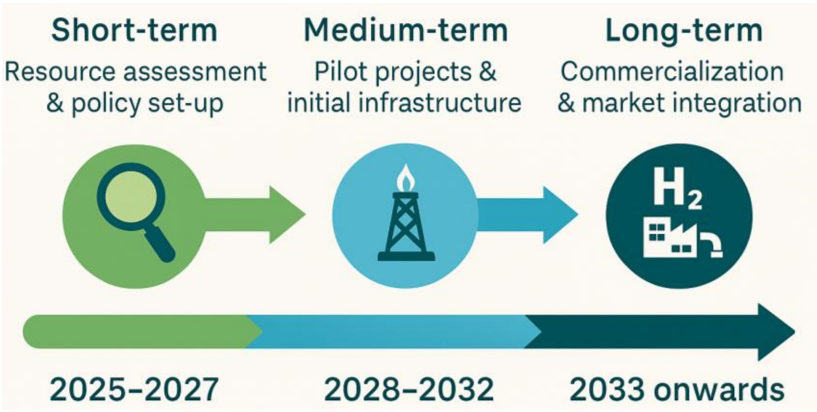




SO2 - Develop roadmaps for natural H_2 exploration

Providing authorities with a roadmap and action plan 2/2

Country-Specific Recommendations



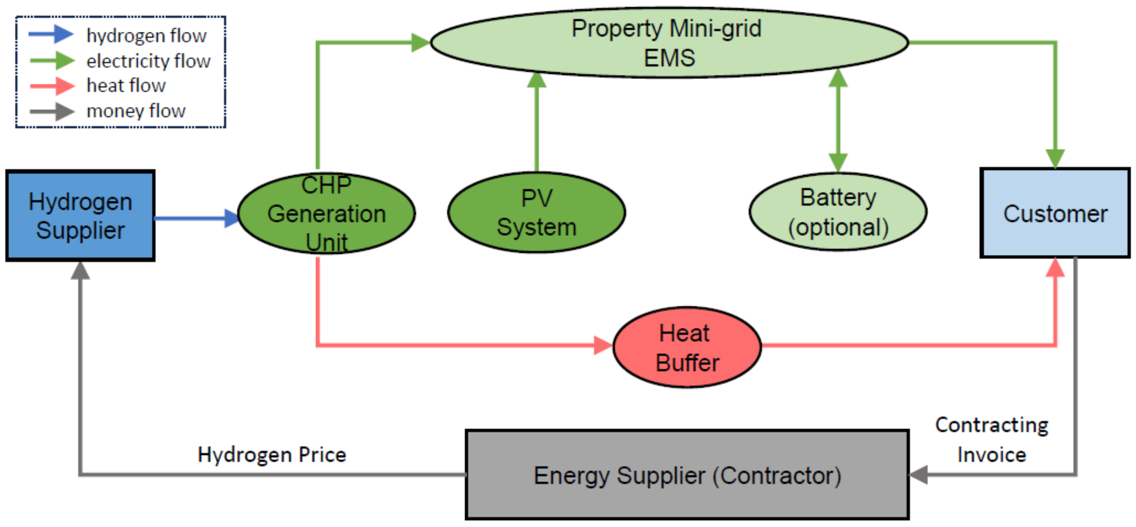
Morocco Integrate H_2 into Mining Code; empower ONHYM Prioritise Tendrara & other basins; pilot ammonia with OCP Maintain international partnerships; apply 'farm-in' model	**Mozambique** Decide classification (petroleum vs mining); coordinate Ministry/INP/Geological Institute; Focus Bilene–Macia area; plan local power blending & community benefits; Seek co-financing (AfDB, EU); replicate farm-in; share revenues
South Africa Amend MPRDA to include H_2; designate PASA/DMRE/DSI roles; Prioritise Chrissiesmeer; explore ultramafic complexes & boreholes; Co-fund pilot with mining/energy firms; engage private investors	**Togo** Issue decree/amend Mining Code; build regulatory capacity; Focus on Dakondji area; drill test well; pilot community/fertiliser; Partner internationally; leverage ECOWAS/AU; secure donor support

Business use cases studied

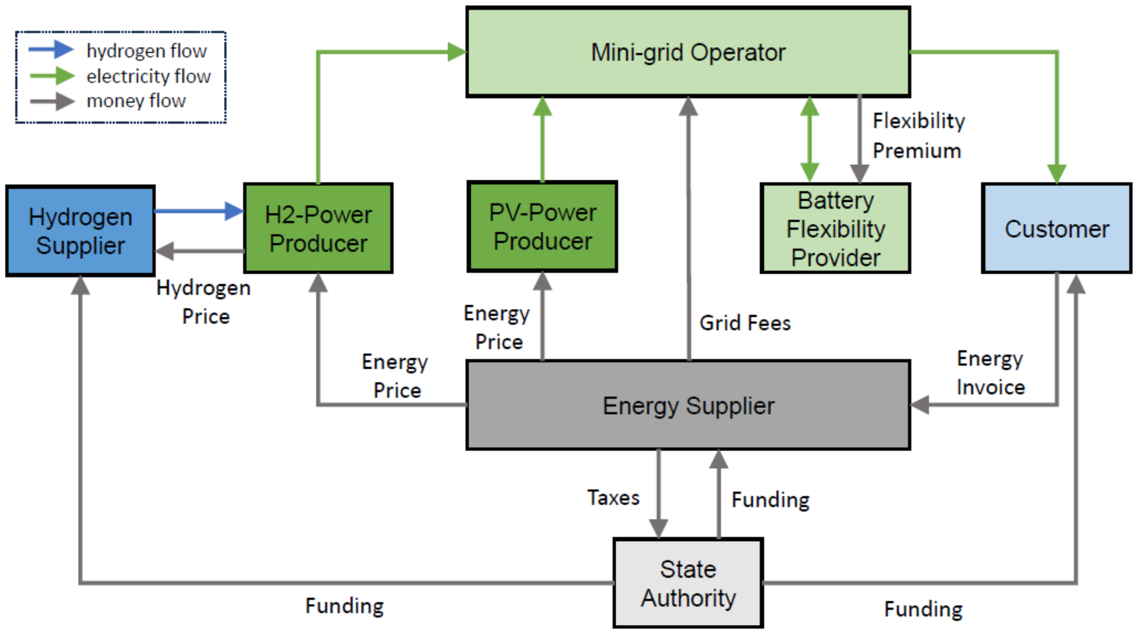
South Africa
Morocco

Mozambique
Togo

BUC - Improvement of security of supply



BUC - Electrification of rural areas



Business use cases studied

- Compared to an electricity price of 0.13 €/kWh in Hendrina the price for white hydrogen should be not more than **1 €/kg** to be competitive with electricity generation run with a gas turbine

- An LCOH of **0.5 $/kg** for natural hydrogen is possible (source: Mathur) – it is not unrealistic

- As result from the sensitivity analysis H_2 price is more important than the full load hours for a gas turbine to produce profitable electricity

- The LCOE of mini-grids is very high (**0.38 €/kWh** for the analyzed example in Benzane - MZ) and customers of low-income communities can not pay much more than **0.09 €/kWh .** So, funding is needed regardless of the used fuel (diesel or hydrogen)

- Hydrogen storage units are very expensive and store only small amounts of hydrogen. A hydrogen bundle of cylinders (200 –300 bar) stores 9 –13 kg (these are only 300 –435 kWh or 30 –44 lt diesel); costs are **8 –12 k€**).

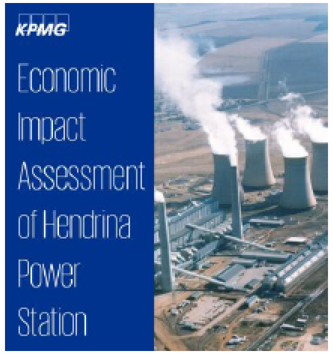
Socio economic Impact – Methodology

Evaluation of the socio-economic situation
- Social and cultural
- Economy and inequality
- Environment and Energy
- Health and Agency

Assessment of Expected Impacts and Recommendations for Improvement
- Impact Pathways
- Impact Assessment Grid

Participatory Engagement
- Semistructure interviews

Based on:



Socio economic Impact – Mini-grid Operator (BM1)

- Context – Benzane is a remote rural village (~900–1 200 people) in Mozambique's Zinave district. There is no grid connection; only small isolated systems serve health care, water and telecom. The province's electrification rate is about 27.7%.

- Social & Cultural – Households of 5–8 members with strong kinship networks. Christian and traditional beliefs coexist; communal rituals and respect for elders foster cohesion.

- Economic & Environmental – Subsistence farming, livestock and beekeeping dominate; infrastructure is limited (school, health post, wells). Unsafe water and wood smoke pose health risks; governance is male-dominated.

- **Anticipated Impact** – A mini-grid can supply reliable, decentralised electricity, enabling businesses, improving services and creating jobs. **Success hinges on inclusive governance, gender equity and complementary interventions in water, health and nutrition.**

Socio economic Impact – Fuel Switch Contractor (BM2)

- Coal Decline – Hendrina's economy has been shaped by coal. Declining mining and decommissioning of power stations have led to poverty, unemployment and social distress; supply chains and public services have deteriorated.

- Diversification & Transition – Opportunities include agriculture, renewable energy and light manufacturing. Provincial and national plans (MGEDP, JET) aim to build an inclusive green economy, but governance gaps, investment shortfalls and skill mismatches remain obstacles.

- **Mission of BM2** – Retrofit existing generation units to operate on natural hydrogen, combined with PV and storage. This supports Hendrina's transition by offsetting job losses and catalysing complementary industries; success requires coordinated policies and financing.

SO4 – build awareness and capacity

- Building capacity workshop for African partners (September 2022), Casablanca. Specialists in Natural H_2 from Air Liquide, USGS, Université Grenoble Alpes, the European Federation of Geologists and NH2E (SME).
- Technical building capacity workshops on field exploration (geochemical) for natural H_2 seeps - Morocco (Feb. 2023) and South Africa (June 2023).
- Workshop "Raising Awareness About Natural Hydrogen" for South African stakeholders , 14 of September 2023, Pretoria, South Africa. Attendees from public and private institutions and sectors including academia, research, mining and energy.
    - Current state of the art in natural hydrogen research,
    - the HyAfrica project,
    - the results of the first HyAfrica field campaign of natural hydrogen exploration in South Africa.
    - discussion regarding national policy requirements and regulatory issues was also held.

SO4 – build awareness and capacity

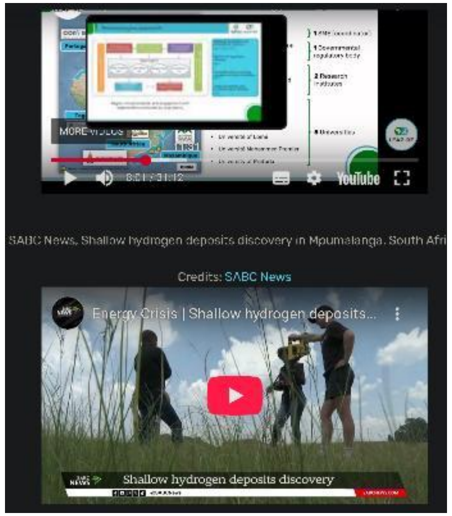
Online training courses

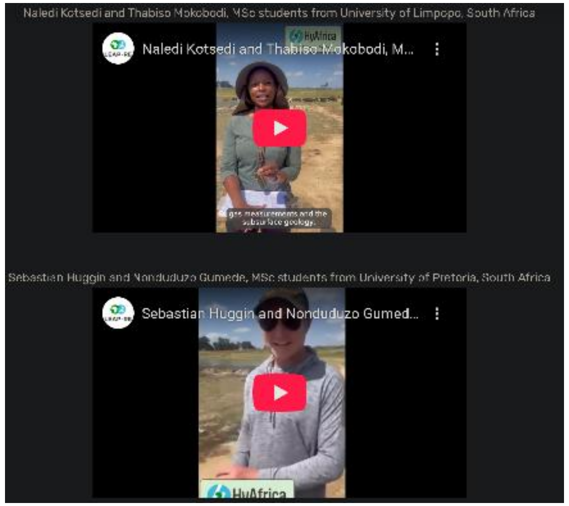
- Utilisation of remotes sensing and GIS for natural hydrogen exploration. Introduction to QGIS. January 2024
- Geophysical tools in natural hydrogen exploration. April 2025

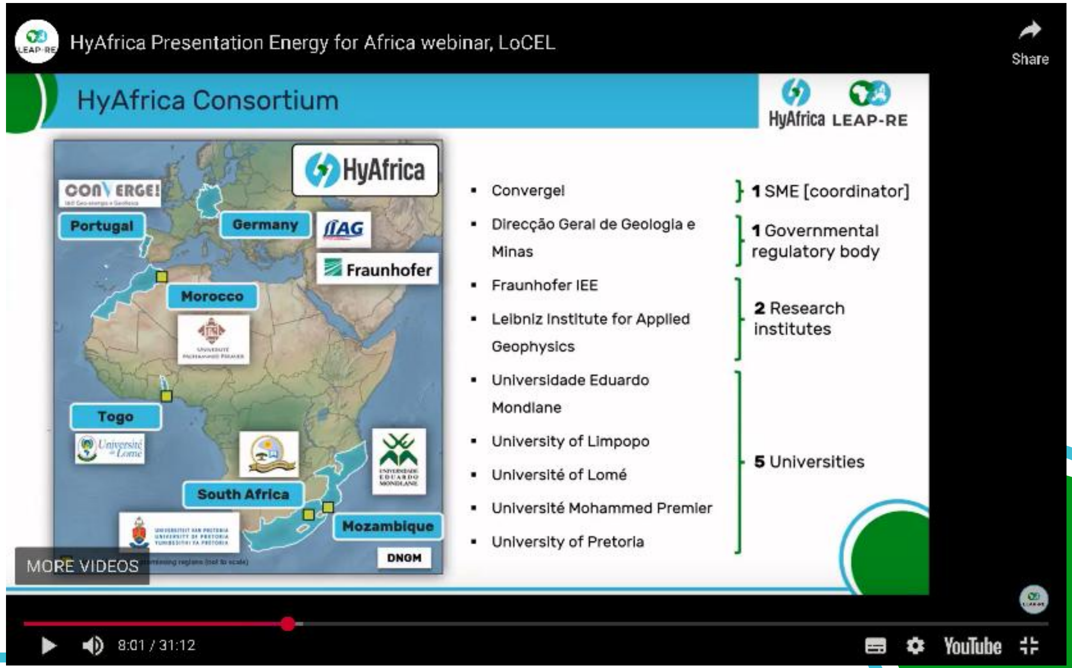
Students engaged in research work:

- PhD students : 1 Mozambique, 1 Morocco
- MSc Students: 2 Mozambique, 4 South Africa
- BSc students: 4 South Africa

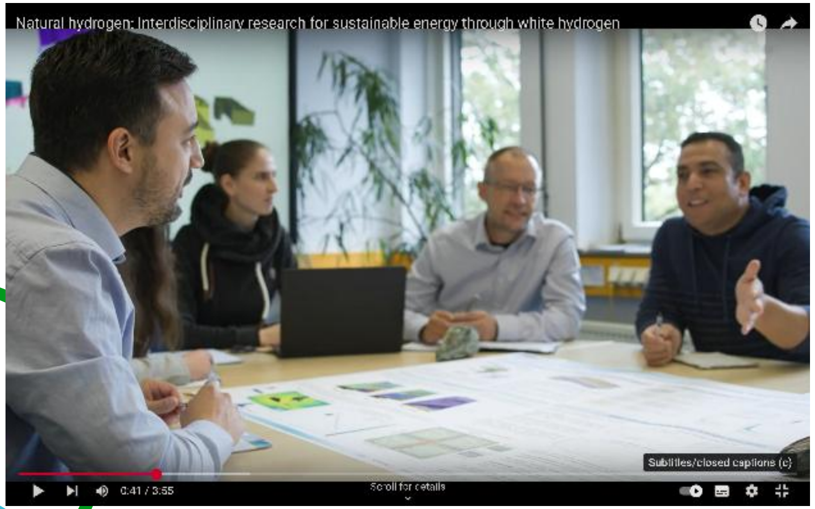
Production of educational videos about natural H_2

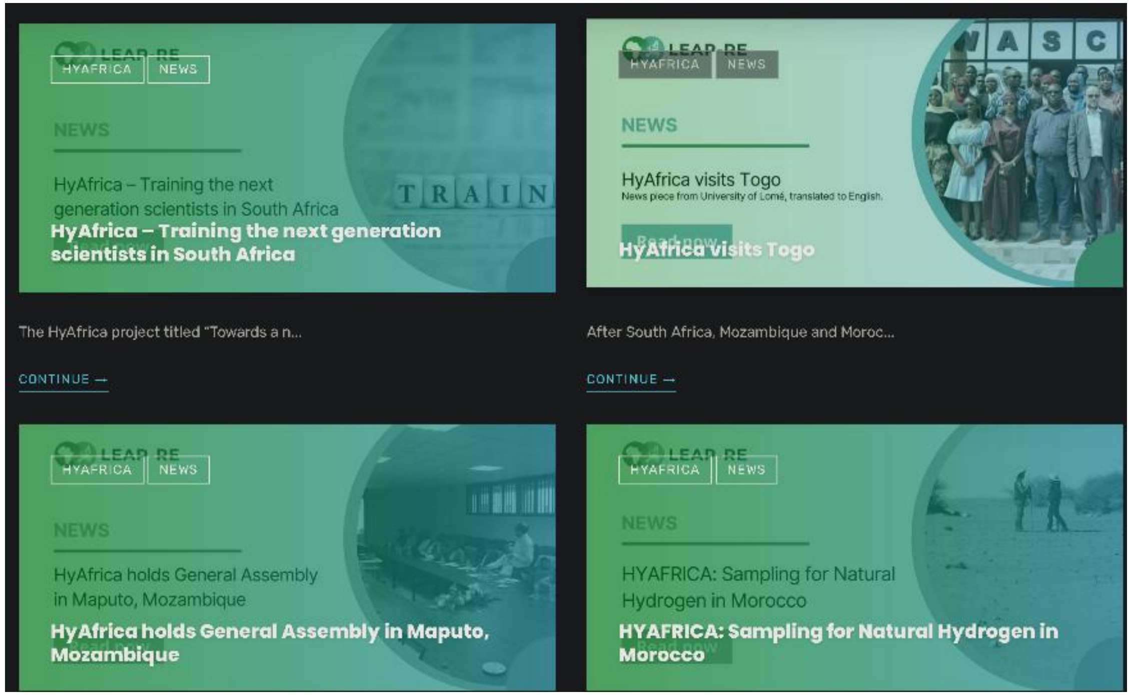






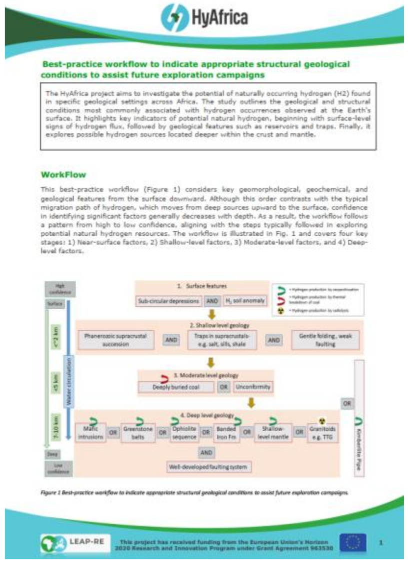
SO4 – build awareness and capacity

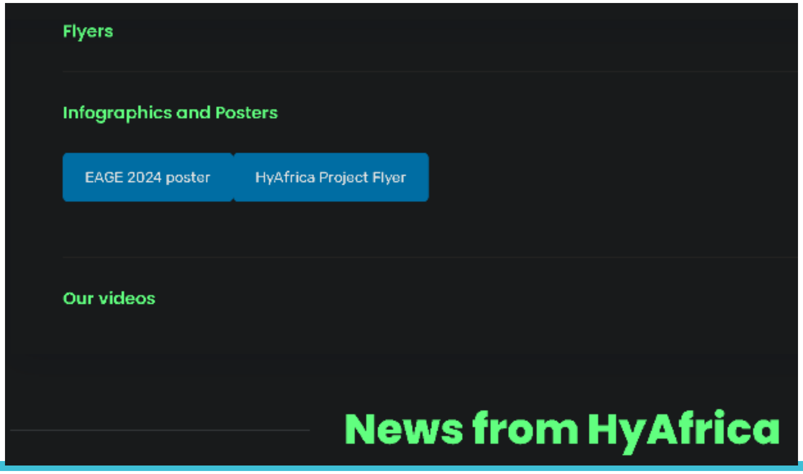




Updated website with embeded videos and images

Leaflets





THANK YOU

CONTACT US FOR MORE INFORMATION

www.leap-re.eu

contact@leap-re.eu

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The LEAP-RE project has received funding from the European Union’s Horizon 2020 Research and Innovation Program under Grant Agreement 963530.