CTCN PALO · 2026 Learning Visit

Green Hydrogen & Fuel Cell — KIST · KIER · KRICT

$H_2O \rightarrow H_2$

Exploring Projected Groundwater Sustainable Yield Across African Countries

with Implications for Green Hydrogen Production

Presented by

Souleymane Fanta KONATE

WASCAL — West African Science Service Centre on Climate Change and Adapted Land Use

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Introduction

Climate & Energy Challenge

Mitigating greenhouse gas emissions is a global priority. The energy sector is a significant source of emissions. Africa heavily relies on traditional biomass and faces a potential increase in emissions.

Green Hydrogen Opportunity

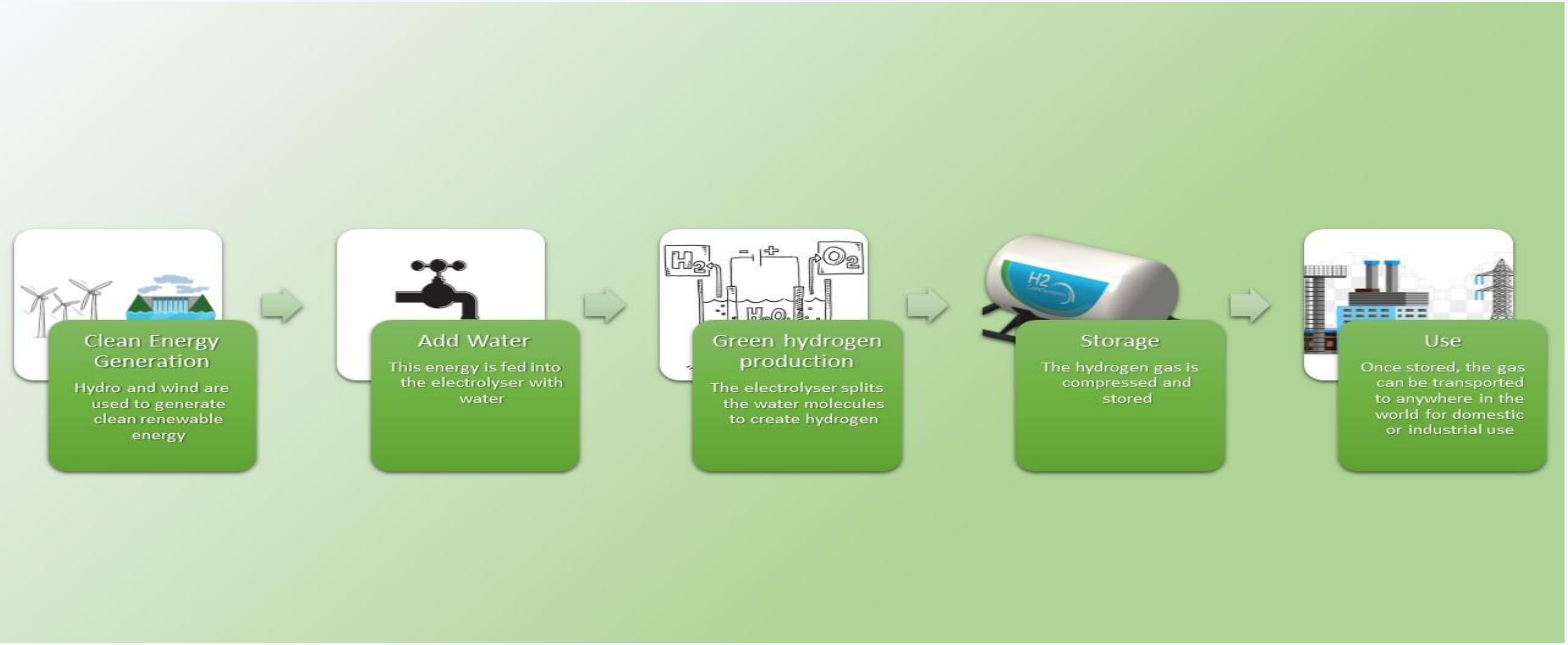
Renewable energy and green hydrogen are central to Africa's sustainable development pathway. However, water consumption and management are key challenges that must be carefully addressed.

Water as a Critical Constraint

Water resources are a critical environmental constraint for green hydrogen production. Careful quantification is required to minimize adverse effects on ecosystems and existing water users.

Green Hydrogen Production — Where Does the Water Come From?

How is Green Hydrogen Produced?



Where Is the Water Coming From? — Key Questions

- ? Which water source has the largest potential: lakes, rivers, groundwater, or seawater?
- ? Which countries or regions are most suitable for green hydrogen production, and which face groundwater stress?
- ? Is it available year-round for large-scale green hydrogen production?
- ? What is the impact of climate change and population growth on the water source?
- ? How much can be extracted without affecting ecosystem services (base flow, etc.)?
- ? Is it economically viable?
- ? What is the limit for human use?
- ? What is the future perspective until 2100?

Groundwater Resources — Why Focus Here?

20×

Africa's groundwater reserves are estimated to be 20× larger than surface water

Main Focus of This Research

- Groundwater reserves in Africa are 20× larger than surface water
- Essential, low-cost and climate-resilient water source
- Accessible in most environments via exploration techniques
- Faces fierce competition among diverse water users

Essential & Low-Cost

A climate-resilient source for water-stressed regions and development needs across the continent.

Widely Available

Can be found in most environments using appropriate exploration techniques — located close to the point of need.

Highly Contested

Favorable attributes make groundwater an appealing resource, resulting in fierce competition among diverse users in Africa.

Research Objectives

Overall Goal

To shed light on the sustainability of groundwater resources for green hydrogen initiatives in Africa.

Obj. 1

Projected GWR & HWU Trends

Understand the trend of projected Groundwater Recharge (GWR) and Human Water Use (HWU) in Africa considering two climate change scenarios:

- Optimistic: RCP 2.6
- Pessimistic: RCP 8.5

Obj. 2

Sustainability of Groundwater Use

Explore the sustainability of groundwater use in Africa by examining the ratio between projected HWU and GWR across both RCP 2.6 and RCP 8.5 scenarios from 2015 to 2100.

Key Terminology

GWR

Groundwater Recharge

Precipitation that does not evaporate or run off, but infiltrates the unsaturated zone to recharge the aquifer the process of resource renewal.

HWU

Human Water Use

Total sectorial water demand comprising: Irrigation + Domestic + Livestock + Industries.

GW Ratio

Groundwater Ratio

Calculated by dividing HWU / GWR over the period 2015–2100. Indicates pressure on groundwater resources.

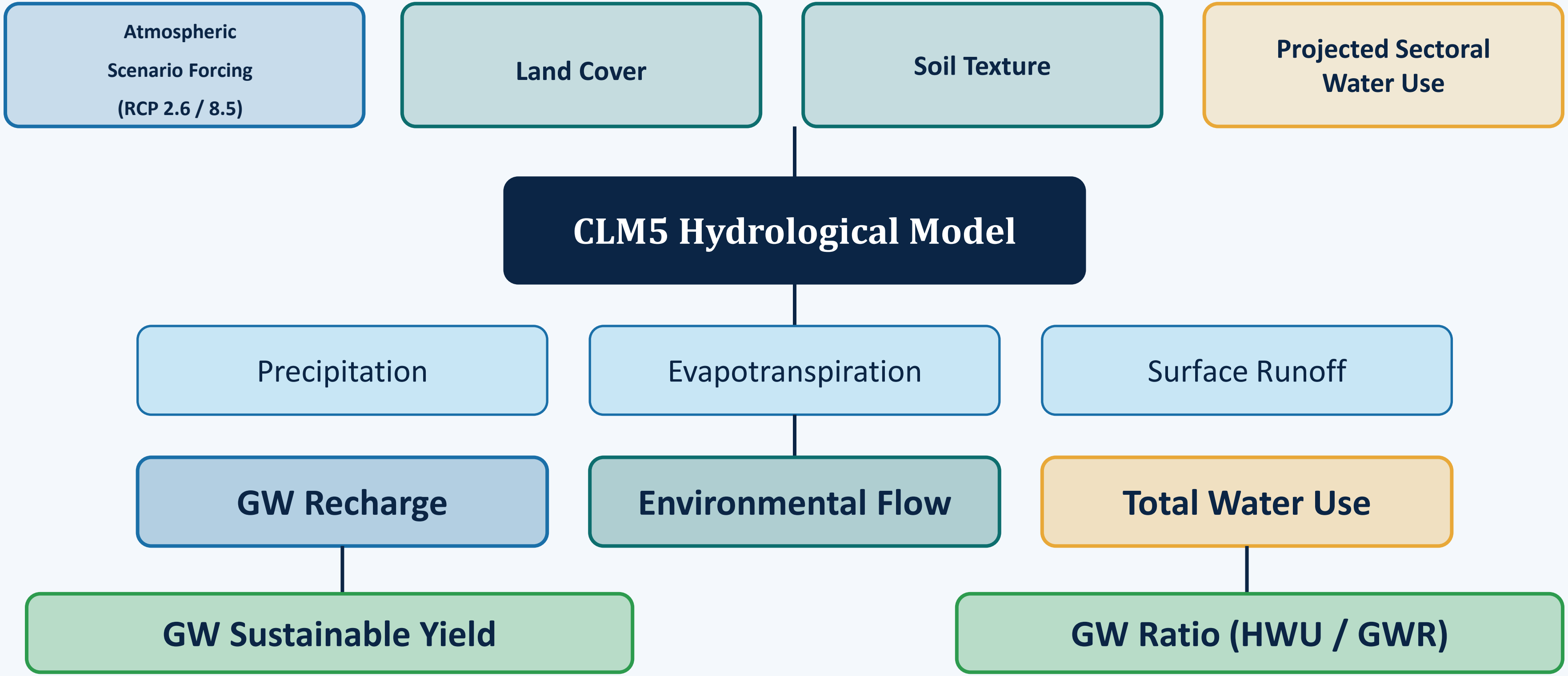
GSY

GW Sustainable Yield

Optimal water withdrawal level: maximizing benefits to the economy, society, and the environment with minimal adverse effects.

Methodology — Flow Chart

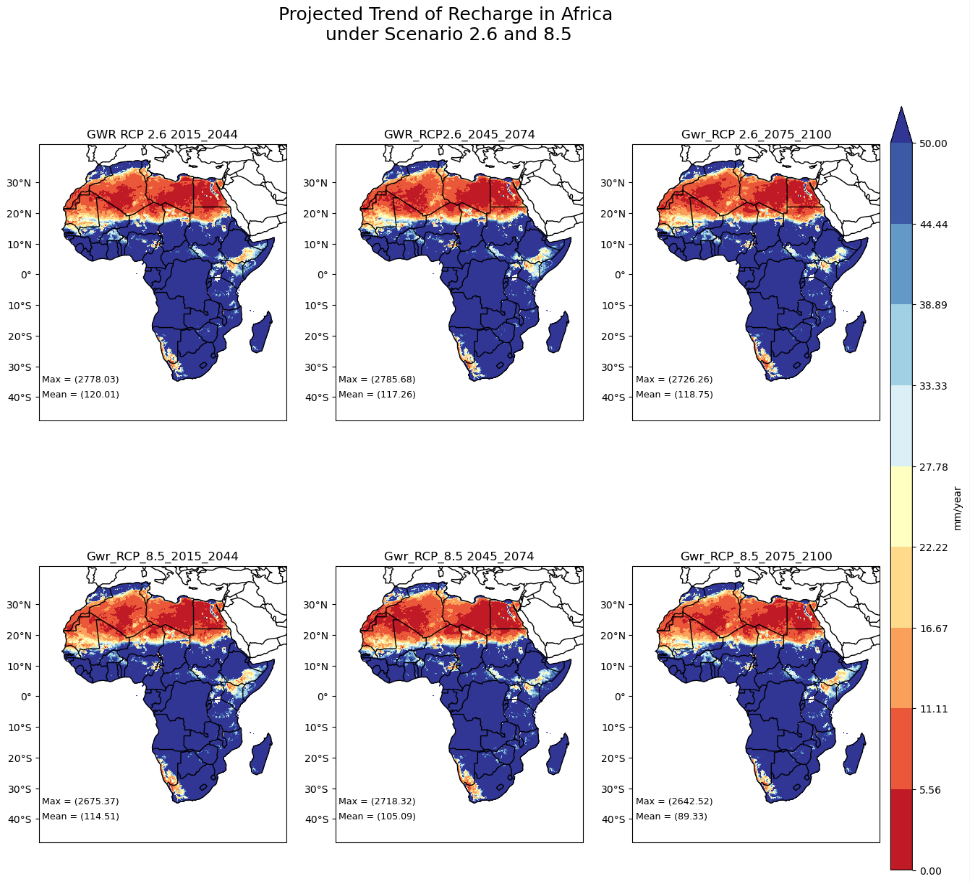
The methodology integrates atmospheric forcing, land cover data, and soil texture inputs into the CLM5 hydrological model to produce projected groundwater recharge and sustainable yield estimates.



Projected Groundwater Recharge (2015–2100)

Ensemble Mean Recharge by Climate Scenario

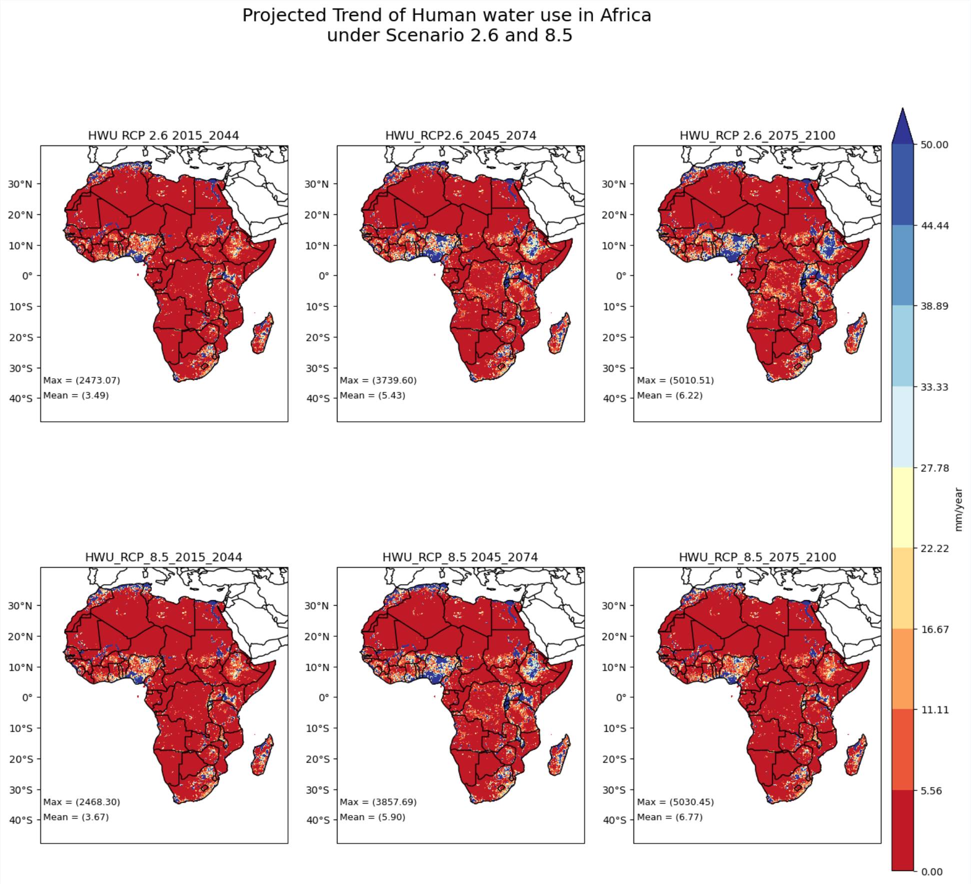
- RCP 2.6: ensemble means range from 118.75 to 120.01 mm/year
- RCP 8.5: ensemble means range from 89.33 to 114.51 mm/year
- RCP 2.6 consistently shows a higher mean recharge compared to RCP 8.5
- Trend: recharge declines more sharply under the pessimistic RCP 8.5 scenario toward 2100



Projected Human Water Use (2015–2100)

Sectoral Water Demand under RCP 2.6 and 8.5

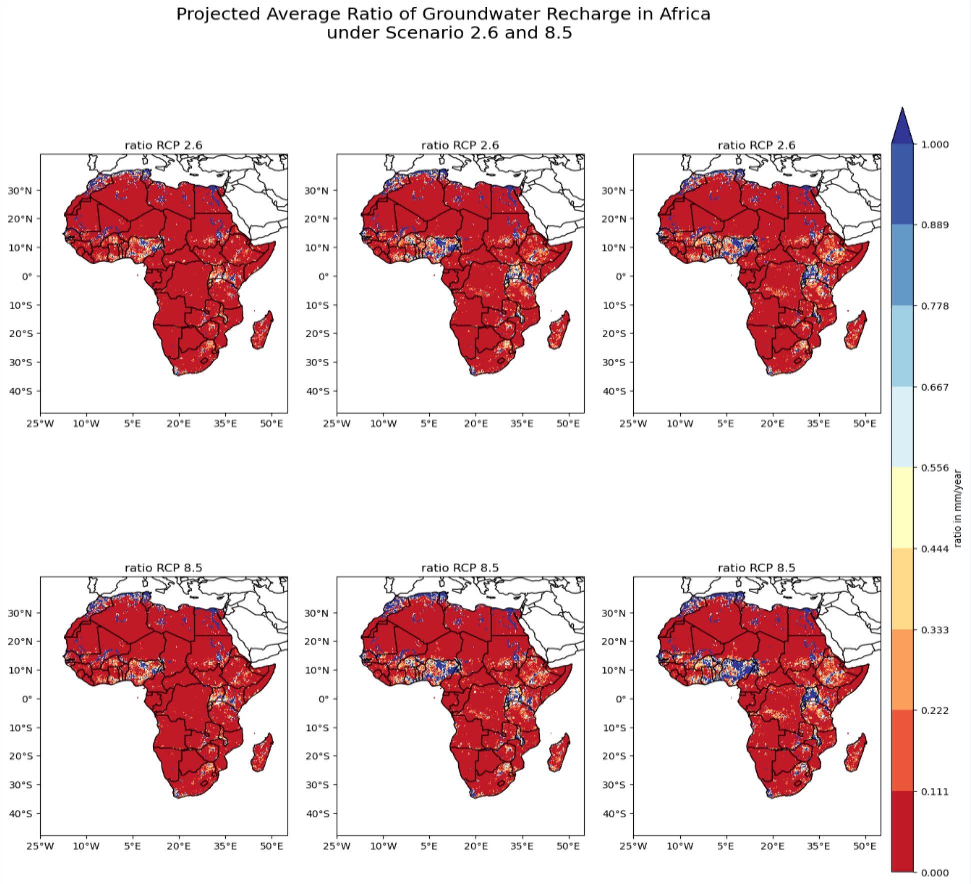
- RCP 2.6 generally indicates lower estimates of human water use compared to RCP 8.5
- Demand includes: irrigation, domestic, livestock, and industrial use
- RCP 8.5 drives higher population growth and agricultural demand increases
- Growing gap between the two scenarios becomes more pronounced post-2050



Projected HWU/GWR Ratio (2015–2100)

Groundwater Pressure Index Across Africa

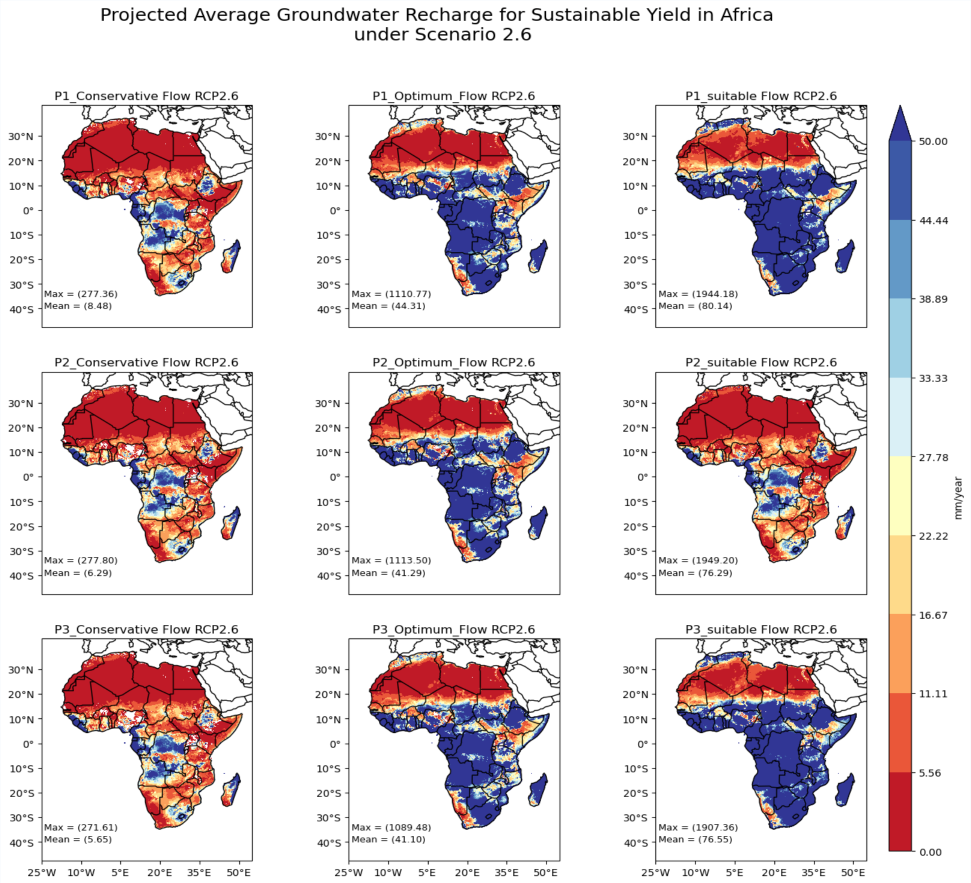
- Ratio = HWU / GWR: values >1 indicate unsustainable extraction
- Northern Africa (especially Egypt) has the highest ratios on the continent
- RCP 8.5 generally exhibits higher ratios than RCP 2.6 across all regions
- West and East Africa show marked increases post-2050 under RCP 8.5



Long-Term Environmental Flow & Sustainable Yield

Regional Hotspots of High Sustainable Yield

- Southwest West Africa: Guinea-Bissau, Guinea, Sierra Leone, Liberia, Nigeria show high sustainable yield
- Central & Southern Africa: Cameroon, Lesotho show high yield
- East Africa: Ethiopia identified as a high sustainable yield region
- These regions may be most suitable for green hydrogen water sourcing



Long-Term Sustainable Yield — Scenario Comparison

41.9 mm/yr

RCP 8.5 (2015–2044)

28.8 mm/yr

RCP 8.5 (2075–2100)

44.3 mm/yr

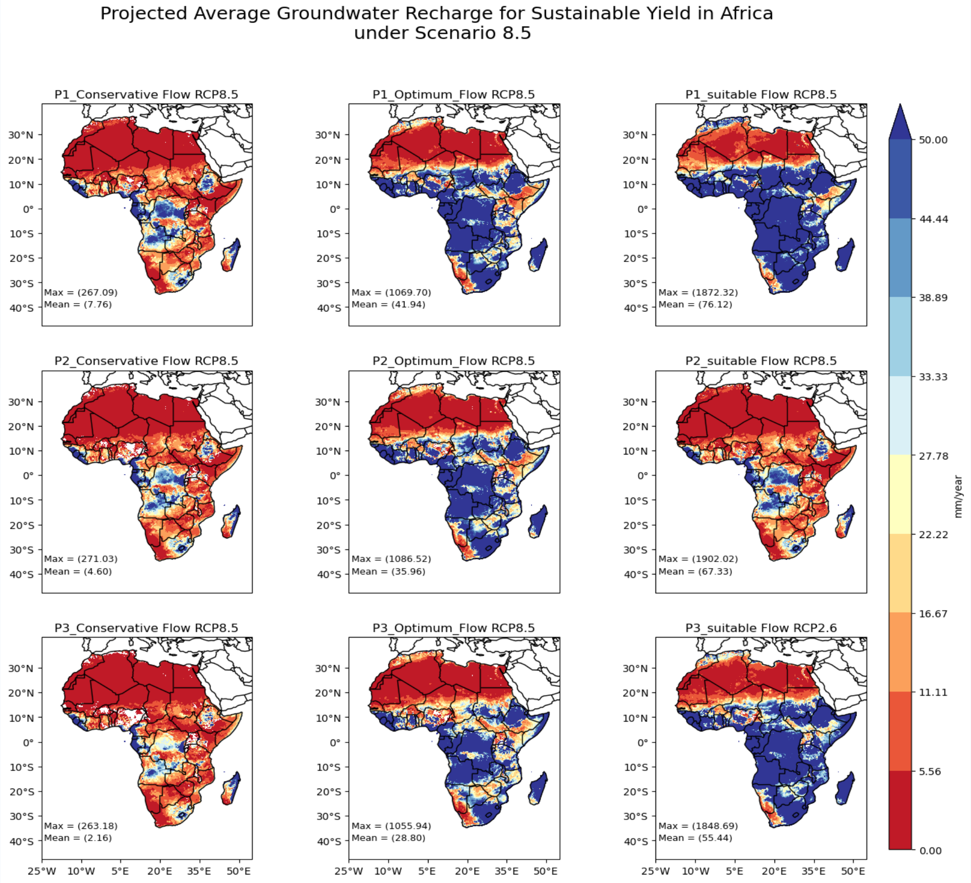
RCP 2.6 (Start)

41.1 mm/yr

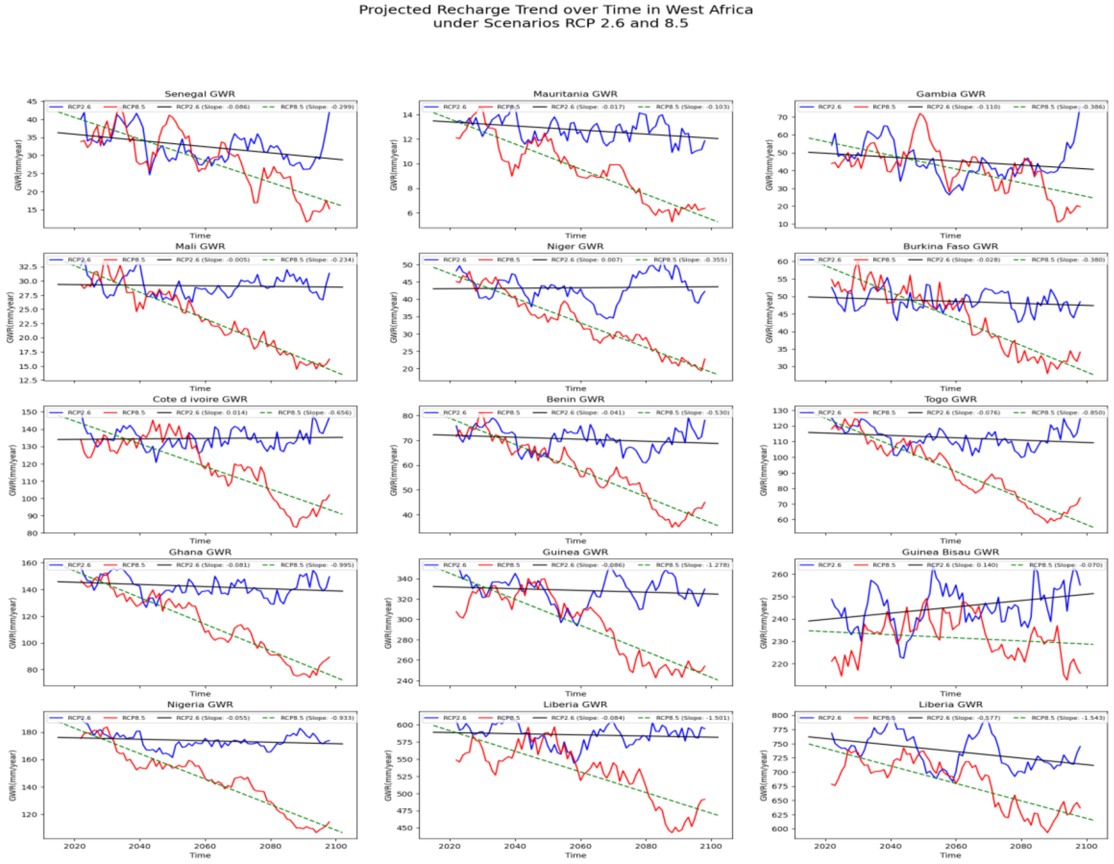
RCP 2.6 (End)

Key Finding

RCP 2.6 shows higher and more stable sustainable groundwater yield. RCP 8.5 presents a strongly declining trajectory — a major challenge for long-term green hydrogen water planning.



Recharge Trends RCP 2.6 and 8.5 — Time Series



West Africa

Negative GWR trends in most countries under both scenarios. Niger, Côte d'Ivoire, and Guinea-Bissau show mixed positive/negative patterns.

Northern Africa

RCP 2.6 ratstrongerio rises until ~2050 then oscillates. RCP 8.5 shows deterioration.

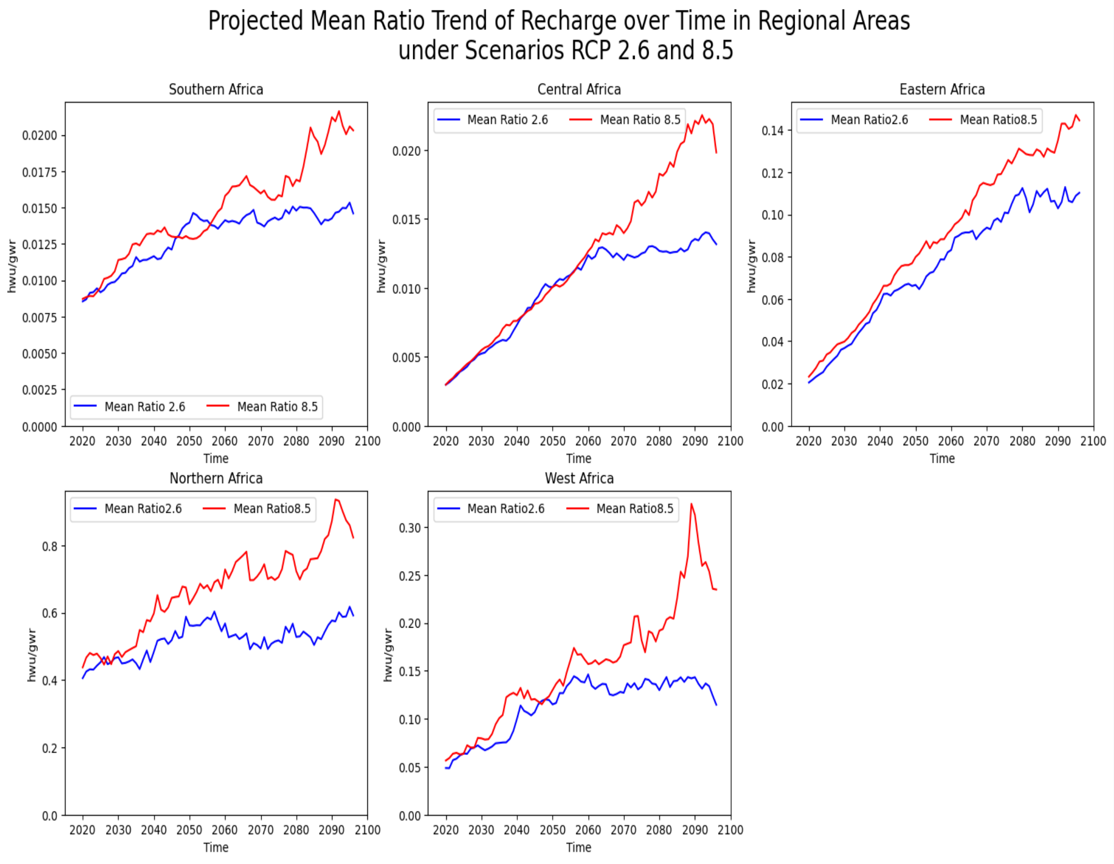
Key Signal

Widespread recharge decline under RCP 8.5 across sub-regions — particularly post-2050.

Implication

Countries with declining GWR face higher water stress for green hydrogen siting.

Recharge Ratio Trends RCP 2.6 and 8.5 — Time Series



Northern Africa

RCP 2.6: ratio rises until 2050, then oscillates.

Greater uncertainty post-2050.

West Africa

Ratio increases until 2050 in RCP 2.6. Post-2050: RCP 2.6 stabilizes while RCP 8.5 rises until 2090.

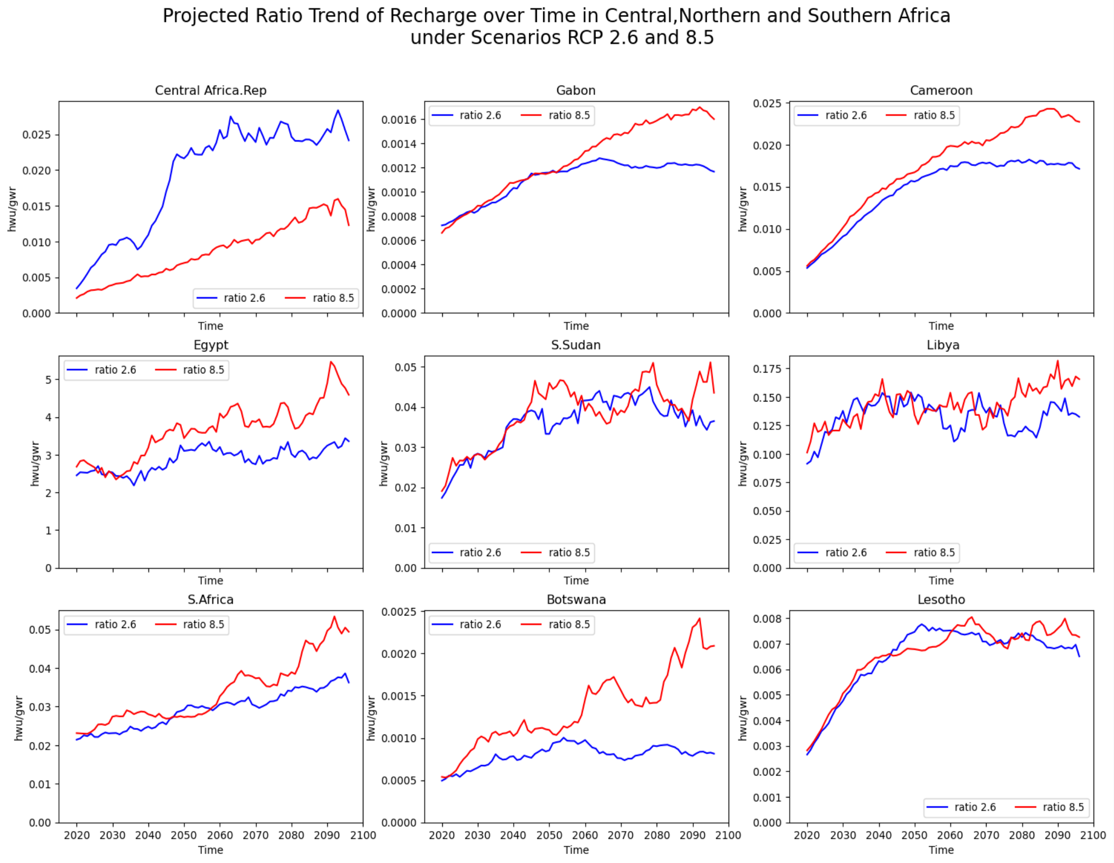
Divergence

The two scenarios diverge significantly after 2050 showing the urgency of limiting warming.

RCP 8.5 Risk

Ratios under RCP 8.5 far exceed RCP 2.6, implying far greater groundwater stress.

HWU/GWR Ratio Trends — Southern, Central & Northern Africa



Southern Africa

South Africa has the highest ratio (up to 0.05).

Botswana has the lowest in the region.

Central Africa

RCP 8.5 < RCP 2.6 in Central African Republic.
Gabon: low ratio, stable until 2060, then rises.

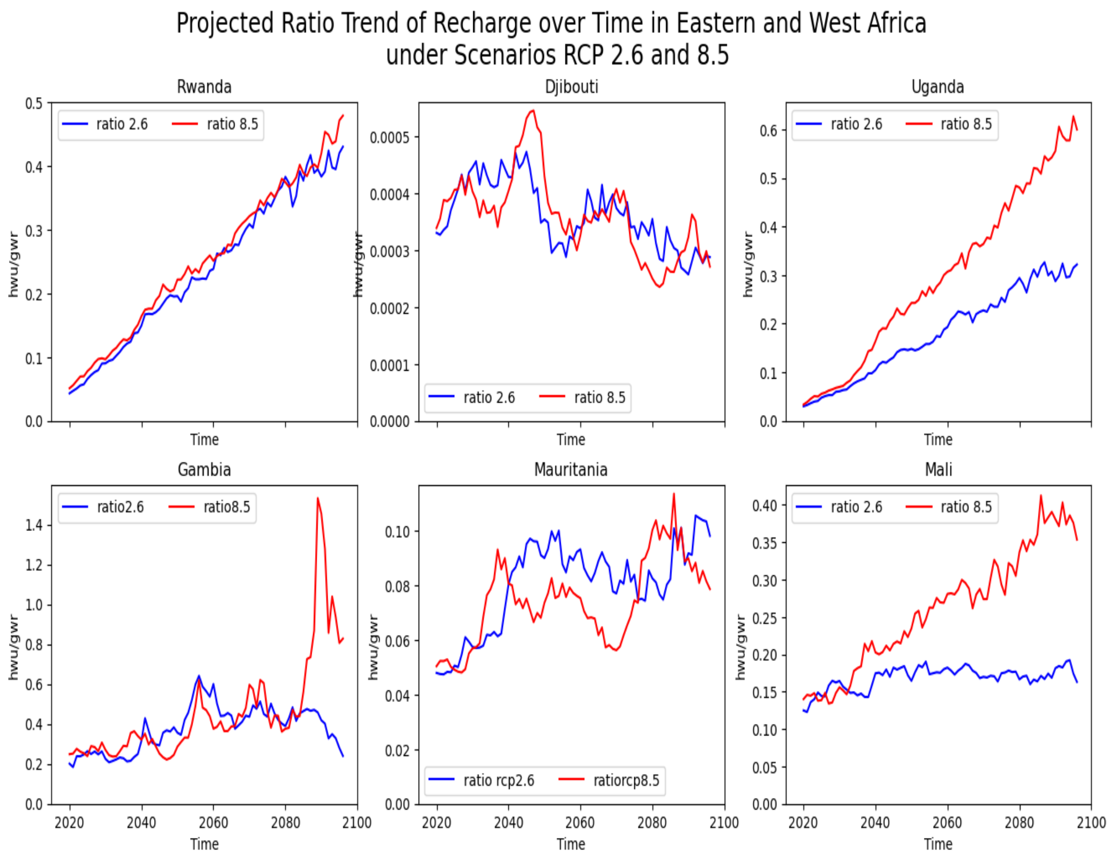
Northern Africa

Egypt has the highest HWU/GWR ratio in all of Africa. Libya has the lowest in the region.

Post-2060

RCP 8.5 rises significantly in Gabon and Central Africa — a warning for long-term planning.

HWU/GWR Ratio Trends — Eastern & West Africa



East Africa — Uganda

Highest recharge ratio in the region (up to 0.6 for RCP 8.5). Djibouti has the lowest.

West Africa — Gambia

Gambia and Mauritania exhibit the highest HWU/GWR ratios in West Africa.

Mali

RCP 8.5 ratios much higher than RCP 2.6 — showing high vulnerability under warming.

Mauritania

Similar patterns in both scenarios with minimal changes — relatively stable outlook.

Conclusions

📉 RCP 2.6 — Minor GWR Decreases

Under the optimistic RCP 2.6 scenario, minor decreases in groundwater recharge are observed, with varying trends across regions and countries.

⚠️ RCP 8.5 — Negative Trend Continent-Wide

Under RCP 8.5, all African regions and countries experience a negative trend in GWR. The most significant impacts are in Central Africa, Southern Africa, and Northern Africa.

📊 Higher Ratios Under RCP 8.5

RCP 8.5 generally exhibits higher HWU/GWR ratios than RCP 2.6 across all countries, except Central African Republic. This signals greater groundwater stress under warming.

✅ RCP 2.6 More Favourable

The RCP 2.6 scenario shows more favourable outcomes for groundwater recharge and sustainable yield, reinforcing the importance of climate mitigation for green hydrogen viability.

Perspectives & Future Work

Model Improvement

CLM5 is a 1-D model neglecting lateral water flow. Coupling CLM5 with a sub-surface lateral flow model would improve accuracy.

Water Quality Analysis

Assess water quality suitability for green hydrogen electrolysis in Africa — purity standards are critical for PEM electrolysers.

Extended Monitoring

Importance of extended, consistent hydrological monitoring networks across Africa to reduce model uncertainty.

Observation Wells

Strategic placement of observation wells in unpopulated and under-monitored areas to fill data gaps.

Limiting Factors

Identify and quantify limiting factors for green hydrogen project development (water access, cost, infrastructure).

Regional Collaboration

Transboundary groundwater governance frameworks are needed many aquifers cross national borders in Africa.

Thank You

for your attention

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