WATER FOOTPRINT AND SOCIAL IMPLICATIONS OF GREEN HYDROGEN PRODUCTION

Case study: Africa

Lappeenranta–Lahti University of Technology LUT

Master's programme in Sustainability Science and Solutions

2025

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Examiners: Professor (tenured) Jouni Havukainen

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ABSTRACT

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Green hydrogen production is an emerging technology for decarbonizing energy systems in Africa. Water utilization is high for green hydrogen production and that could lead to water scarcity. This thesis assesses water footprint and social aspects of solar, and wind powered hydrogen production under water scarce conditions. Volumetric Water Footprint (WF_{vol}) Method and the Water Stress-Adjusted Water Footprint ($WF_{adjusted}$) Method were used in this study. The $WF_{vol,H2}$ of wind powered and solar powered hydrogen production were 9.2 m^3/tH_2 and 34.7 m^3/tH_2 respectively. Country specific water stress indices were used to adjust these values to indicate the spatial variability of $WF_{adjusted}$. Wind powered hydrogen production shows the lowest $WF_{adjusted}$. The countries with the highest water scarcity indices were Libya (8.1714), Algeria (1.4481), Egypt (1.4117) and Sudan (1.1866) while marking those as the countries with the highest $WF_{adjusted}$. Full Load Hours were compared with $WF_{adjusted}$, allowing country level recommendations for the most suitable renewable energy source to power the hydrogen production while minimizing water stress. Social implications were analysed using a triangular analysis of stakeholder surveys and literature. The results highlight the low public awareness, high costs associated with hydrogen production, usage of seawater with desalination, need for the strong policy frameworks, community participation and trust building mechanisms. The findings show the alignment of the hydrogen development mainly with the SDG 6 (clean water and sanitation), 7 (affordable and clean energy), 9 (industry, innovation and infrastructure) and 13 (climate action). This study provides one of the continent-wide assessments connecting technical water footprinting and social dimensions of green hydrogen production in Africa.

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November 2025, Lappeenranta, Finland

Warnakulasuriya Ruvini Jesmine Tissera.

SYMBOLS AND ABBREVIATIONS

ALK	Alkaline Electrolysis
AWARE	Available Water Remaining
CCS	Carbon Capture and Storage
CF	Capacity Factor
CO_2	Carbon dioxide
CO_2-eq	Carbon dioxide equivalent
DOE	Department of Energy in United States
EL	Electricity needed per tonne of Hydrogen
ESIA	Environmental and Social Impact Assessment
EU	Europe
FAO	Food and Agriculture Organization of the United Nations
FLH	Full Load Hours
FLH_{solar}	Full Load Hours of solar PV
FLH_{wind}	Full Load Hours of wind turbine
GHG	Greenhouse Gas
GW	Giga Watt
H_2	Hydrogen
H^+	Protons
H_2O	Water
HWSI	Water Saving Intensity of Green Hydrogen
HWSP	Water Saving Potential of Green Hydrogen

ISO	International Organization for Standardization
JV	Joint Venture
Kg	Kilogram
kWh	Kilowatt hour
L	Litre
LCWCA	Life Cycle Water Consumption Assessment
LHV	Lower Heating Value
LOHC	Liquid Organic Hydrogen Carrier
m^3	Cubic meter
Mt	Metric ton
MW	Mega Watt
NA	Not Available
NGO	Non-Governmental Organization
O_2	Oxygen
OH^-	Hydroxide ions
PEM	Proton Exchange Membrane
PtX	Power to X
PV	Photovoltaic
PVout	Photovoltaic electricity output
R&D	Research and Development
SADC	Southern African Development Community
SAF	Sustainable Aviation Fuel
SDG	Sustainable Development Goals

SEZ	Special Economic Zone
SMR	Steam Methane Reforming
TDM	Thermal Decomposition of Methane
TJ	Terajoule
USA	United States of America
W	Feedwater needed stoichiometrically
WACC	Weighted Average Cost of Capital
$WF_{adjusted}$	Water stress adjusted water footprint
WF_{EL}	Water footprint of the electricity source
WF_{solar}	Water Footprint of solar electricity
WF_{vol}	Volumetric Water Footprint
Wfwind	Water Footprint of wind electricity
WSF	Water Scarcity Footprint
WSI	Water Scarcity Index

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DECLARATIONS

Turnitin

The originality of this thesis has been reviewed with the Turnitin similarity checking service.

AI usage

The author of the thesis, Ruvini Tissera, used the following AI-tools during the preparation of the thesis:

1. Grammarly
    a. Purpose of use: To correct the grammar mistakes
    b. Explanation of the use of the tool: I downloaded Grammarly on my computer and used to correct the grammar mistakes.
2. ChatGPT 5
    a. Purpose of use: To find some research papers related to some topics and to understand some facts that are unclear.
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Responsibility

The author, Ruvini Tissera, takes full responsibility for the content of this thesis and has reviewed and edited the content generated by the possible use of AI tools.

1 Introduction

Global Hydrogen demand nearly accessed 94 Mt in 2021, serving the fertilizer and oil and gas industries with the targets for significant extension into power generation, industry, and transportation as part of the global energy transformation (Olaitan, et al., 2024). With the concept of decarbonization goals, the targeted hydrogen production capacity increased from 66 Mt/year in 2021 to 106 Mt/year in 2022 (Olaitan, et al., 2024). More than $500 billion investments bound to over 130 extensive projects globally, mainly in Europe and China (Henriksen, et al., 2024). As shown in Figure 1, the projected distribution of green and blue hydrogen production is concentrated in a few major countries. These data focus on future low carbon pathways, and therefore, the grey hydrogen is not included, which currently accounts for most of today's hydrogen supply.

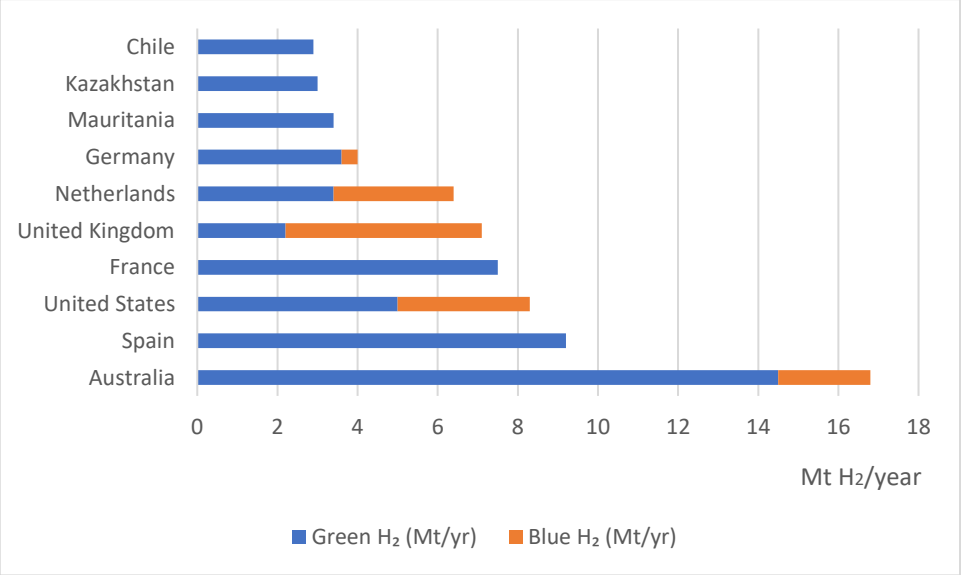

Figure 1 - Top 10 projected hydrogen producing countries (Adapted from (Olaitan, et al., 2024)).

Several African countries have established ambitious roadmaps to become hydrogen exporters. Morocco, for instance, launched a complete green hydrogen strategy in 2021 to emerge as a top international hydrogen economy player. Algeria has set a target of exporting 1 Mt of hydrogen by 2040, and Tunisia has indicated aspirations to export 5.5 Mt by 2050 (Pinto, et al., 2024). Africa's developing position in the global energy transition is

highlighted by these strategies. As shown in Figure 2, the global hydrogen demand is projected to vary notably across the sectors in the Net Zero Scenario for 2020 – 2030.

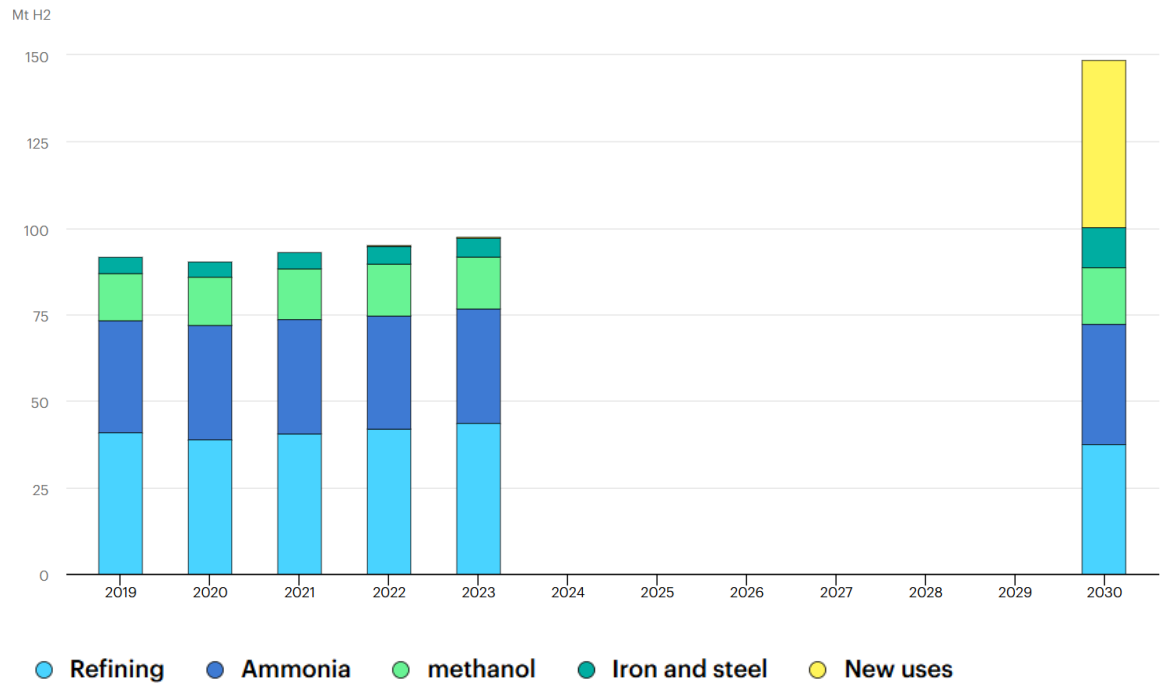

Figure 2 - Sector-wise Global Hydrogen Demand in the Net Zero Scenario, 2020-2030 (IEA, 2025)

The Department of Energy in the United States (DOE), introduced the Hydrogen Energy Earthshot initiative, and it expects a reduction of costs in clean hydrogen production to $1/kg within 10 years and moreover, increasing the interest in low-carbon hydrogen pathways (Henriksen, et al., 2024). This increasing demand highlights the significance of assessing hydrogen production through life cycle assessment frameworks, which focus not only on Greenhouse gas emissions but also on main resource parameters such as water consumption (Elgowainy, et al., 2015).

The incorporation of hydrogen into the global energy systems underscores the critical linkage between water and energy, which is called as water energy nexus. Hydrogen production, particularly through electrolysis (green hydrogen) and fossil fuel reforming with carbon capture (blue hydrogen), requires huge amounts of water for feedstock properties, cooling, and purification and thus directly links energy generation to freshwater availability (Olaitan, et al., 2024). Therefore, the development of hydrogen technologies needs to be assessed not only on their ability to limit carbon but also on their impacts on water, especially in those regions which are already facing physical or economic shortages of water.

Africa's hydrogen demand is predicted to rise relatively sharply due to the rising energy demand on the African continent, rising population growth, and industrialization growth on the continent. For transportation and electricity, the expected hydrogen demand in Niger alone is predicted to be 0.0117 Mt in 2040 as part of an overall rise in interest in hydrogen on the continent (Agyekum, 2024).

Africa presents a huge potential for green hydrogen production, mainly due to its massive renewable energy resources and strategic location compared to Europe. The key opportunities which Africa possesses to produce green hydrogen include, the proximity to EU markets (20.93% relevance), plenty of renewables (34.88%), and population advantages such as a young population (Agyekum, 2024). However, these opportunities in Africa are complemented by major challenges such as a lack of regulatory frameworks (28.95%), inadequate infrastructure and funding (15.38%), political instability, and lack of necessary skills and education (11.76%), which inhibit the large-scale deployment (Agyekum, 2024).

African hydrogen production is at its infancy stages, and most countries are at the pilot project or planning level. In Niger, for example, no substantial electrolytic hydrogen production is occurring despite official hydrogen cooperation with Germany and high solar potential. Solar PV-driven electrolysis is still the most viable option due to improved resource conditions and affordability (Bhandari, 2022).

In Africa, hydrogen is expected to be produced primarily using water electrolysis with renewable sources such as wind and sunlight (Agyekum, 2024). Wind-powered green hydrogen production generates the smallest carbon footprint at 0.6 kg CO_2-eq per kg H_2, whereas solar-powered green hydrogen production is associated with a higher carbon footprint of 2.5 kg CO_2-eq per kg H_2 (Patel, et al., 2024). Alkaline and PEM technologies are preferred in electrolysis options, with solar PV-based electrolysis particularly preferred in countries such as Niger due to the low rate of wind resources (Bhandari, 2022).

Water consumption varies depending on the process applied in the production of hydrogen. Electrolysis takes approximately 9 litres of water to yield 1 kg of hydrogen (Madsen, 2022) . While that is minimal relative to other water-consuming industries, its impact rises in desert nations like North Africa, where water usage is a prime issue (Pinto, et al., 2024).

Despite increased interest in hydrogen, there is a lack of water footprint analyses of the production of hydrogen in Africa. Most studies only look at resource availability and costs without accounting for environmental impacts particularly water-use-related impacts.

It is crucial that this research helps alert policymakers to the environmental implication of green hydrogen, particularly its water consumption, which is critical in sustainable deployment. It also supports other United Nations Sustainable Development Goals (SDGs) including SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), and SDG 13 (Climate Action). By providing a site-specific analysis of the water footprint of green hydrogen, this research helps informed decision-making toward equitable and sustainable African energy transition.

The objectives of this research are to quantify the water footprint of green H_2 production, identify the impact associated with water scarcity and competition for water resources while providing country-specific recommendations for the optimal renewable energy source to power the hydrogen production with the target of minimizing water stress effects. Another objective is to assess the social implications of water use for green hydrogen production, especially in water-stressed regions.

The research questions are as follows.

1) What is the water footprint of green hydrogen production?
2) How does green hydrogen production align with sustainable development goals (SDG), particularly those related to water and energy?
3) What are the social implications of increased water use for green hydrogen production, particularly in vulnerable communities?

2 Background of the Study

2.1 Hydrogen Production

Hydrogen is highly recognized as a versatile and clean energy carrier that can be produced via different primary energy sources, ranging from fossil fuels to renewable energy sources (Dash, et al., 2023).

The study of Patel et al. (2024) shows that the steam methane reforming (SMR) is employed mainly for the production of grey hydrogen. Natural gas is combined with steam to produce hydrogen in this process. A great deal of CO_2 is released into the environment when this process is applied, and it is the most carbon-intensive process for hydrogen production. SMR technology coupled with CCS is used to convert grey hydrogen to blue hydrogen. It minimizes the global warming impact by 25-40% rather than grey hydrogen. Turquoise hydrogen is produced by thermal decomposition of methane (TDM), where methane is decomposed into hydrogen and solid carbon instead of CO_2. As the carbon is stored in the solid state, the process does not have the direct release of CO_2 emissions hence its impact is less than blue or grey hydrogen. Solid carbon is utilized in industrial processes (Patel, et al., 2024). While brown hydrogen is made of brown coal, black hydrogen is made of black coal. Gasification is used to produce brown and black hydrogen. This method turns carbon-rich substances into hydrogen and carbon dioxide and thereby releases GHG emissions into the atmosphere (Brown & Roberts , 2021).

Green Hydrogen is hydrogen production method in which hydrogen is produced using renewable electricity, such as wind, solar or hydropower electricity in an electrolyser. The process by which green hydrogen is produced is called water electrolysis. Although the traditional hydrogen production methods, such as steam methane reforming, emit much carbon dioxide, green hydrogen emits a very less amount of CO_2 (for the manufacturing of solar or wind energy systems) making it a sustainable and environmentally friendly energy carrier (Rai, et al., 2021). Figure 3 shows a comparison of grey, blue and green hydrogen.

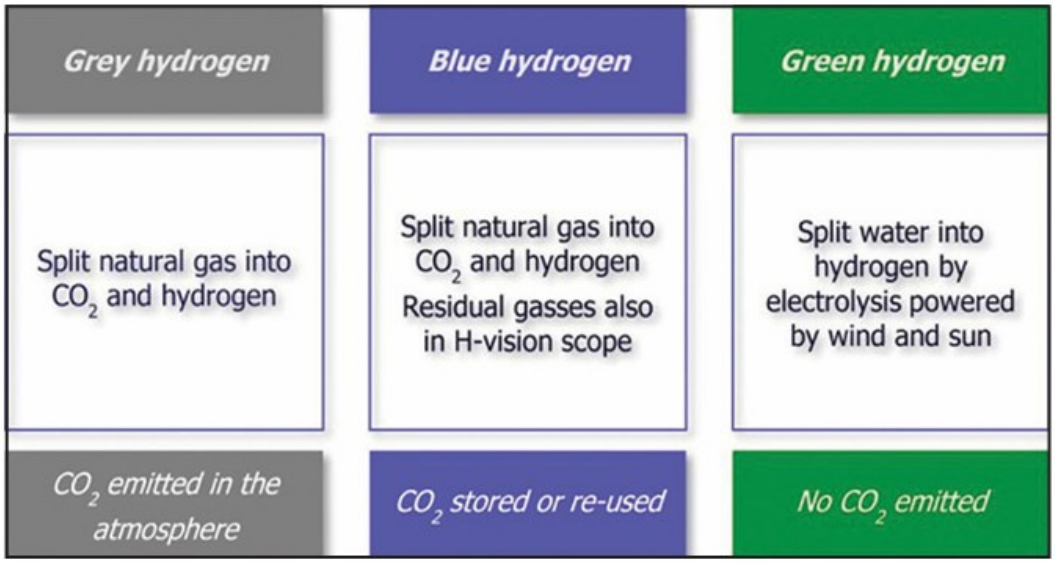

Figure 3 – Hydrogen production methods (Rai, et al., 2021)

In electrolysis, an electric current which is produced by a renewable energy source is used to split water (H_2O) into hydrogen (H_2) and oxygen (O_2) (Pinto, et al., 2024). Green hydrogen is mainly produced via two most used electrolyser technologies. They are as alkaline electrolysis (ALK) and proton exchange membrane (PEM). Both methods are used widely globally. Electrolysis is rapidly growing and a more flexible method with high efficiency (Bhandari, 2022), as shown in the figure 4. This diagram shows a comparison between the working principles of alkaline and PEM electrolysers for the hydrogen production. In the alkaline electrolyser, hydroxide ions (OH-) move through a diaphragm from the cathode to the anode, where water splits into oxygen and hydrogen. In a PEM electrolyser, protons (H+) move through the membrane from the anode to the cathode, generating hydrogen at the cathode and oxygen at the anode.

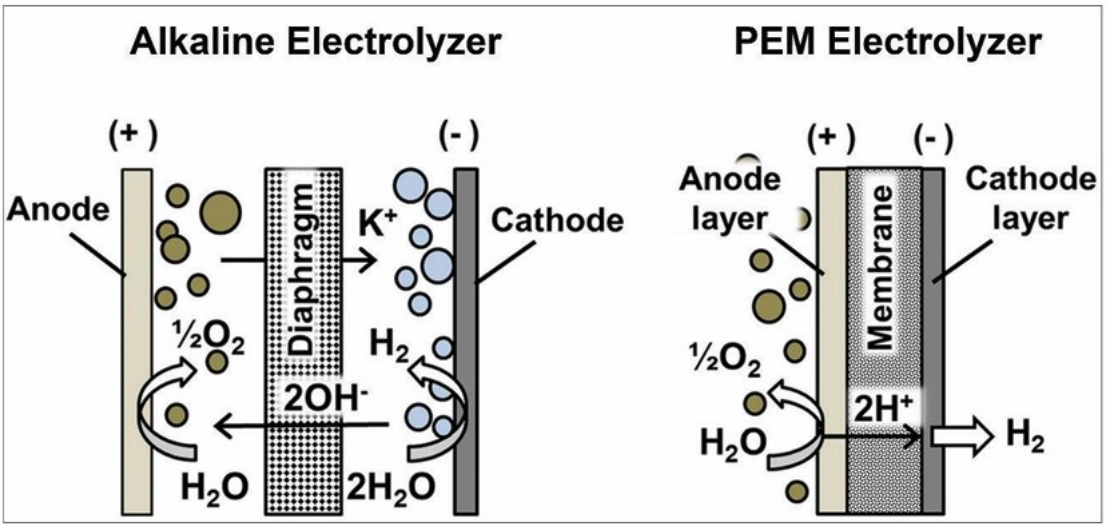

Figure 4 – Simplified diagram of Alkaline Electrolyser vs PEM Electrolyser (Gunawan, 2022).

This comparison highlights how each method uses a different type of ion transport mechanism, leading to distinct system designs.

2.2 Global Hydrogen Demand

In the process of transitioning to a low carbon future, hydrogen is considered as a main energy carrier, globally. Global hydrogen demand hits nearly 94 Mt in 2021, mainly serving fertilizer and refining sectors (Olaitan, et al., 2024). About 95% of this hydrogen is produced currently from fossil fuels (via-SMR) or coal (via gasification). This causes for notable greenhouse gas emissions and resource use (Pinto, et al., 2024).

The study of Rai et al. (2021) shows that, due to very low fraction which is about 6% of the produced hydrogen, is used as pure hydrogen, the role of hydrogen is limited currently in this wide energy system. As the international organizations are committed to climate change mitigation, mainly under frameworks such as the Paris agreement, a growing interest can be seen in expanding the role of green hydrogen. Green hydrogen paves the way for a zero-emission energy sector and mainly targets the sectors where direct electrification is technically or economically impracticable, such as steel and cement industries, energy storage and long-distance transport (Rai, et al., 2021).

Rai, et al., (2021) highlights the global transport sector as one of the major factors for the increase in hydrogen demand. The number of vehicles is expected to be 2.5 billion by 2050, which is 4 times larger than the current statistics. This development justifies the need for changes in the energy sector to break the connection between economic growth and carbon emissions. This makes green hydrogen a reliable and sustainable energy strategy. So, while the current demand for pure hydrogen remains limited, the potential for green hydrogen to transform the global energy sector is considerable (Rai, et al., 2021).

Therefore, green hydrogen production through water electrolysis driven by renewable electricity has been identified as a cleaner option. However, this shift opens the way for new environmental problems, mainly related to water availability and demand (Pinto, et al., 2024). As shown in Figure 5, the potential for global green hydrogen production varies across the regions.

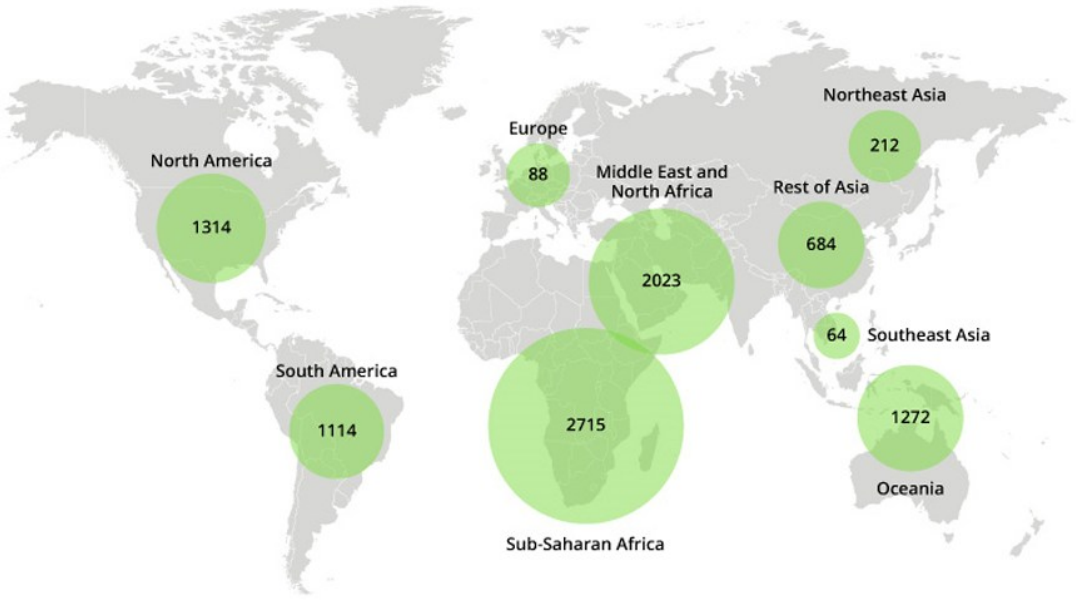

Figure 5 - Global Green Hydrogen Production potential (in exajoules) (Snousy, et al., 2025).

2.3 Hydrogen production projects in Africa

African hydrogen projects are now in demand as the continent shifts towards clean energy. Most are focused on green hydrogen powered by renewable sources such as solar and wind. These projects tend to be large projects and target to serve local markets as well as European and Asian markets. While some small-scale projects are already processing, most of the projects are at feasibility or at early stages of development. The driving factors for these projects are Africa's vast renewable energy resources, proximity to export market, and increased global investment. Challenges exist in policy, infrastructure and finance, but Africa will become a growing hub for cost competitive green hydrogen and its derivatives.

2.3.1 Tsau Khaeb Green Hydrogen Project (Namibia)

The Tsau Khaeb green hydrogen project is the first large scale green hydrogen project in Namibia, which is led by the Hyphen Hydrogen Energy in partnership with the Government of the Republic of Namibia. This project is in the Tsau Khaeb National Park, and the focus of this project is to produce green hydrogen and derivatives for export and local use. This will lead Namibia to become a leader in the global green energy transition (Hyphen, 2025). The production capacity of this project is 300,000 tons per year and the project values $9.4 billion (Hollands, 2021).

Hyphen signed the agreement in 2023, taking responsibility for funding, technical work, and project operations. The preparations for the Environmental and Social Impact Assessment (ESIA) are set to start in 2025 (Hyphen, 2025). In addition to the energy production, this project focuses socio economic development, job creation and the green industrialization of Namibia. This project targets to generate around 15000 job opportunities while the construction and around 3000 permanent positions once operational (Patrick, 2023).

2.3.2 Daures Green Hydrogen Village

The Daures Green Hydrogen Village is in the Erongo region in Namibia, and it is the first net zero green hydrogen and farming spot in Africa. This project produces green hydrogen to make ammonia-based fertilizer, with the use of solar power and wind energy. This

supports crop cultivation in arid regions. This project focuses to give solutions for food insecurity, minimizing fertilizer dependency, create job opportunities and increase climate resilience (NamibiaToday, 2025). This project is on a semi-industrial scale. The phases of the project target to produce 350,000 tons of ammonia per year and the project value for the phase I is 15.1 million Euros (gh2namibia, 2022)

2.3.3 Swakopmund Green Hydrogen Project

The Swakopmund Green Hydrogen Project is led by HDF Energy Namibia. This project is establishing as the first utility scale renewable energy power plant in Namibia. The project targets to produce 100% green, consistent base power supply, supporting to minimize greenhouse gas emissions and reduces Namibia's reliance on imported energy. Also, the project focuses on constructing the first green hydrogen fuel station in Namibia, providing green transport solutions. This project goes with Namibia's vision to become Africa's first zero emission country and with Swakopmund's vision of turning into a sustainable and livable city by 2040 (HDF, 2022). This hybrid power plant targets at delivering 50 MW power during day and 6 MW power during night. Also, this project comprises 85MW solar capacity and 230MWh of energy storage. The project value is estimated at N$ 4,5 billion (Dokso, 2023).

2.3.4 HydroJeel/ Jorf Lasfar Hydrogen Platform (Morocco)

HydroJeel, is a division of the InnovX group in partnership with Morocco's phosphate giant OCP. HydroJeel is leading the Jorf Hydrogen platform in Jorf Lasfar, Morocco. This facility is assisted by Germany's PtX Development Fund. The project values € 30 million. This project targets to produce up to 100,000 tons of green ammonia annually by 2026, powered by fully renewable wind and solar energy. Also, the project focuses on reducing 300,000 tons in CO_2 emission, reducing Morocco's dependence on fossil fuel-based fertilizers, and to place the country as a growing hub for green hydrogen and sustainable industrialization (7newsMorocco, 2025).

2.3.5 Fortescue-OCP JV (Morocco)

The Fortescue-OCP has launched a 50:50 joint venture (JV) based in Morocco with the target of developing a green hydrogen ecosystem. This project focuses on the renewable hydrogen supply, ammonia and fertilizer supply to the local markets as well as European and other markets. This project also targets to develop a technology and R&D hub located near to Mohammed VI Polytechnic University to advance research in green hydrogen, renewable energy and mineral processing (Njovu, 2024).

2.3.6 H2-Industries Waste-to-Hydrogen (Egypt, East Port Said)

H2-Industries is constructing a 1 GW waste to hydrogen facility in East Port Said, Egypt, with the initial approval from the Suez Canal Economic Zone authority. The plant will transform 4 million tons of organic waste and plastics that cannot be recycled, to produce about 300,000 tons of green hydrogen annually based on Liquid Organic Hydrogen Carrier (LOHC) technology. This project expects to deliver hydrogen at about half the current levelized cost of other production methods. The project will reduce emissions, combat waste pollution, and export hydrogen to export markets or convert it into low-cost synthetic diesel and sustainable aviation fuel (SAF) (Vassileva, 2022).

2.3.7 Hive Hydrogen Green Ammonia (South Africa, Coega SEZ)

Hive Hydrogen South Africa, supported by Hive energy and Built Africa, is evolving one of the world's largest green ammonia projects at the Coega Special Economic Zone (SEZ) in Nelson Mandela Bay. This project is powered by 3.5 GW of renewable energy. It includes a planned 1230 MW solar farm. This $5.7 billion plant will produce 1 million tons of green ammonia annually. As this project has direct access to the deep-water port of Ngqura, it is easy for the exports to the Far East, Europe and USA. With South Africa's world-class renewable energy resources, export infrastructure, skilled workforce, Hive Hydrogen aims to reach sustainable energy development and to position the region as a global leader in green hydrogen and ammonia production (HIVEENERGY, 2024).

2.3.8 HySHiFT Project (South Africa, Mpumalanga)

The HySHiFT Project in Secunda, Mpumalanga, is a renewable hydrogen project, guided by a consortium including Linde, Sasol, ENERTRAG and HydRegen Energy. The target of this project is to produce sustainable aviation fuel (SAF/e-kerosene). This is processed by using a planned 200 MW electrolyser and 450 MW of renewable power to generate green hydrogen, which will be combined with Sasol's Fischer-Tropsch facilities. This project has received €15 million in German funding for its first phase, which includes a 40 MW electrolyser. Once operational, this project will produce around 50 000 tons of power to liquid kerosene annually. This project is shortlisted under Germanys H2Global platform for possible long term offtake agreements (Barradas, 2023).

2.4 Water challenges in Africa

Although Africa is exclusively placed in the global hydrogen economy because of its abundant solar and wind resources, at the same time, the continent is among the most water-stressed globally. North African countries such as Tunisia, Morocco and Algeria face severe physical water scarcity problems and are among the driest regions in the world. Despite the long-term targets of Tunisia to export 5.5 Mt of hydrogen to Europe by 2050, the water scarcity calls for integrated planning across the water-energy sectors (Pinto, et al., 2024). As shown in the Figure 6, the overall water risk varies significantly across Africa, with the highest risk concentrated in Northern and Southern regions.

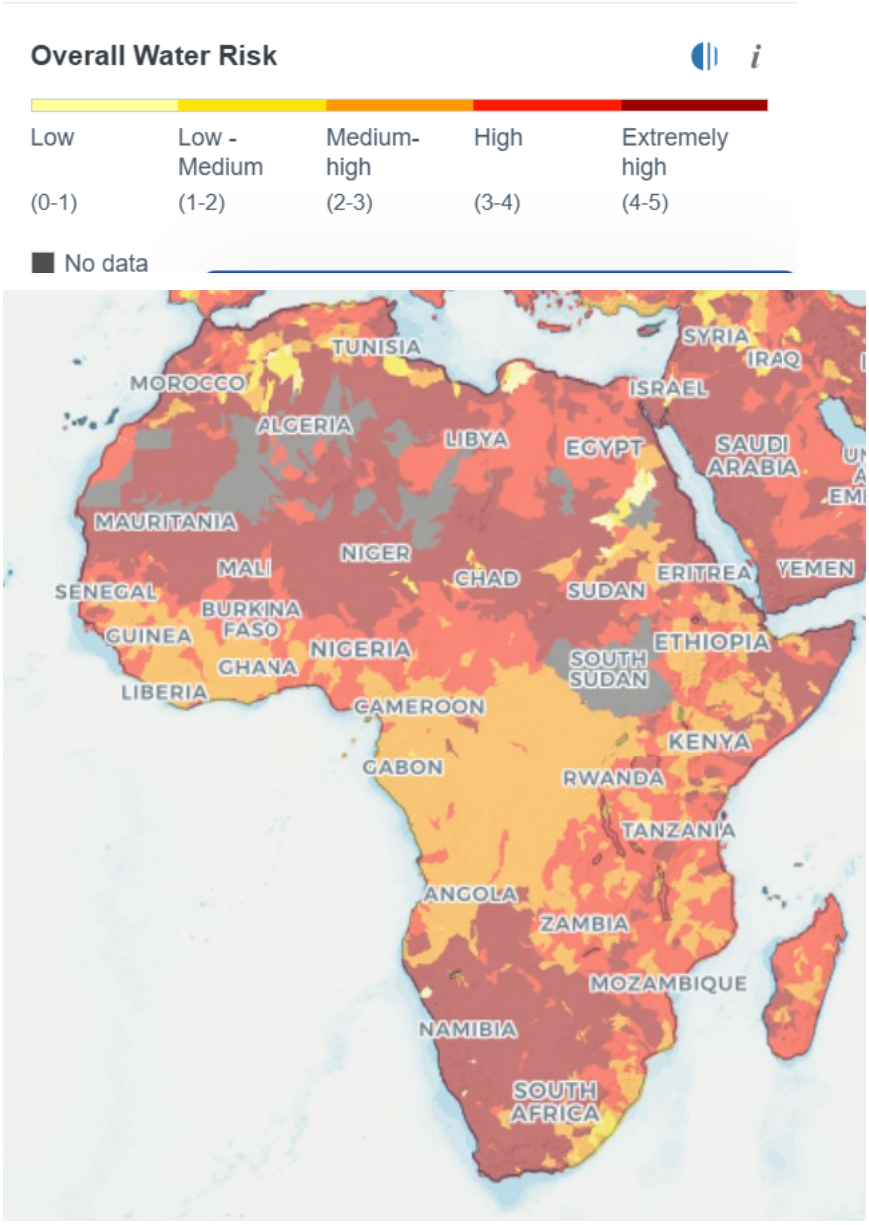

Figure 6 – Overall water risk in African countries (World Resources Institute, 2025)

The case study of Niger shows the pressure of the water scarcity. Although Niger owns huge solar potential and the hydrogen partnership with Germany, there is a lack of ongoing operational hydrogen production via electrolysis. Nearly 0.0117 Mt of hydrogen demand is predicted by 2040 for the electricity and transport sectors. As it is not large in scale, even 5% land use for solar PV could meet this demand, showing technical practicability. But freshwater scarcity creates a serious problem in the implementation (Bhandari, 2022). As shown in Figure 7, meeting hydrogen demand in the electricity and transportation sectors will require considerable additional solar power capacity for hydrogen production in Niger.

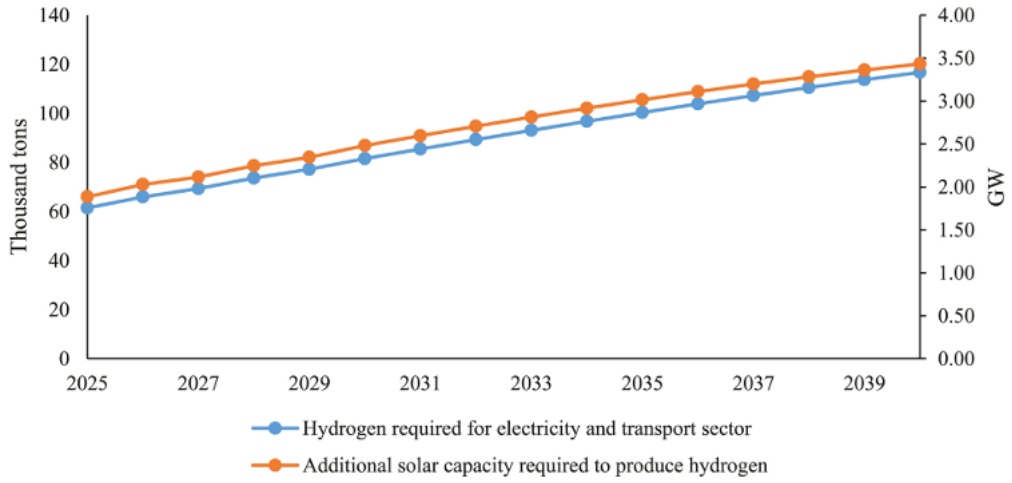

Figure 7 - Hydrogen requirement for the fields of transportation and electricity and the additional solar power requirement to produce hydrogen in Niger (Bhandari, 2022).

Water scarcity is not only a technical issue, but also a strategic barrier that could discourage investments in the hydrogen economy. Investors are becoming more careful due to the socio-environmental problems connected with hydrogen production in water stressed areas. The water risks connected with the infrastructure gaps and political instability may cause unspecified delays in project fulfilment and can increase the Weighted Average Cost of Capital (WACC), making the projects less profitable (Pinto, et al., 2024).

Africa provides significant opportunities for the green hydrogen production due to its abundant renewable energy resources, significant geographic position, and possible socio-economic potential. The African continent owns approximately 350 GW of hydroelectric potential, 1000 GW of solar energy potential, 15 GW of geothermal potential and 110 GW of Wind energy potential, with particularly high solar irradiation levels across most of the regions (Agyekum, 2024). These resources pave the way for cost-effective, large-scale hydrogen generation through water electrolysis powered by renewables. Geographical closeness of Africa to Europe, prevailing trade relations, potential infrastructure gives strong possibility for hydrogen export, mainly to meet the EU decarbonization goals. Also, the young generation of the continent, about 70% under the age of 30, provides a ready workforce to advance hydrogen technologies. The policy framework, Africa's agenda 2063, further creates arrangements for industrial development, climate change mitigation, and sustainable energy transition. Together these factors place Africa as a suitable place for

global green hydrogen supply if proper infrastructure, investment and regulatory measures are carried out (Agyekum, 2024).

2.5 Water Footprint and water scarcity

The water footprint is a comprehensive indicator which measures the total volume of freshwater consumed directly and indirectly of a product, service or a process. It includes blue, green and grey components (Yano, et al., 2015). According to the Water Footprint Network, green water footprint is the rainwater stored in the ground or vegetation and evaporated, transpired or incorporated into crops and forest trees, mostly relevant in agriculture and forestry. Blue water footprint is utilized to quantify the consumption of surface and ground water (such as from rivers, lakes and aquifers) taken off for irrigation, industry or domestic consumption and not recycled to its original source. Grey water footprint is the volume of fresh water required to dilute pollutants from production processes to comply with water quality standards and is a measure of pollution (Hoekstra, et al., 2011).

Among the different methods of hydrogen production, green hydrogen produced via electrolysis powered by renewable energy has the smallest water footprint, while the methods using fossil fuels or biomass have significantly higher water footprints (Olaitan, et al., 2024), as shown in figure 8.

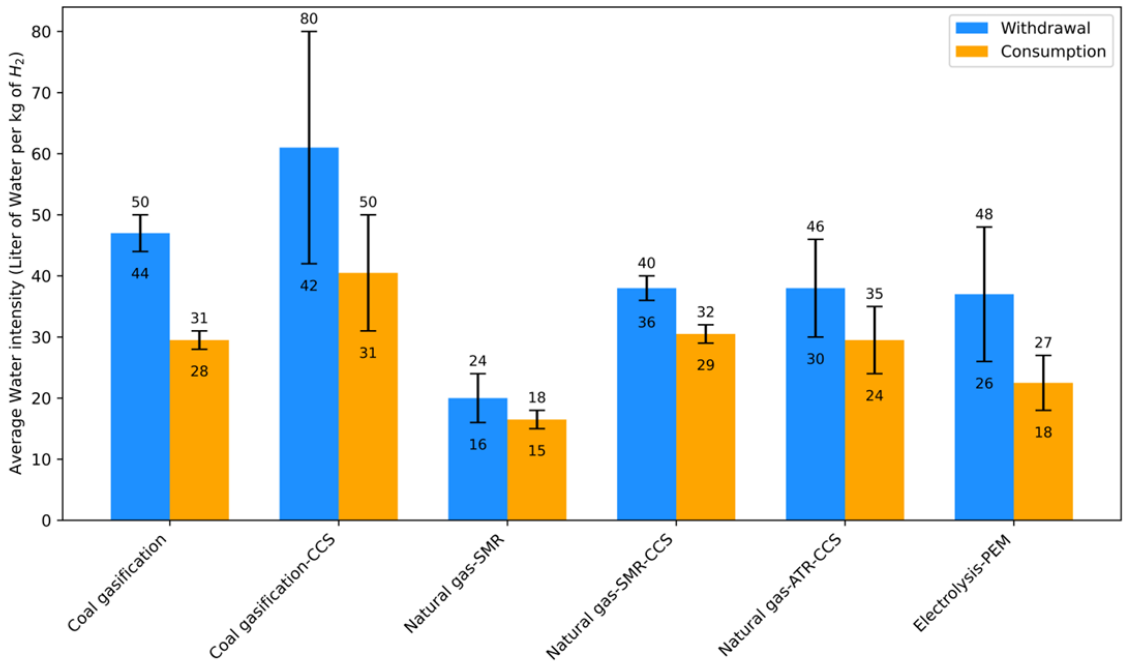

Figure 8 – Average water withdrawal and water consumption for hydrogen production (L/kg of H2) (Lin, et al., 2025)

Water Scarcity can be explained as the gap between the freshwater supply and the demand under the existing conditions and it is a multidimensional challenge covering both the physical shortages and socioeconomic limitations on water access, mainly in arid regions such as Sub-Saharan Africa and North Africa (Hasan, et al., 2019). When the water footprint assessments relate to water scarcity analysis, the result is a scarcity weighted evaluation that not only quantifies the water consumption but also evaluates its environmental and social impacts in the water stressed areas. Understanding these dynamics is very important when analysing it in the context of hydrogen production.

Nearly 9 kg of ultrapure water is used to produce 1 kg of Hydrogen via electrolysis, with further water losses from cooling, desalination and purification varying according to the local conditions and the technology usage (Mika, et al., 2024). Although these water demands are fair when comparing with other sectors, it becomes critical in arid regions.

Water use in the hydrogen production can be mainly determined by the volumetric water footprint method, which constitutes direct and indirect water consumption (L/kg H2) and the water scarcity footprint method, which adjust the volumetric footprint values using the region-specific water stress indices (Du, et al., 2024)

Also, there are some other frameworks that determines the water footprint of green hydrogen production. Life Cycle Water Consumption Assessment (LCWCA), which covers both direct and indirect freshwater consumption throughout the life cycle of hydrogen production from resource extraction to production and distribution (Elgowainy, et al., 2015). Water Scarcity Footprint (WSF) using AWARE method, adjusts the water use by the regional water availability using the AWARE model (Available Water Remaining) (Du, et al., 2024). Water Saving Intensity (HWSI) and Water Saving Potential (HWSP) methods which compares water demand of green hydrogen to conventional hydrogen production methods (Du, et al., 2024).

Also, the choice of the energy source has a huge impact on the overall sustainability of the hydrogen production as solar and wind energy vary in capacity factor and also intermittency profile (Staab & Dickinson, 2023). In contrast, water availability is also a significant factor for electrolytic hydrogen production as the water requirements for electrolysis can intensify the water stress in already water stressed regions (Tonelli, et al., 2023). Therefore, the choice of energy source is essential in identifying the optimum green hydrogen production practices.

2.6 Social implications

The initiation of green hydrogen infrastructure in water stressed regions paves the way for many social concerns. Using freshwater for hydrogen production may reduce its availability for domestic and agricultural use. This fact causes equity problems mainly in rural and marginalized communities which are already stressed with water scarcity issues. Also, the communities are facing land use issues due to political interference. This also causes social implications (Agyekum, 2024). To analyze these implications, social impact assessment must include knowledge of hydrogen technologies, stakeholder participation, trust in institutions, and alignment with Sustainable Development Goals (SDGs) (Agyekum, 2024). Green hydrogen production in Africa line up with the sustainable development goals by encouraging a transition to a green economy, allowing clean energy access (SDG 7), supporting sustainable industrialization and innovation (SDG 9), fostering economic growth and job creation (SDG 8), and contributing to climate action (SDG 13) through significant reductions in GHG emissions.

Furthermore, the study of Agyekum, (2024) which was conducted among the hydrogen related stakeholders, was analyzed using structured questionnaires. They conducted this study by using the survey responses of the stakeholders across Africa with the target of identifying the advantages and disadvantages of green hydrogen production. Through that study they identified critical social dimensions such as, limited public awareness of hydrogen technologies, limited institutional awareness of hydrogen technologies, water competition with agricultural and domestic needs, lack of policy trust and skilled labor. The questionnaire identified the concerns on water use, sustainability targets, and the connection of hydrogen initiatives with wide socioeconomic development goals. It highlights the need for socially informed planning, socially informed decision making and participatory approaches into the hydrogen strategies to make sure the equitable and sustainable adoption across water stressed regions (Agyekum, 2024). This justifies the need for social awareness of the water footprint assessment prior to initiating green hydrogen projects.

3 Materials and Methods

To study water use associated with green hydrogen production from an African point of view, two methods were employed: the Volumetric Water Footprint Method and the Water Stress-Adjusted Water Footprint Method. Both provide absolute and regionally referenced measures of water use. The inventory was extracted from the literature and from FAO aqua stats and analyzed according to ISO 14046 standard (ISO 14046, 2014).

Blue water is used for hydrogen production. Although blue water is fresh surface or ground water; in the African context there is a scarcity in freshwater as the available freshwater is mainly used for drinking facilities and agriculture. Therefore, the best sustainable option is desalinated seawater. As Africa is a hub for renewable energy, the scarce resource; freshwater, can be substituted for energy by desalinating sea water, as desalinating requires energy. So, in water footprint studies, desalinated seawater is usually treated as a blue water substitute, as when seawater is desalinated, the output is freshwater (Hoekstra, et al., 2011). While desalinated seawater represents a practical substitute for freshwater in water-scarce regions, the process is very energy intensive. Its environmental performance strongly

depends on the use of low carbon or renewable electricity for desalination so as not to shift impacts from water scarcity to carbon emissions.

The interpretation of the best energy source for hydrogen production was analyzed using FLH, $WF_{adjusted}$ and the symmetric difference between them. The social implications were addressed through a survey and literature data.

Data visualizations were done using Microsoft Excel, Flourish Studio (Flourish , 2018) and Datawrapper (Datawrapper, 2011). These tools were used to produce interactive maps and graphs based on the collected research data.

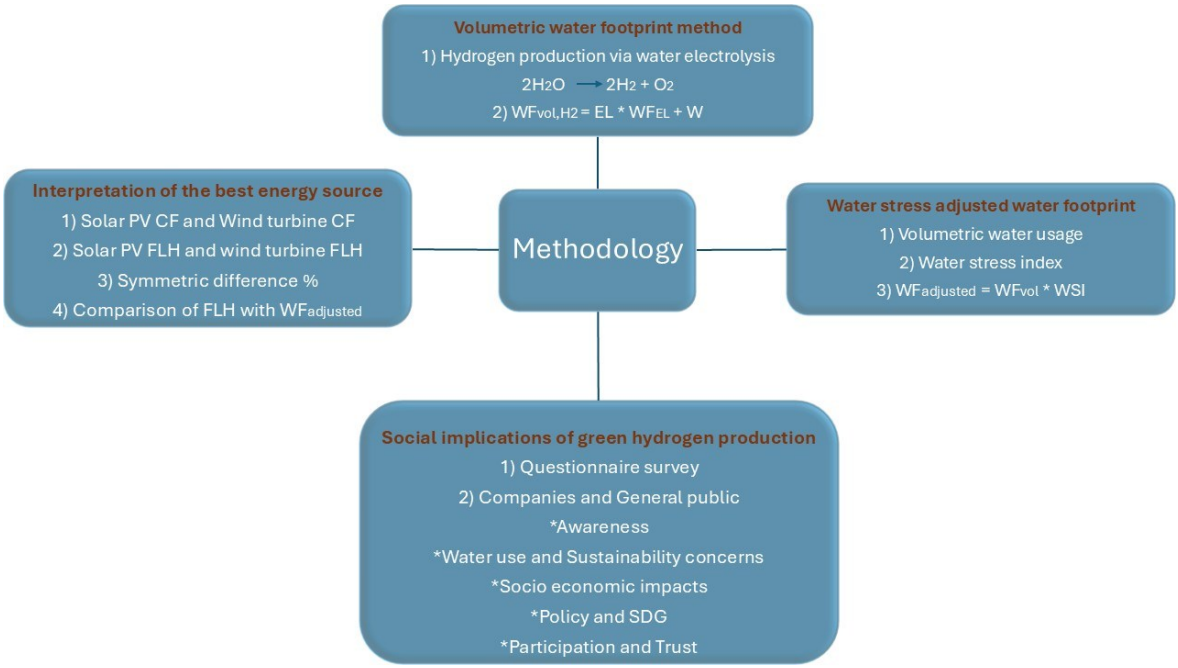

Figure 9: Summary of the Methods used in this study

Figure 9 presents the overall methodology, showing how water footprint calculations, energy source evaluation and social implications are analysed in this study.

3.1 Volumetric water footprint method

In this study, water electrolysis pathway is used to calculate the volumetric water footprint of hydrogen production. In water electrolysis pathway, hydrogen is produced via an electrochemical conversion of water.

$$2H_2O \rightarrow 2H_2 + O_2$$

Volumetric water footprint of hydrogen production can be calculated using the equation 1. All the data were gathered from literature.

$$WF_{vol,H_2} = EL * WF_{EL} + W \quad (1)$$

Where,

$WF_{vol,H2}$ = Volumetric water footprint (m^3/tH_2)

WF_{EL} = Water footprint of the electricity source (m^3/TJ)

EL = Electricity needed per tonne of H_2 (TJ/tH_2)

W = Feedwater needed stoichiometrically (m^3/tH_2)

As it focuses on the green hydrogen production in this study, electricity from solar and wind is considered here. Also, according to the 2022 status data, electrical efficiency is 51 kWh/kg H_2 (0.1836 TJ/tH_2) with 65% LHV (DOE, 2022). For electrolysis, the feedwater needed stoichiometrically is 9 m^3/tH_2 (9kg water per kgH_2). WF_{solar} is 140 m^3/TJ and WF_{wind} is 1.3 m^3/TJ (Olaitan, et al., 2024).

In the volumetric water footprint calculation, the variable is the water footprint of the electricity source. Therefore, the water footprint of solar electricity and the water footprint of wind electricity was analysed according to the Mekonnen et al., (2015). Totals follow Olaitan et al., (2024), while construction vs operation shares were derived from Mekonnen et al., (2015) minimum – maximum ranges (using the average share) and were applied to the equation 1 to identify the shares of the volumetric water footprint of hydrogen production. Here, W, the fixed $9m^3/tH_2$ represents the stoichiometric feed water required by electrolysis and is therefore assigned entirely to the operation stage.

3.2 Water stress adjusted water footprint

To analyse the environmental importance of the water use within the regions in Africa, the volumetric water usage was further multiplied by the WSI to identify the water scarcity in the region. The Water Stress Adjusted Footprint was calculated based on the equation 2 (Wang, et al., 2015).

$$WF_{adjusted} = WF_{vol,H2} * WSI \quad (2)$$

Where, WSI have no units, $WF_{adjusted}$ and WF_{vol} both have the same unit of m3/tH2. The WSI value is the ratio of total water withdrawals to renewable water resources. It was directly taken from the: FAO AQUASTAT Dissemination System. The values in percentage were converted to decimal (ratio) for the easy clarification.

WSI values are categorized as,

No stress (<0.25)

Low stress (0.25 – 0.5)

Medium stress (0.5–0.75)

High stress (0.75-1)

Critical stress (>1)

(FAO, 2021).

3.3 Interpretation of the most suitable power source to power the green hydrogen production in each country by comparing $WF_{adjusted}$ and FLH

In order to find the most suitable energy source to power the hydrogen production in each country of the African continent, the following method was utilized. The capacity factors of wind turbines and solar PV for each country in Africa were modeled using the Renewables.ninja open data source (Pfenninger & Staffell, 2024). All the capacity factors were sourced for the year 2024. Then the capacity factors were multiplied by the number of hours per year (8760 h). Then comes the Full Load Hours (FLH) of wind turbines and solar PV. The capacity factor is the ratio of the power plant's energy actually produced during a

given year to the energy it would have produced if it had operated at its full capacity for every hour of that year (NREL, 2025).

Full Load Hours (FLH) is the number of hours a power plant would need to run at its rated capacity (full power) to generate the same energy it actually produced over a period (Franke, et al., 2024). The annual equivalent full load hours can also be calculated by multiplying the capacity factor by 8760, which represents the total hours in a year (Ministry of Energy and Mineral Resources, 2024) (Equation 3).

$$Full\ Load\ Hours = Capacity\ Factor * 8760 \quad (3)$$

Where, CF doesn't have a unit and 8760 is hours (h). Therefore, the final unit of the FLH is hours/year (h/year).

Solar FLH and wind FLH were compared using the symmetric difference % of the FLHs (Equation 4). The symmetric percentage difference of wind and solar FLH provides a balanced dimensionless measure of how far apart the two technologies are. Normalizing by the average of the two FLH values allows comparison across countries with very different absolute FLH levels, while treating wind and solar symmetrically rather than enabling one as the reference. In this study, only the magnitude of the symmetric difference was used and therefore the metric was reported as an absolute percentage difference (always ≥ 0).

$$Symmetric\ difference(\%) = \frac{|Wind\ FLH - Solar\ FLH|}{(Wind\ FLH + Solar\ FLH)/2} * 100 \quad (4)$$

When choosing the suitable power source, some assumptions were used.

1) If one power plant (solar or wind) FLH is >>20% higher than the other in a country, it was chosen unless its $WF_{adjusted}$ was worse (more than 5 m^3/tH_2); if so, a single technology was not forced.

2) If the FLHs are within 0% to 20% symmetric difference, $WF_{adjusted}$ was the determinant of the energy source.

Since FLH is directly proportional to the CF and the hours per year is a constant value, calculating the symmetric difference using FLH is mathematically equivalent to using CF. FLH was chosen for this analysis because it is expressed in hours per year and is therefore more clear for interpreting how many "full power hours" each technology effectively provides in each country. Thus, the selection of the best energy source (wind / solar) to power the hydrogen production for each country was done.

3.4 Social implications of green hydrogen production

A questionnaire was developed and distributed among the hydrogen production-related companies including CWP Global, Africa Green Hydrogen Hub and many others as well as among the African general public for obtaining varied views on green hydrogen production. This dual target approach was implemented with the vision of obtaining a deep understanding of both the industry level and community level views, thereby providing an overview of awareness, sustainability concerns, socio-economic impacts and trust. By including all these sets of stakeholders, this study includes technical as well as socio-economic issues encompassing the production of green hydrogen in Africa, which is important in determining its long-term sustainability and development of policies.

The survey consisted of 6 sections including, general awareness of Green Hydrogen, Water use and sustainability concerns, social and economic impacts, policy and sustainable development alignment, participation and trust, demographic information. The survey questions can be found in appendix 1.

As low number of responses received for the survey, triangular analysis was done. For that journal articles were used in addition to the survey responses.

4 Results

In this section the results for the volumetric water footprint, water stress adjusted water footprint of solar powered hydrogen production vs wind powered hydrogen production for each country in the African continent were computed. Also, wind FLH and solar FLH of each country in the African continent were computed. Finally, the results obtained from the questionnaire and the literature data for the social implications of green hydrogen production were separately shown.

4.1 Volumetric Water Footprint

Based on equation 1, the volumetric water footprint of solar powered hydrogen production and wind powered hydrogen production are as follows.

$WF_{vol,H2}(solar) = 0.1836\ TJ/tH_2 * 140\ m^3/TJ + 9\ m^3/tH_2 = 34.7\ m^3/tH_2$

$WF_{vol,H2}(wind) = 0.1836\ TJ/tH_2 * 1.3\ m^3/TJ + 9\ m^3/tH_2 = 9.2\ m^3/tH_2$

According to the calculation, solar powered hydrogen production have a higher volumetric water footprint than wind powered hydrogen production (Figure 11)

According to Olaitan et al., (2024) WF_{solar} is 140 m^3/TJ and WF_{wind} is 1.3 m^3/TJ. Those values were extracted from Mekonnen et al., (2015). According to that, the water footprint of the electricity source analysis is shown in the Table 1.

Table 1: Breakdown of the Water footprint of solar electricity vs wind electricity (Mekonnen, et al., 2015)

	Construction (m^3/TJ)	Operation (m^3/TJ)	Total (m^3/TJ)
Solar PV Electricity	5.3 -221 (86)	1.1 – 82 (19)	6.4 - 303
Wind Electricity	0.1 – 9.5 (1)	0.1 – 2.1 (0.2)	0.2 – 12

Here Mekonnen et al., (2015) mentioned that these numbers are rounded off and within the brackets are median values which were used for the calculations. Olaitan et al., (2024) adopted the value of 140 m^3/TJ within the range that Mekonnen et al., (2015) mentioned but reflects more water-intensive PV operations scenarios, such as panel cleaning in dry and dusty regions. This seems more realistic rather than directly obtaining the median value. According to Table 1, it is clear that the Water footprint of solar electricity is higher than the water footprint of wind electricity.

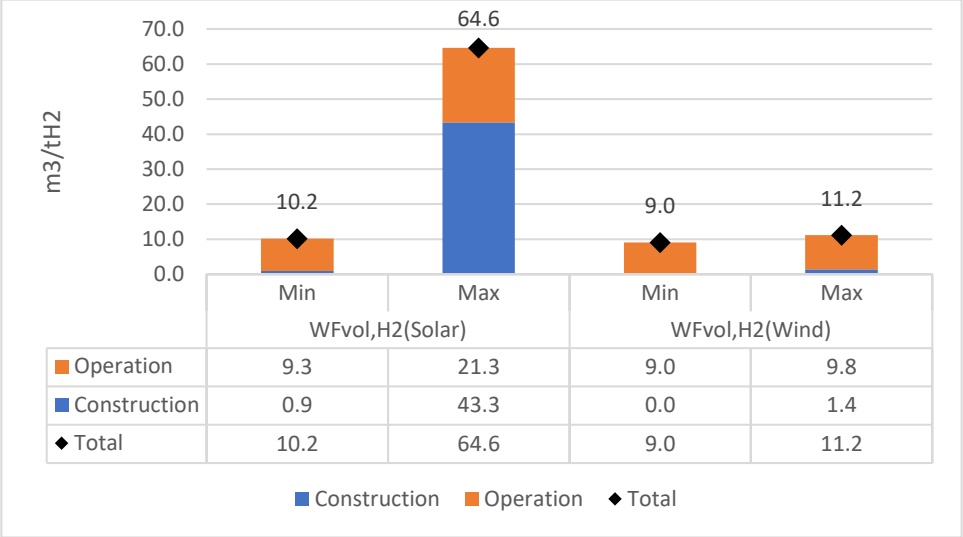

Figure 10: Min-Max Volumetric Water Footprint of Hydrogen production, split by construction and operation

Figure 10 shows volumetric water footprint of hydrogen production according to the minimum – maximum ranges of the water footprint of solar electricity and wind electricity, given in Mekonnen et al., (2015). The bars show the construction/ operation contributions.

According to the average construction and operation share of the water footprint of the electricity source extracted from Mekonnen et al., (2015), the construction and operation shares of the volumetric water footprint of hydrogen production can be shown in Figure 11.

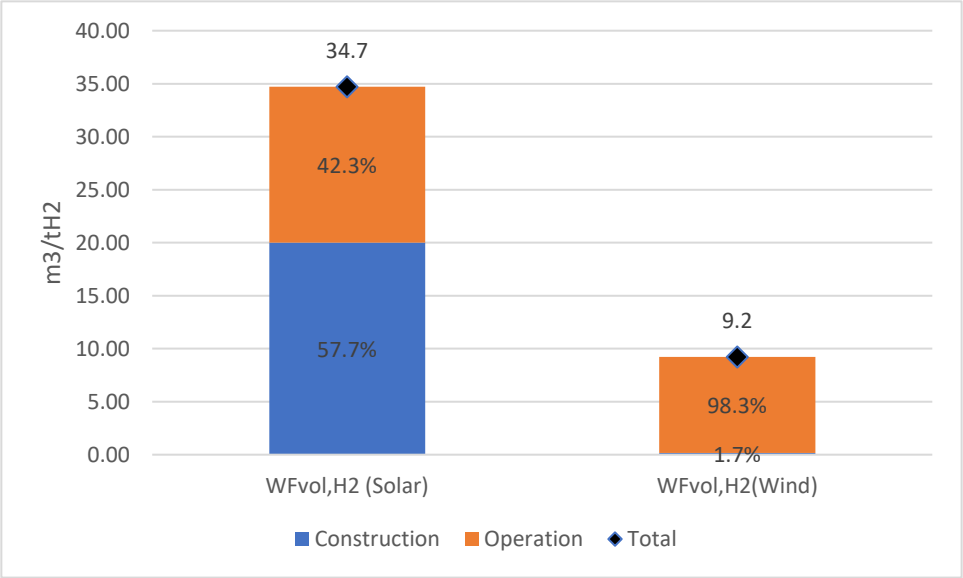

Figure 11: The construction and operation shares of the Volumetric Water Footprint of Hydrogen production

Construction share of solar powered hydrogen production is higher than the operation share, while operation share is higher in wind powered hydrogen production.

4.2 Water Stress Adjusted Water Footprint

For the calculation of $WF_{adjusted}$, WSI values are needed. There are totally 54 countries in African continent. But the WSI data was found only for 50 countries in Africa, and those data were collected through the FAO AQUASTAT Dissemination System (FAO, 2022). WSI values for the countries in Africa and the $WF_{adjusted}$ values are indicated in the Table 2. In the Table 2, the brightness of the colour increases with the stress in the WSI column; from no stress, low stress, medium stress, high stress to critical stress according to the ranges mentioned in Methods. Graphical presentation of the values in an African map can be found in figure 12, 13 and 14.

Table 2 - Country based WSI values (FAO, 2022) and $WF_{adjusted}$ values

Country	WSI	$WF_{adjusted}$ (solar powered) (m3/tH2)	$WF_{adjusted}$ (wind powered) (m3/tH2)
Algeria	1.4481	50.25	13.32
Angola	0.0187	0.65	0.17
Benin	0.0098	0.34	0.09
Botswana	0.0223	0.77	0.21
Burkina Faso	0.0782	2.71	0.72
Burundi	0.1019	3.54	0.94
Cabo Verde	0.5968	20.71	5.49
Cameroon	0.0156	0.54	0.14
Central African Republic	0.0034	0.12	0.03
Chad	0.0429	1.49	0.39
Comoros	0.0083	0.29	0.08
Democratic Republic of the Congo	0.0023	0.08	0.02
Republic of the Congo	NA	NA	NA
Djibouti	0.0633	2.20	0.58
Egypt	1.4117	48.99	12.99
Equatorial Guinea	0.0018	0.06	0.02
Eritrea	0.1118	3.88	1.03
Eswatini	0.7756	26.91	7.14

Ethiopia	0.3226	11.19	2.97
Gabon	0.0050	0.17	0.05
Gambia	0.0221	0.77	0.20
Ghana	0.0631	2.19	0.58
Guinea	0.0137	0.48	0.13
Guinea-Bissau	0.0150	0.52	0.14
Ivory Coast	NA	NA	NA
Kenya	0.3324	11.53	3.06
Lesotho	0.0257	0.89	0.24
Liberia	0.0026	0.09	0.02
Libya	8.1714	283.55	75.18
Madagascar	0.1126	3.91	1.04
Malawi	0.1750	6.07	1.61
Mali	0.0800	2.78	0.74
Mauritania	0.1325	4.60	1.22
Mauritius	0.2297	7.97	2.11
Morocco	0.5075	17.61	4.67
Mozambique	0.0175	0.61	0.16
Namibia	0.0031	0.11	0.03
Niger	0.1102	3.82	1.01
Nigeria	0.0967	3.36	0.89
Rwanda	0.2020	7.01	1.86
Sao Tome and Principe	0.0188	0.65	0.17
Senegal	0.1628	5.65	1.50
Seychelles	NA	NA	NA
Sierra Leone	0.0050	0.17	0.05
Somalia	0.2453	8.51	2.26
South Africa	0.6760	23.46	6.22
South Sudan	0.0423	1.47	0.39
Sudan	1.1866	41.18	10.92
Tanzania	NA	NA	NA
Togo	0.0339	1.18	0.31
Tunisia	0.9811	34.04	9.03
Uganda	0.0583	2.02	0.54
Zambia	0.0284	0.99	0.26
Zimbabwe	0.4609	15.99	4.24

NA – Not available

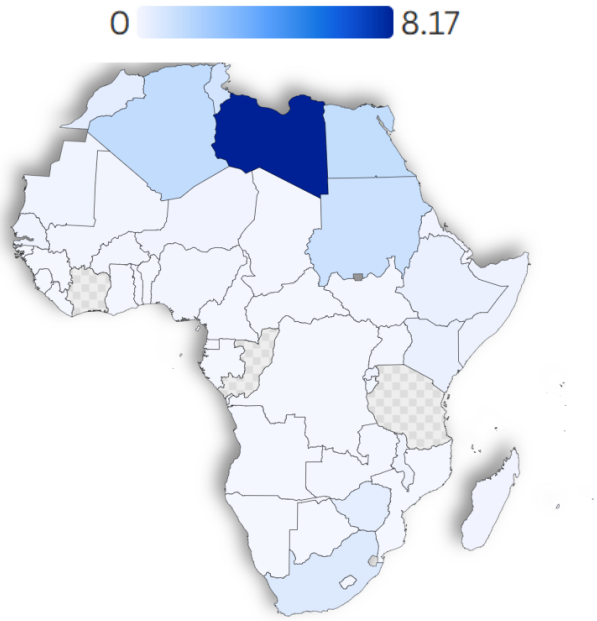

Figure 12: WSI index of African countries

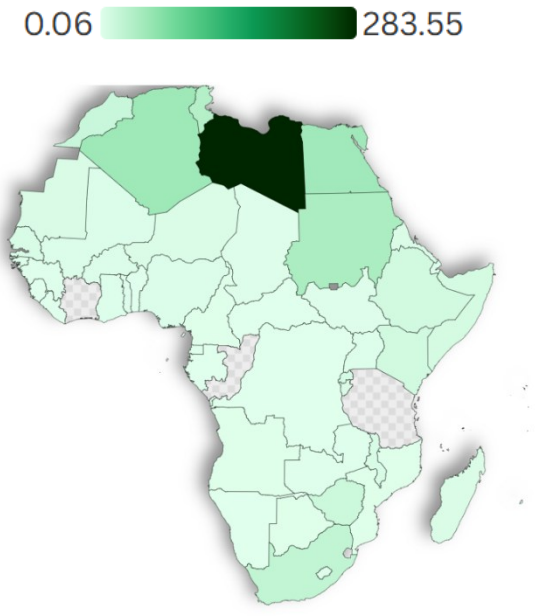

Figure 13: $WF_{adjusted}$ (solar-powered)

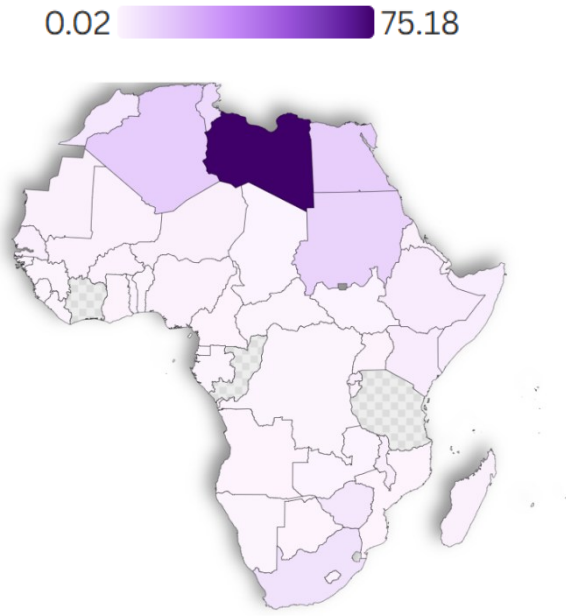

Figure 14: $WF_{adjusted}$ (wind-powered)

Figures 15, 16, 17, 18, 19 show the $WF_{adjusted}$ of solar powered vs wind powered in Northern Africa, Western Africa, Central Africa, Eastern Africa and Southern Africa respectively. The region categorization was taken from the United Nations Statistics Division M49 classification (UNSD, 2025).

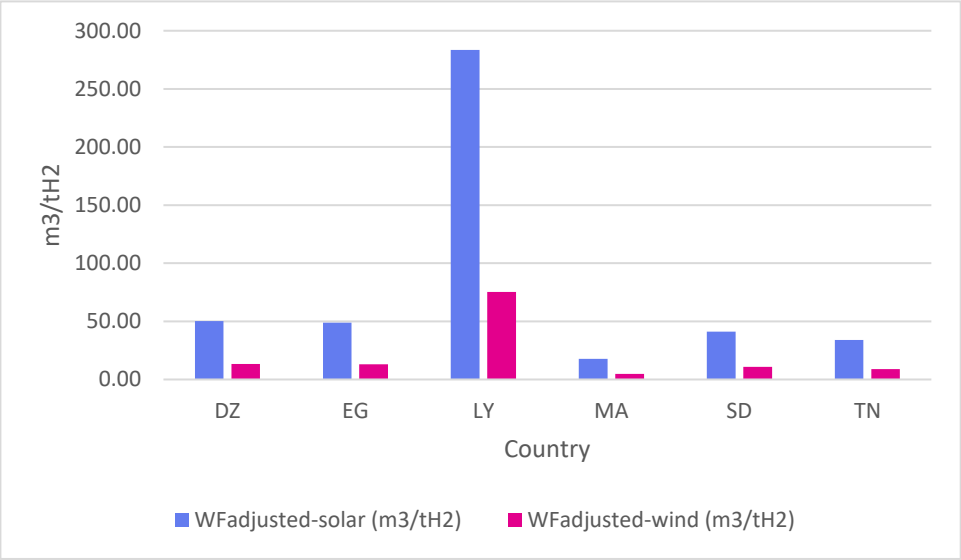

Figure 15: $WF_{adjusted}$- solar powered vs $WF_{adjusted}$- wind powered in Northern Africa

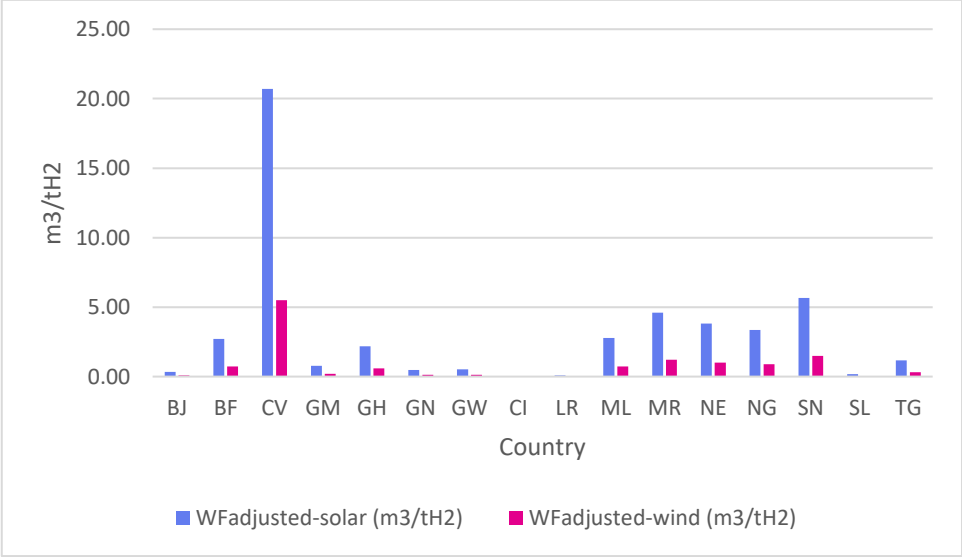

Figure 16: $WF_{adjusted}$- solar powered vs $WF_{adjusted}$- wind powered in Western Africa

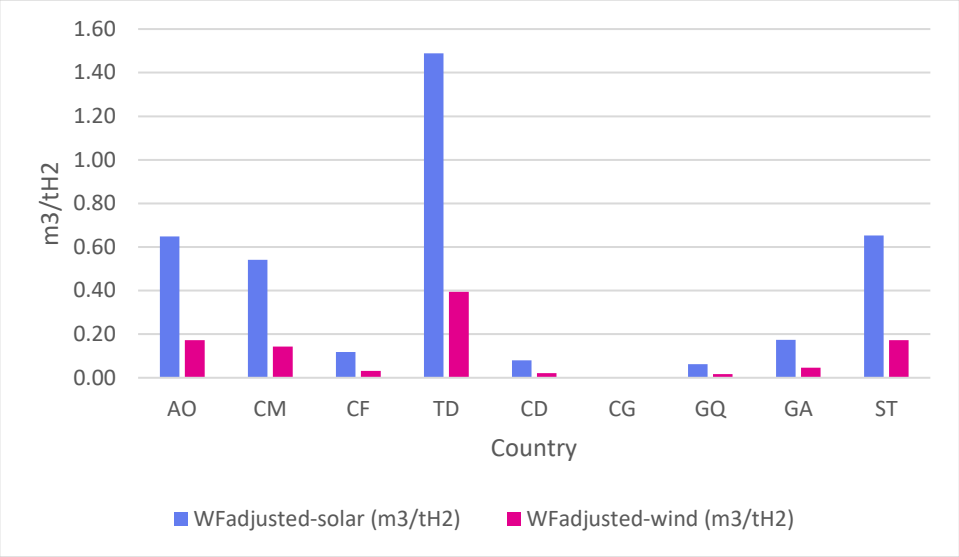

Figure 17: $WF_{adjusted}$- solar powered vs $WF_{adjusted}$- wind powered in Central Africa

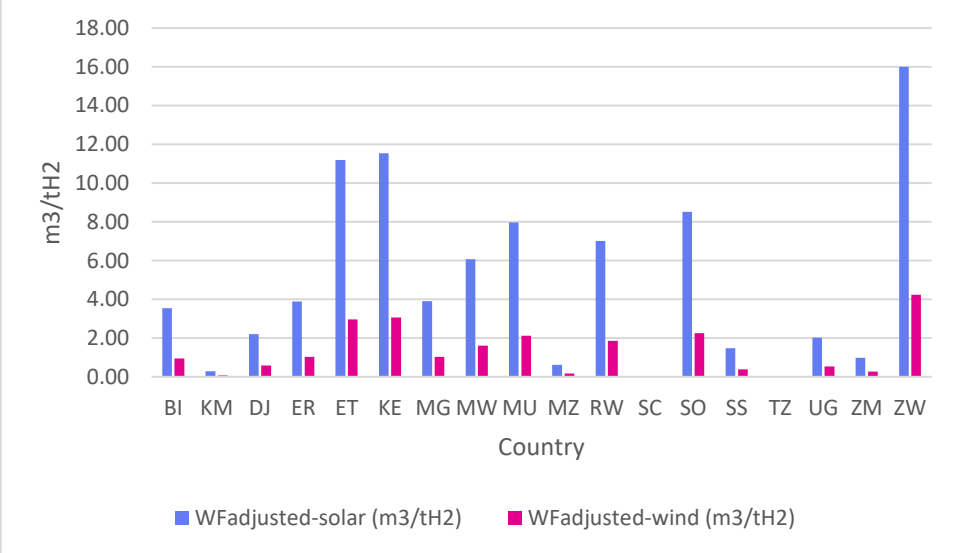

Figure 18: $WF_{adjusted}$- solar powered vs $WF_{adjusted}$- wind powered in Eastern Africa

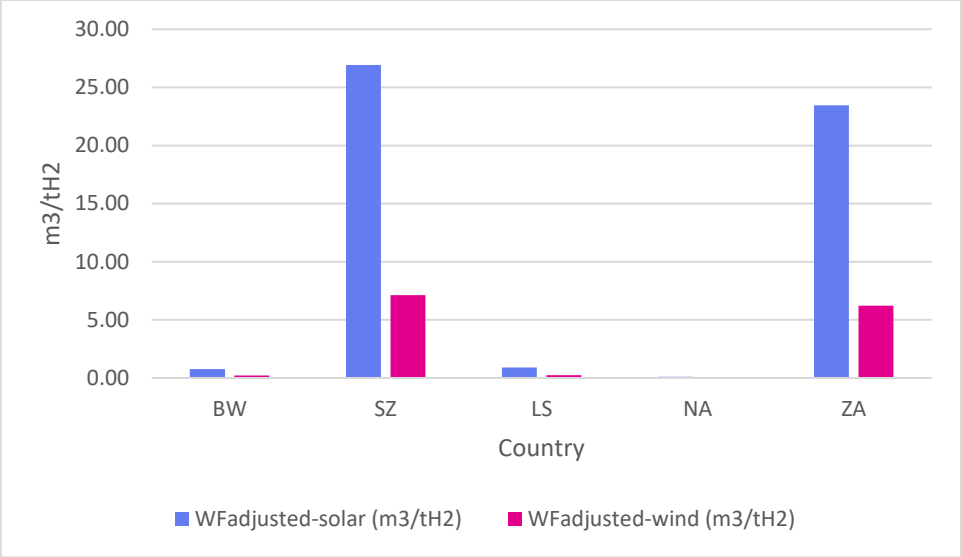

Figure 19: $WF_{adjusted}$- solar powered vs $WF_{adjusted}$- wind powered in Southern Africa

According to Figure 15 to 19 , overall solar powered pathways show higher $WF_{adjusted}$ values compared to wind, with Libya displaying the highest value among all the African countries.

4.3 Interpretation the most suitable power source to power the green hydrogen production in each country by comparing $WF_{adjusted}$ and FLH

Full Load Hours of wind turbines vs solar PV were calculated using equation 3 and calculated values can be found in Table 3. The CF data needed for the equation 3 were gathered by Renewables.ninja online simulation platform (Pfenninger & Staffell, 2024). The values are visually shown in a scatter plot graph in the figure 21. These full load hours and adjusted water footprints were used to interpret the most suitable energy source to power the green hydrogen production in each area.

In this analysis, FLH was used as an indicator of the energy yield of each technology serving as a proxy for the expected hydrogen output per unit of installed capacity, while $WF_{adjusted}$ was used as an indicator of the water use impact per unit of hydrogen produced. Hence, the two indicators were combined in a stepwise decision rule to identify the most suitable technology in each country.

Based on the decision criteria laid out in section 3.3, for countries where one technology outperformed the other by greater than 20% in FLH (without being substantially worse in

$WF_{adjusted}$) were assigned that technology as preferred. For countries where FLH values were within 0-20% symmetric difference, the technology with lower $WF_{adusted}$ was chosen.

Table 3: Comparison of Country based FLH and the symmetric difference between them

Country	Wind turbine CF	Solar PV CF	FLH wind turbine (h/year)	FLH solar PV (h/year)	Symmetric difference between FLH_{solar} & FLH_{wind} (%)
Algeria	53.90%	21.30%	4721.64	1865.88	86.70
Angola	15%	19.70%	1314.00	1725.72	27.09
Benin	18.10%	16.30%	1585.56	1427.88	10.47
Botswana	30.10%	22.20%	2636.76	1944.72	30.21
Burkina Faso	22.40%	18.10%	1962.24	1585.56	21.23
Burundi	7.33%	17.70%	642.11	1550.52	82.86
Cabo Verde	37.60%	19.40%	3293.76	1699.44	63.86
Cameroon	4.49%	15.80%	393.32	1384.08	111.48
Central African Republic	12.90%	17.20%	1130.04	1506.72	28.57
Chad	38.50%	20.50%	3372.60	1795.80	61.02
Comoros	17.10%	18.40%	1497.96	1611.84	7.32
Democratic Republic of the Congo	4.41%	14.30%	386.32	1252.68	105.72
Republic of the Congo	2.12%	13.60%	185.71	1191.36	146.06
Djibouti	25.20%	18.70%	2207.52	1638.12	29.61
Egypt	45.10%	22.70%	3950.76	1988.52	66.08
Equatorial Guinea	2.82%	13.20%	247.03	1156.32	129.59
Eritrea	14.10%	20.10%	1235.16	1760.76	35.09
Eswatini	19.20%	21.20%	1681.92	1857.12	9.90
Ethiopia	2.60%	20.40%	227.76	1787.04	154.78
Gabon	2.24%	13.60%	196.22	1191.36	143.43
Gambia	20.80%	17.20%	1822.08	1506.72	18.95
Ghana	13.70%	16.10%	1200.12	1410.36	16.11
Guinea	12.40%	17.70%	1086.24	1550.52	35.22
Guinea-Bissau	16.60%	16.10%	1454.16	1410.36	3.06
Ivory Coast	13.60%	16.40%	1191.36	1436.64	18.67
Kenya	45.20%	18.40%	3959.52	1611.84	84.28
Lesotho	20.00%	24.20%	1752.00	2119.92	19.00
Liberia	10.10%	14.70%	884.76	1287.72	37.10

Libya	37.60%	22.10%	3293.76	1935.96	51.93
Madagascar	18.20%	20.50%	1594.32	1795.80	11.89
Malawi	23.60%	20.30%	2067.36	1778.28	15.03
Mali	34.70%	19.60%	3039.72	1716.96	55.62
Mauritania	34.40%	20.80%	3013.44	1822.08	49.28
Mauritius	49.90%	19.80%	4371.24	1734.48	86.37
Morocco	39.50%	21.20%	3460.20	1857.12	60.30
Mozambique	18.70%	20.10%	1638.12	1760.76	7.22
Namibia	28.10%	23.20%	2461.56	2032.32	19.10
Niger	29.90%	21.60%	2619.24	1892.16	32.23
Nigeria	19.00%	17.30%	1664.40	1515.48	9.37
Rwanda	6.03%	17.10%	528.23	1497.96	95.72
Sao Tome and Principe	11.30%	12.10%	989.88	1059.96	6.84
Senegal	28.10%	17.50%	2461.56	1533.00	46.49
Seychelles	26.60%	15.10%	2330.16	1322.76	55.16
Sierra Leone	12.10%	15.20%	1059.96	1331.52	22.71
Somalia	54.00%	20.10%	4730.40	1760.76	91.50
South Africa	30.60%	22.90%	2680.56	2006.04	28.79
South Sudan	18.10%	17.50%	1585.56	1533.00	3.37
Sudan	39.00%	20.80%	3416.40	1822.08	60.87
Tanzania	22.70%	19.60%	1988.52	1716.96	14.66
Togo	13.60%	16.10%	1191.36	1410.36	16.84
Tunisia	40.30%	20.30%	3530.28	1778.28	66.01
Uganda	9.47%	16.30%	829.57	1427.88	53.01
Zambia	34.20%	20.70%	2995.92	1813.32	49.18
Zimbabwe	28.00%	21.70%	2452.80	1900.92	25.35

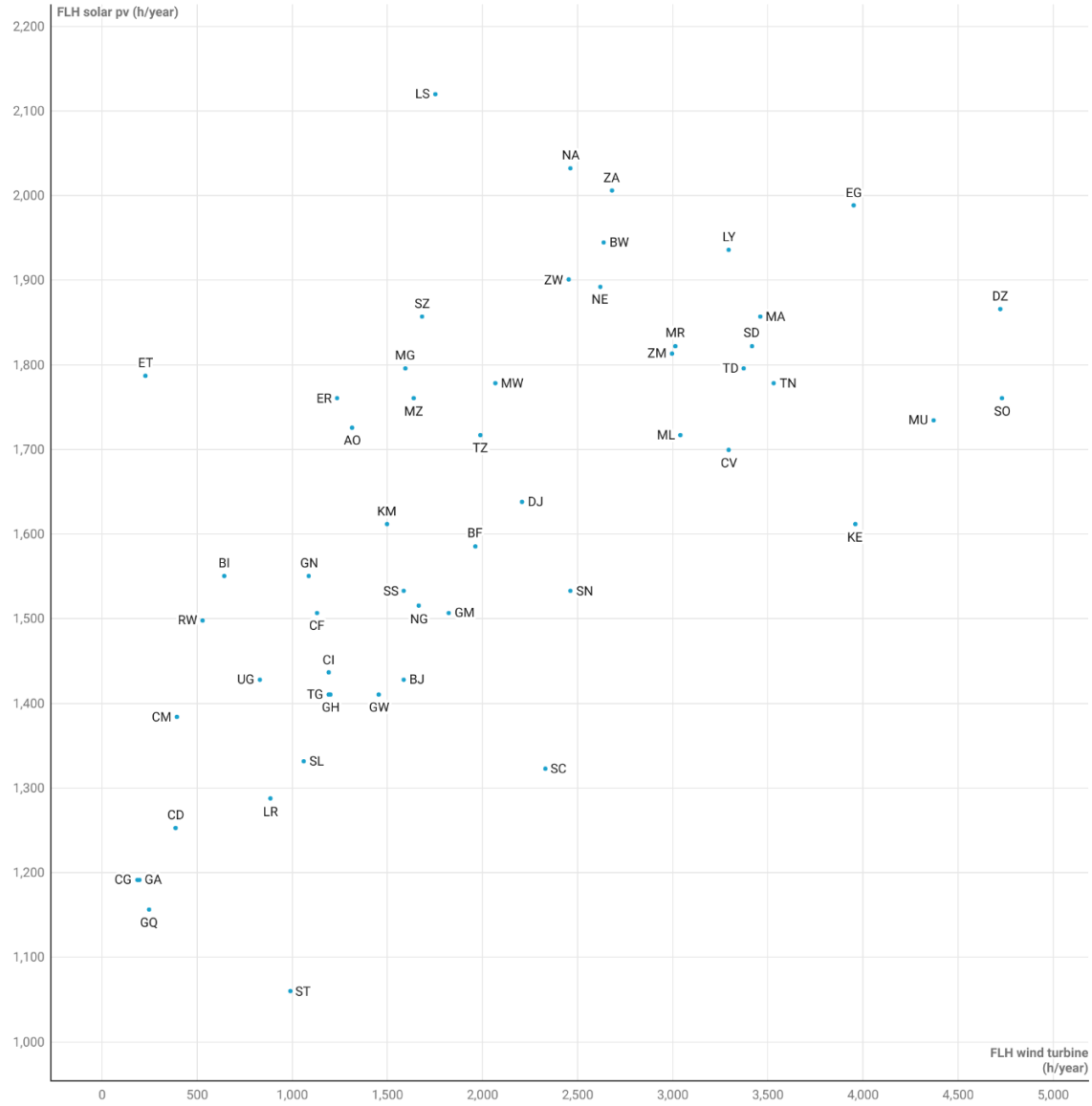

Figure 20: FLH wind turbine vs FLH solar PV in African countries

The figure 20 compares the annual FLH of solar PV and wind turbines for all African countries, representing the energy yield of both technologies. Each point represents one country, positioned according to its wind FLH (x-axis) and solar FLH (y-axis). The country codes can be found in appendix 2. Countries positioned further to the right in the graph have stronger wind potential, while countries positioned higher in the graph have stronger solar potential. According to the figure 21, the large variation in resource FLH across the continent forms the basis for identifying where one technology has a clear advantage prior to considering water use impacts.

Figures 21, 22, 23, 24, 25 show the variation between the $WF_{adjusted}$ of solar powered hydrogen production and wind powered hydrogen production and FLH of solar and wind in Northern Africa, Western Africa, Central Africa, Eastern Africa and Southern Africa respectively. Therefore, there are two points in these figures corresponding to solar and wind. Technologies that are positioned toward the lower right corner (high FLH and low $WF_{adjusted}$) represent favourable options. Final selections of the most suitable technology for each country do not solely rely on these scatterplots but follow the decision criteria described in section 3.3. In this way, the plots visualize the trade-off between energy yield and water impact and can be used by planners to identify the suitable option for electricity supply to green hydrogen production.

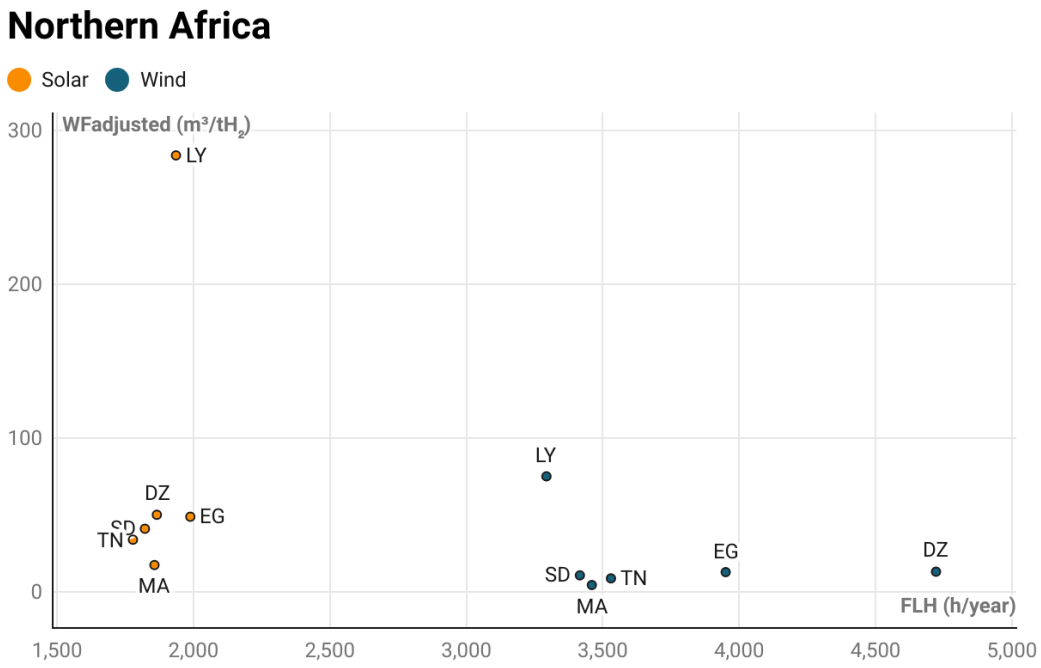

Figure 21: FLH vs $WF_{adjusted}$ in Northern Africa

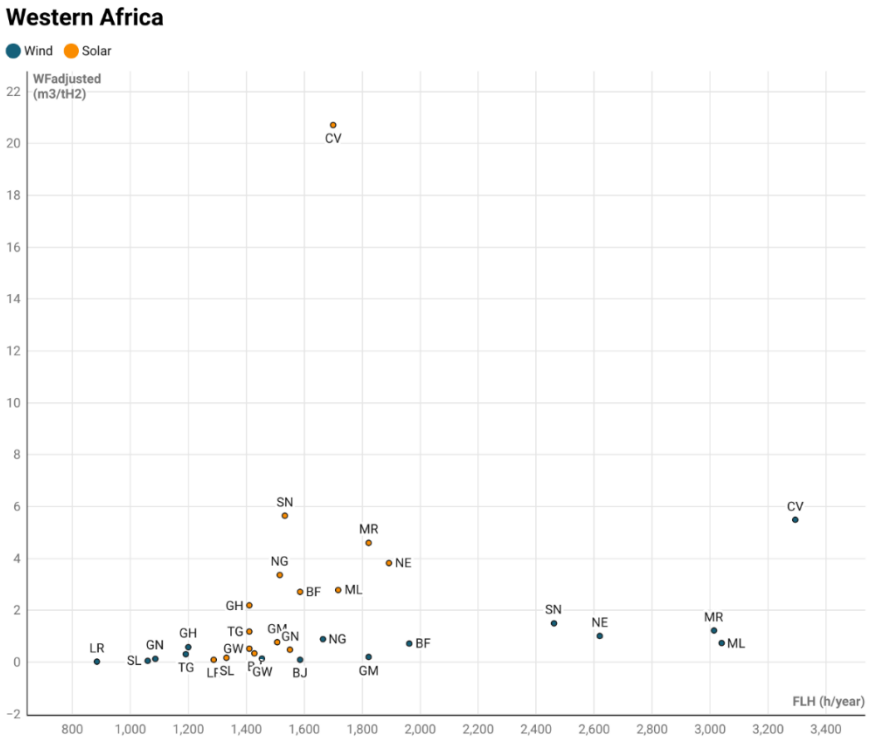

Figure 22: FLH vs $WF_{adjusted}$ in Western Africa

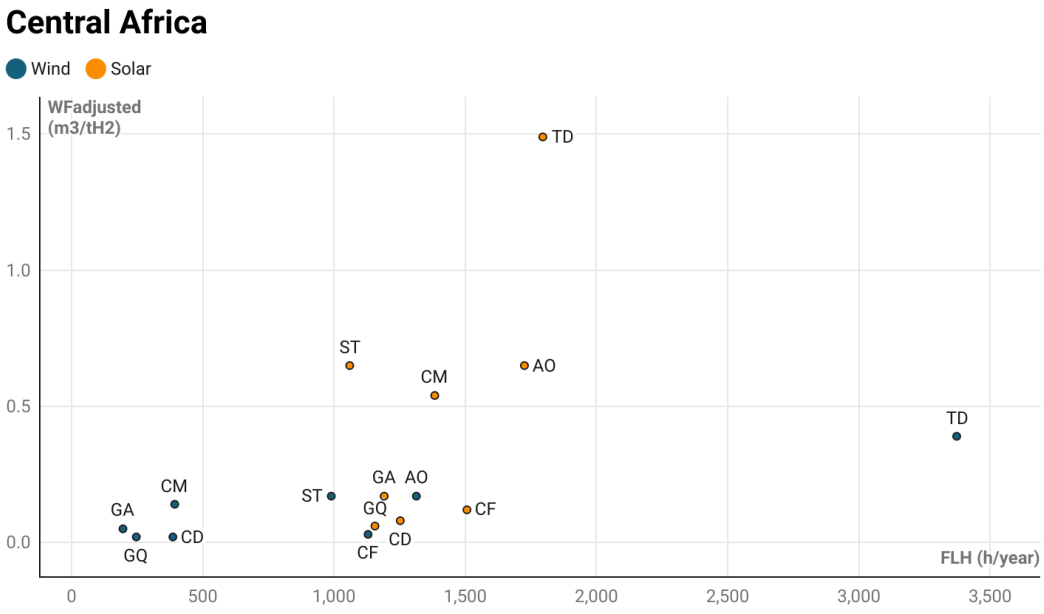

Figure 23: FLH vs $WF_{adjusted}$ in Central Africa

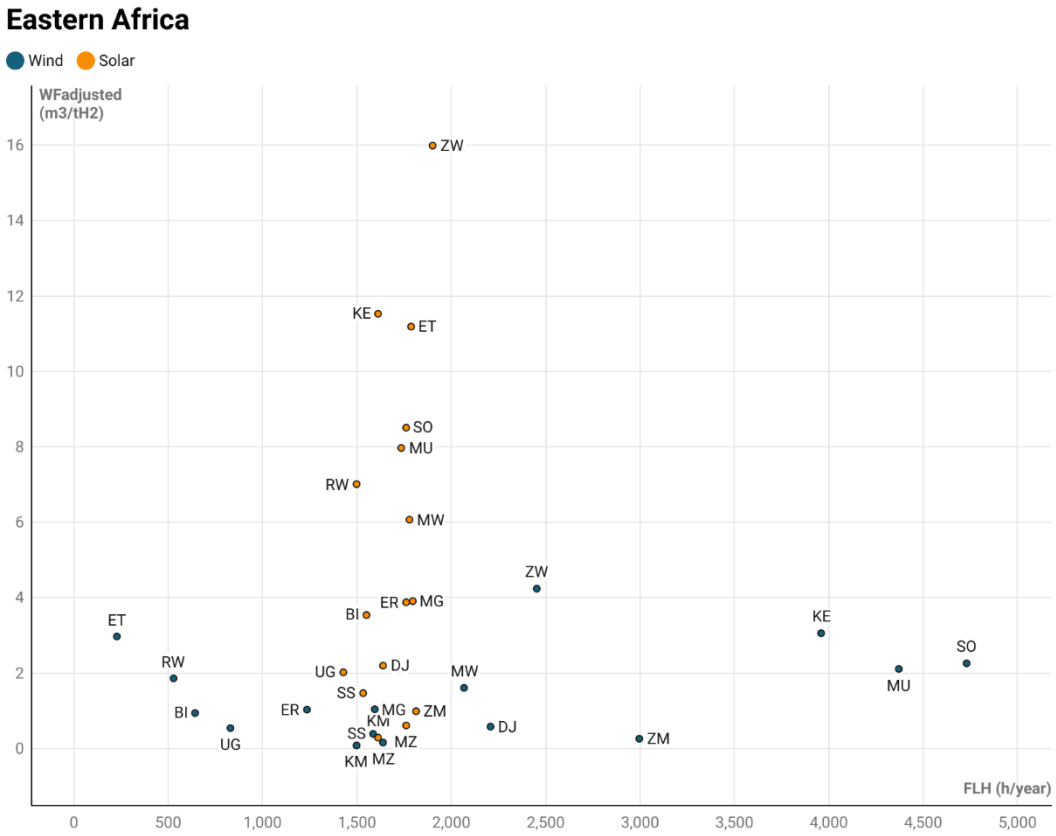

Figure 24: FLH vs $WF_{adjusted}$ in Eastern Africa

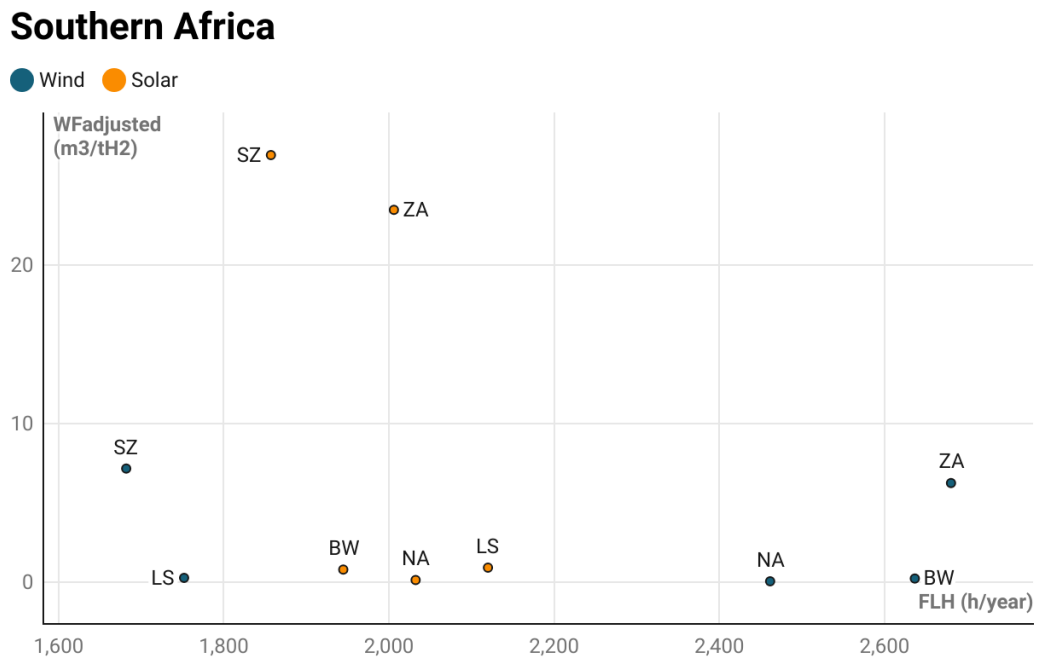

Figure 25: FLH vs $WF_{adjusted}$ in Southern Africa

Table 4 presents the most suitable energy source to power the hydrogen production in African countries, and this analysis is solely based on the $WF_{adjusted}$, FLH parameters and the decision criteria mentioned in section 3.3. Also, for this analysis, only solar and wind technologies were considered. Due to the WSI data unavailability for Republic of the Congo, Ivory Coast, Seychelles and Tanzania, those countries were not used in this analysis.

Table 4: Most suitable energy source to power the hydrogen production in African countries

Country	Most suitable energy source to power the hydrogen production
Algeria	Wind
Angola	Solar
Benin	Wind
Botswana	Wind
Burkina Faso	Wind
Burundi	Solar
Cabo Verde	Wind
Cameroon	solar
Central African Republic	Solar
Chad	Wind
Comoros	Wind
Democratic Republic of the Congo	Solar
Republic of the Congo	-
Djibouti	Wind
Egypt	Wind
Equatorial Guinea	Solar
Eritrea	Solar
Eswatini	Wind
Ethiopia	Solar-Wind hybrid
Gabon	Solar
Gambia	Wind
Ghana	Wind

Guinea	Solar
Guinea-Bissau	Wind
Ivory Coast	-
Kenya	Wind
Lesotho	Wind
Liberia	Solar
Libya	Wind
Madagascar	Wind
Malawi	Wind
Mali	Wind
Mauritania	Wind
Mauritius	Wind
Morocco	Wind
Mozambique	Wind
Namibia	Wind
Niger	Wind
Nigeria	Wind
Rwanda	Solar-Wind hybrid
Sao Tome and Principe	Wind
Senegal	Wind
Seychelles	-
Sierra Leone	Solar
Somalia	Wind
South Africa	Wind
South Sudan	Wind
Sudan	Wind
Tanzania	-
Togo	Wind
Tunisia	Wind

Uganda	Solar
Zambia	Wind
Zimbabwe	Wind

According to these results, the most suitable energy source for most of the African countries is wind energy; in powering hydrogen production.

4.4 Social implications of green hydrogen production

The results received for the questionnaire are mentioned here under each section. Also the literature results needed for the triangular analysis is described here.

4.4.1 General awareness of green hydrogen

Section 1 in the survey focused on the general awareness of green hydrogen. The survey angle in this section was about familiarity, positivity, importance and promising applications. Figures 26, 27, 28, and 29 show the summary of the responses received from the survey, under section 1, by 8 respondents.

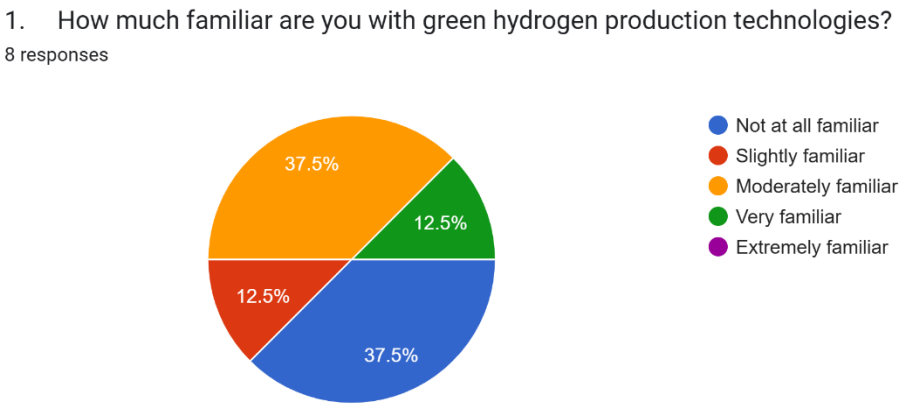

Figure 26: Familiarity with green hydrogen production technologies in Africa

2. In general, how would you describe your idea towards green hydrogen production in Africa?

8 responses

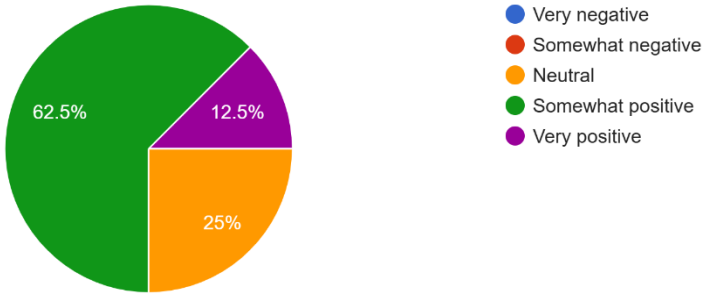

Figure 27: Positivity towards green hydrogen production in Africa

3. How important do you think green hydrogen will be for Africa's future energy targets?

8 responses

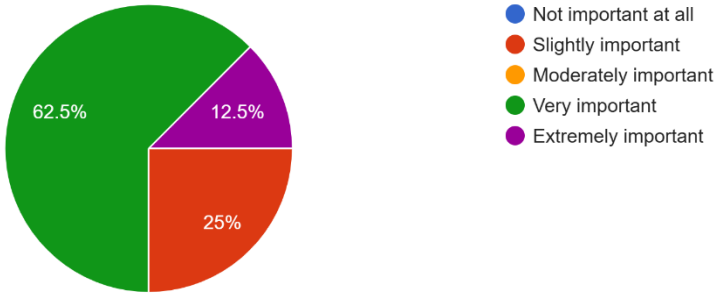

Figure 28: Importance of green hydrogen in Africa

4. What do you see as the most promising application of green hydrogen in Africa? (Select up to 3)

8 responses

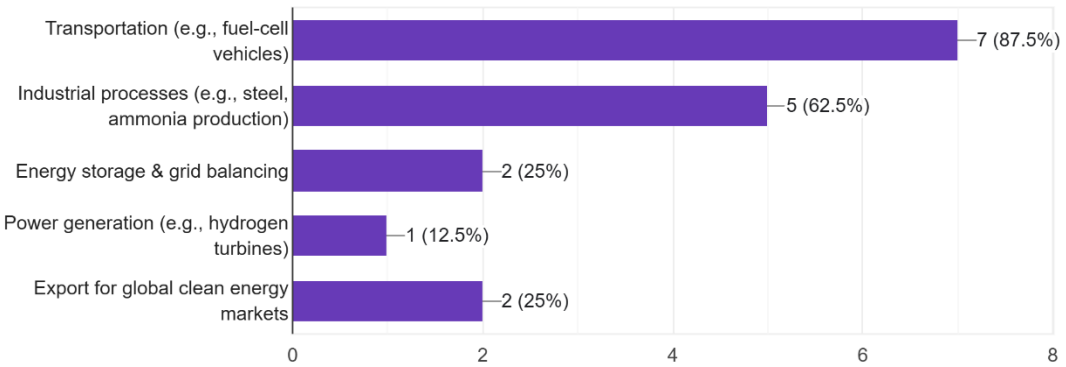

Figure 29: Promising applications of green hydrogen in Africa

According to the literature review, in African/ global south contexts, green hydrogen is often not familiar within the general community; this affects the awareness and understanding. Also, public awareness and acceptance mostly depend on clear communication and the noticeable local benefits. Therefore, a lack of knowledge and awareness is a barrier (Gevaert, et al., 2022). Although the younger generation offers a youthful workforce, they have very little knowledge about renewable energy and hydrogen production. Therefore, skills and gaps reduce the familiarity (Agyekum, 2024).

Most emphasized applications of green hydrogen expected in Africa are transportation (fuel cell vehicles), industrial feedstocks, energy storage, energy generation, and exports (Imasiku, et al., 2021). Also, the production of green chemicals/ reagents, the production of green steel, and green iron are applications of green hydrogen. Also, green hydrogen serves food security as it could expand production and remove the issues connected with fossil fuel usage in food production (Hamukoshi, et al., 2022).

4.4.2 Water use and sustainability concerns

Section 2 of the survey focused on water use and sustainability concerns. The survey angle was about the level of concern, preferred sources and balancing the uses. Figure 30, Figure 31, Figure 32 show the summary of the responses received for the survey under section 2, by 8 respondents.

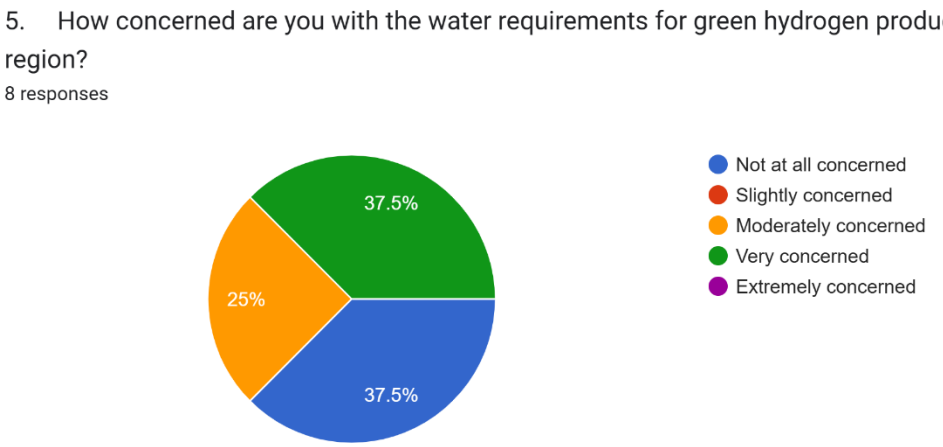

Figure 30: Level of concern about the water requirements

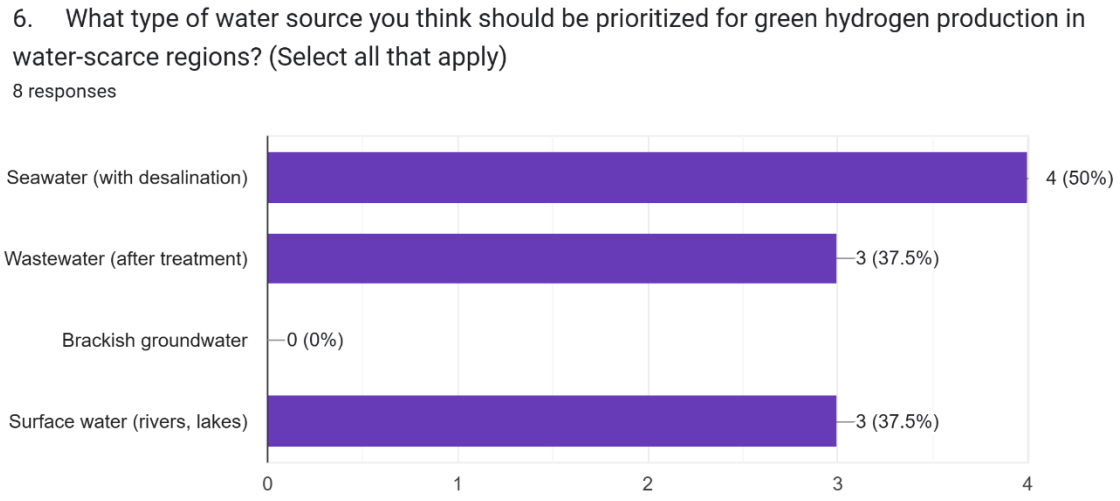

Figure 31: Preferred source of water for green hydrogen production

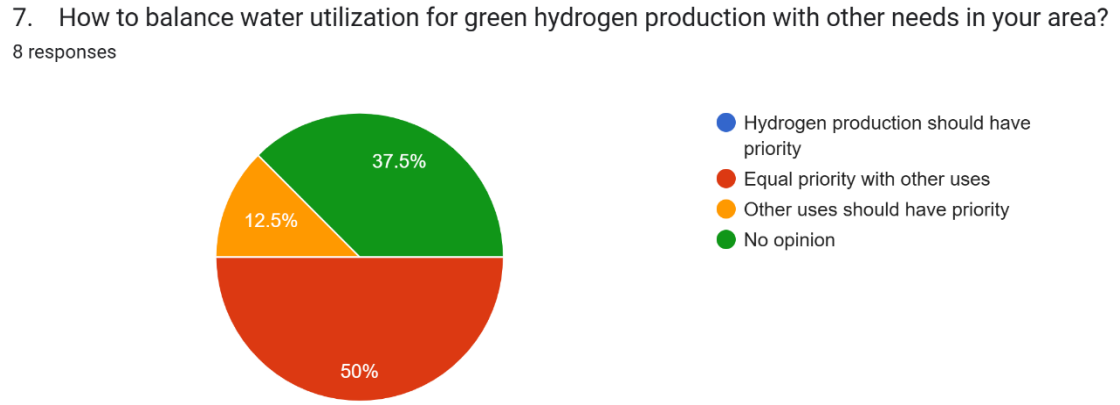

Figure 32: Balancing the water use for green hydrogen production with other uses

According to the literature, Electrolysis takes approximately 9 litres of water to yield 1 kg of hydrogen (Madsen, 2022). Most of the regions in Africa, such as sub-Saharan Africa, Madagascar, South Africa, Namibia and many others are water-stressed countries. Therefore, converting freshwater to hydrogen could worsen the water scarcity (Chigbu & Eze, 2023). Although desalination is used as a solution for the water scarcity, it also has issues such as, high energy requirement, release of a toxic hypersaline discharge (Chigbu & Eze, 2023). Recycling of wastewater and desalination are widely suggested to avoid conflicts

with human uses (Uzoagba, et al., 2025). Imasiku et al. show the need for logical policy frameworks and integration of hydrogen into long-term energy plans (Imasiku, et al., 2021). If water and energy sector policies are not connected well, it will create competition between the hydrogen and water sectors (Komorowski & Grzywacz, 2024).

4.4.3 Social and Economic impacts

Section 3 of the survey was focused on the social and economic impacts. The survey angle was about possible benefits, risks and fairness mechanisms. Figure 33, Figure 34 and Figure 35 show the summary of the responses received for the survey under section 3, by 8 respondents.

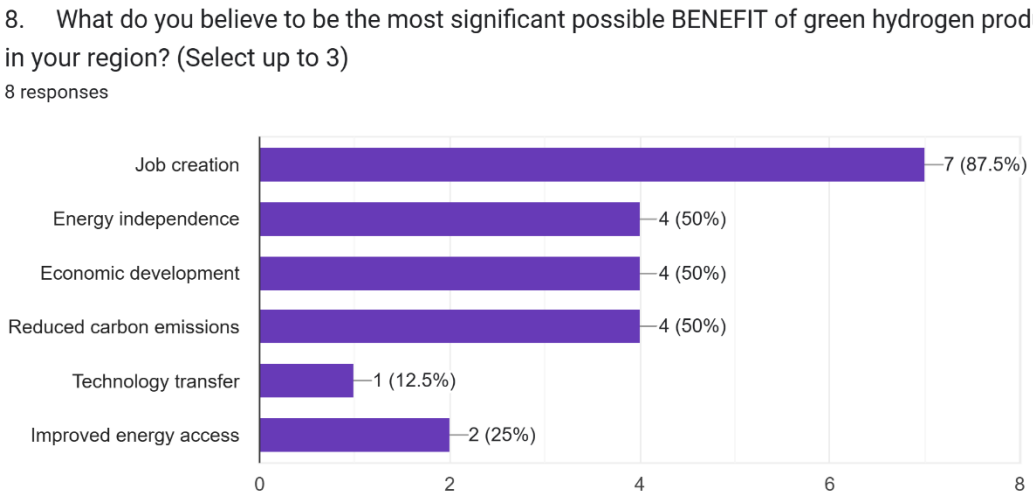

Figure 33: Possible benefits of green hydrogen production in Africa

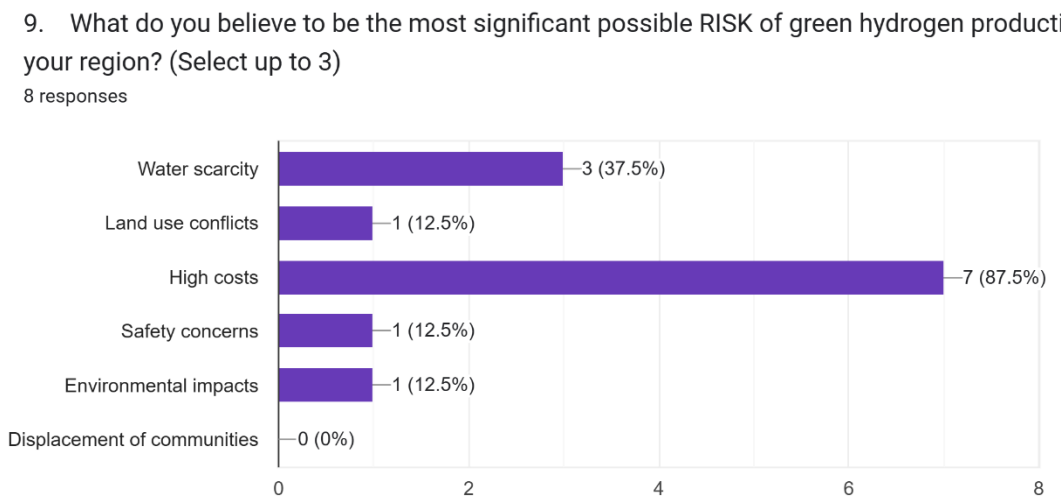

Figure 34: Possible risks of green hydrogen production in Africa

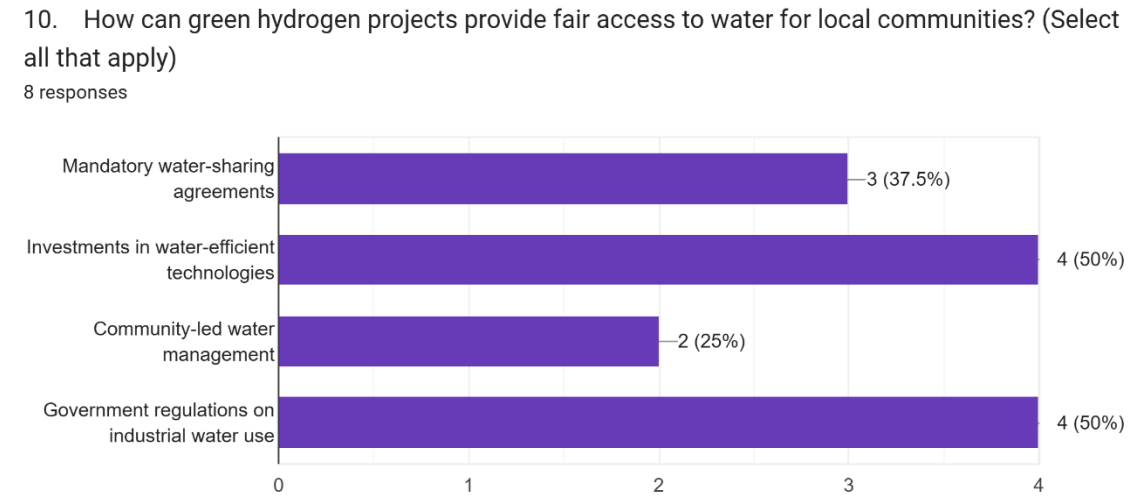

Figure 35: Fairness mechanisms of water by green hydrogen projects

According to the literature, green hydrogen can create jobs in the fields of construction, operation and manufacturing (power to X). Therefore, economic benefits play a significant part in developing the social well-being and infrastructure in the area (Hamukoshi, et al., 2022). Countries such as Namibia, South Africa, Morocco, Egypt see hydrogen exports as main economic drivers as they have the potential to export hydrogen to Europe countries and due to the availability of national policy practices and also the international collaborations. Green hydrogen presents an opportunity for African nations to promote

energy self-sufficiency, enhance sustainable economic development, enable low-carbon industrialization and realize the rising energy need of the continent (Komorowski & Grzywacz, 2024).

The study of Agyekum, (2024), mentioned some opportunities for the development of hydrogen production in Africa. Those include access to the EU market for exportation (20.90%), huge amount of renewable energy resources (34.88%), young population (13.95%), alignment with agenda 2063 (9.3%), and potential ammonia production (20.9%). From these opportunities, availability of renewable energy resources was the most significant opportunity for hydrogen energy development in the region (Agyekum, 2024).

The study also emphasizes significant barriers that are likely to slow down development. They are the high costs of hydrogen (11.78%), resistance to change (8.82%), corruption within the energy sector (4.52%), land access issues (7.06%), political instability and insecurity in some areas (11.76%), poor skills and training (11.76%), poor infrastructure and finances (15.38%), and absence of appropriate regulatory and legal framework (28.95%) (Agyekum, 2024).

In the areas where there are abundant renewable energy sources, they also face issues due to water stress in those areas. In 2020, around 187 million people in Sub-Saharan Africa had issues in accessing safe drinking water. Also, as the green hydrogen production mainly target exporting to EU countries, the African regions face injustice as the local demand is not met (Komorowski & Grzywacz, 2024). Community led management, water efficient technologies and regulations are recommended as fair mechanisms, such as Decree No. 2010-822 of 31 December 2010 took the center of attention on the development of water and sanitation and electric power plans (Imasiku, et al., 2021).

4.4.4 Policy and sustainable development alignment

Section 4 of the survey was focused on the policy and sustainable development alignment. The survey angle was about SDGs linked to hydrogen and suggested policies. Figure 36 shows the summary of the responses received for the survey under the section 4, by 8 respondents.

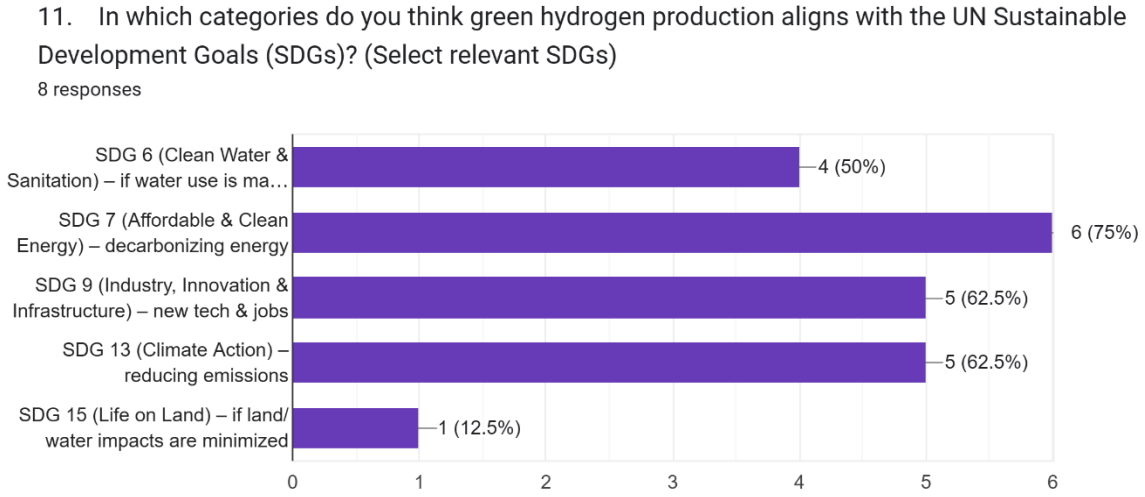

Figure 36: SDGs linked to hydrogen production in Africa

The 12th question of the survey was an open question, which was about the policies or regulations required to ensure sustainable use of water for green hydrogen production. Only a few responses were received, and their suggestions were as follows: regulations that empower stakeholders onsite are needed, communities must be part of the decision makers to ensure fairness and local content, the water source for new green hydrogen projects cannot be from currently available production sources, all green hydrogen projects should get water from desalination, ideally.

According to Imasiku et al. (2021), green hydrogen production has close associations with several of the Sustainable Development Goals. In the case of SDG 6 (Clean water and sanitation), hydrogen technologies would enable coastal nations to desalinate, increasing access to agriculture and domestic water. Also, it directly supports SDG 7 (affordable and clean energy) by supplying a clean alternative to fossil fuels based on renewable energy and potentially making energy more accessible in Africa. SDG 9 connects with hydrogen production via the huge market requiring new pipelines, storage tanks, transport systems and industrial applications which support sustainable industrialization and innovation. Hydrogen also supports SDG 13 (climate action) as it reduces greenhouse gas emissions and supports decarbonizing power, transport and industries. Also, hydrogen production connects with SDG 15 (life on land) by reducing environmentally caused degradation due to fossil fuels, sustainable resource management, and by helping to protect biodiversity. Hydrogen production also connects indirectly with other SDGs, such as SDG 2 (zero hunger) through

green ammonia-based fertilizer production and SDG 8 (decent work and economic growth) through employment opportunities and exportation in the hydrogen value chain (Imasiku, et al., 2021).

Most of the member states of the Southern African Development Community (SADC) countries lack hydrogen-specific policies as the prevailing renewable energy policies in SADC countries have neglected hydrogen in their framework. Policy amendments to fit in with the green hydrogen will provide strength to set up a sustainable market for hydrogen production by promoting decarbonization (Hamukoshi, et al., 2022).

The policy recommendations provided in the literature can be described as follows: Imasiku et al. (2021) identify some of the policies to apply in Southern African countries to speed up towards a hydrogen economy. They recommend applying hydrogen in national, regional and local long-term energy plans, expecting to provide clear pathways to sectors such as refineries, chemicals, iron and steel, transport, infrastructure, and energy storage. To initiate a sustainable market, governments are trying to induce commercial demand for green hydrogen by identifying the issues of fossil fuel reliance, widening the supply chain, and making carbon-intensive energy sources less competitive. As private enterprises are characterized by high risks of entry at the deployment phase, authors advocate risk-sharing schemes, incentives, concessional loans, tax credits, and rewards to encourage investment. The R&D also needs to be financed by the public financial institutions to reduce costs and increase the efficiencies of electrolyzers, fuel cells, and desalination technologies in coastal states. Imasiku et al. (2021) also suggests the elimination of regulatory barriers and making standards easier through clear licensing and extensive stakeholder participation. It also emphasizes the importance of greater international cooperation to enable bilateral partnerships, knowledge sharing, and the adoption of the best applications. Finally, it suggests the development of existing infrastructure by transforming seaports to core points of hydrogen, retrofitting coal and natural gas infrastructure, building hydrogen ready shipping lanes and freight corridors for regional use and international trade (Imasiku, et al., 2021).

4.4.5 Participation and trust

Section 5 of the survey was focused on the participation and trust. The survey angle was about preferred participation methods and trust in actors. Figure 37 and Figure 38 show the summary of the responses received for the survey under section 5, by 8 respondents.

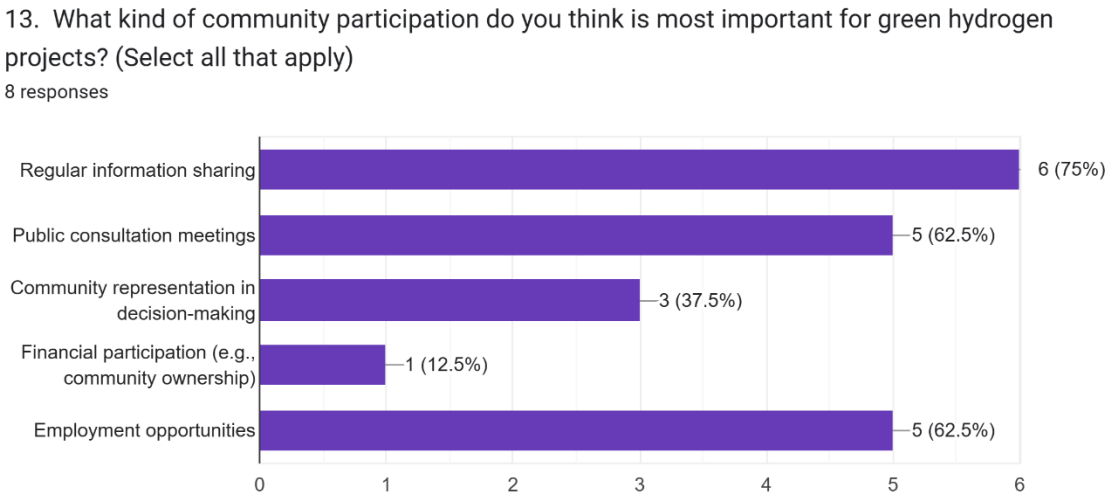

Figure 37: Preferred community participation method in green hydrogen projects

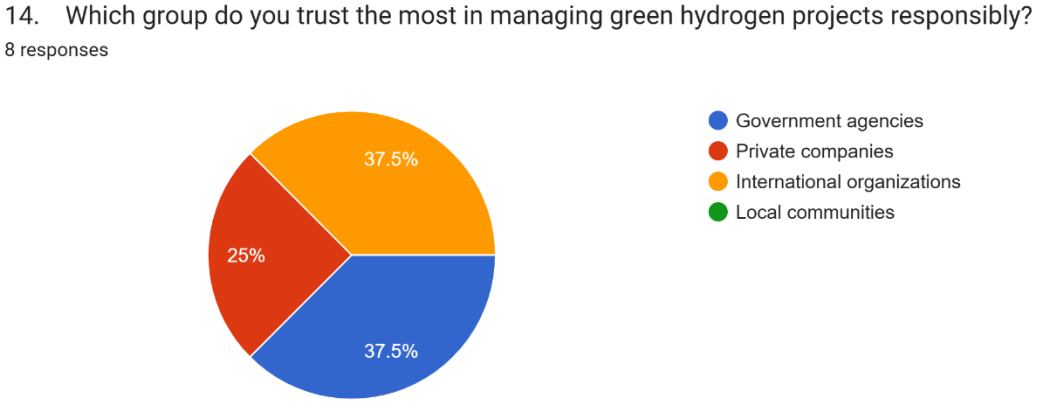

Figure 38: Trust of the community over the actors of the green hydrogen projects

According to the literature, community participation is essential as social acceptance increases with the benefit sharing, community ownership, and consultations (Gevaert, et al.,

2022). Creation of job opportunities across the value chain is also considered as a major community participation method. The African hydrogen partnership has identified 6 potential landing zones for the development of green hydrogen, namely, Nigeria-Ghana, Morocco, Tanzania-Rwanda-Kenya, Egypt, Ethiopia-Djibouti, and South Africa. Project development in these areas is expected to yield significant socio-economic benefits; for example, each gigawatt of installed power-to-X (P2X) capacity is approximated to create 300 to 700 jobs along the value chain (Agyekum, 2024).

Moreover, trust requires strong governance, such as standards, policies, certifications, and mechanisms for resolving issues. They create confidence in governments, businesses, and societies (Chigbu & Eze, 2023).

Section 6 of the survey was about demographic information. Most of the respondents were from Kenya and Nigeria. 50% of the respondents were from the academia/research field. 25% of the respondents were from the energy production field. 12.5% of the respondents were from the government/policy field, and the remaining were from NGO/community organizations. 50% were not involved in hydrogen-related activities yet, and 25% were involved in for more than 5 years. 12.5% were involved in hydrogen-related activities between 1-3 years, and the remaining were involved in less than 1 year.

5 Discussion

The results of the volumetric water footprint, water stress-adjusted water footprint, solar FLH vs wind FLH (interpretation of the most suitable power source to power the green hydrogen production in each country), and the triangular analysis for the questionnaire results were further discussed in this section.

5.1 Volumetric Water Footprint

According to the calculations in this study, it is shown that the volumetric water footprint of hydrogen production, which is powered by solar energy, is higher than which is powered by wind energy.

Although solar PV systems consume a low amount of water operationally, most of their water footprint comes from the manufacturing stage, particularly from processes such as polysilicon and wafer production. These are water-intensive, involving the processing steps of manufacturing, such as cleaning, and chemical processing. This upstream water footprint is significantly larger than wind, which has much lower water demand in manufacturing (SustainabilityDirectory, 2025).

In the operational process, solar PV systems don't require cooling, but they require occasional water for panel cleaning, mainly in dry and dusty climates. If the cleaning does not happen in the operational period, dust, pollen, dirt, and other debris will minimize the efficiency of the PV system. Therefore, some water usage is unavoidable in maintaining the performance of solar PV systems. Still, this operational water demand remains lower than the manufacturing level water use (SustainabilityDirectory, 2025).

Wind turbines are more water efficient than solar PV, as there is no considerable water usage during operation, and their manufacturing water footprint is also significantly lower than solar PV. This makes wind one of the energy sources that has the lowest water footprint across its lifecycle (Cleveland, 2025)

In this study, the volumetric water footprint of hydrogen production is split into operation and construction stages. The operation category includes the direct process water demand of electrolysis (W) which is 9 m3/tH2 in addition to the operation stage water of the electricity supply, for both solar powered and wind powered hydrogen production. Although, wind electricity has a very small water footprint, the fixed electrolysis water (W) dominates the wind pathway's operation share. The 98.3% operation share of the volumetric water footprint of wind powered hydrogen production therefore reflects electrolysis water, not water use by the wind turbines themselves only.

Also, the volumetric water footprint results show that solar powered hydrogen uses almost four times more water compared to wind powered hydrogen. This means that, especially in those African countries that face scarce water resources, wind-based hydrogen production is more compatible with SDG 6 on water use efficiency (SDG 6.4). Both options are based on renewable electricity and thus contribute to SDG 7, enabling low carbon hydrogen; however, this is accomplished with a lower water burden via wind power.

5.2 Water Stress Adjusted Water Footprint

The water stress-adjusted water footprint adjusts the water use by country-level water stress. It highlights the strong spatial imbalance of the water stress on the continent. Countries with critical water stress in North Africa include Libya, Algeria, Egypt, and Sudan, while they have the highest adjusted water footprints. Countries with medium to high stress include Cabo Verde, Eswatini, Morocco, South Africa, Tunisia, while Ethiopia, Kenya, Somalia, and Zimbabwe show low water stress. Countries such as, Central African Republic, Democratic Republic of the Congo, Equatorial Guinea, Gabon, Liberia, Namibia, Sierra Leone, and some other countries show no water stress according to the categories presented by FAO (2021). Also, a place can have a lower volumetric water footprint, yet a higher stress-adjusted water footprint, if the local water scarcity is high, such as in the case of Libya.

The choice of the technology matters when calculating the water stress-adjusted water footprint, as solar-powered hydrogen production has a much higher water footprint, about three-quarters on average, than wind-powered hydrogen production. It is important to note that, since solar panels are generally manufactured outside of African countries, their construction related water footprint would usually occur outside of the country (imported country); but in this study it was assumed that panel construction occurred within each assessed country, and these construction values were included when calculating the water footprint.

For four countries, the WSI data were not found in this study: the Republic of the Congo, the Ivory Coast, Seychelles, and Tanzania, which it will affect the interpretations. Also, the use of national-scale WSI can mask the sub-national variability of water stress. In the overall view, it is better to focus on the countries with critical water stress first and to prioritize the efficiency efforts, regional planning, and mitigation. Also, shifting from solar-powered hydrogen production to wind-powered hydrogen production can efficiently reduce the water stress by a considerable amount.

The $WF_{adjusted}$ reveal that for those countries where the WSI values are high; the effective water impact of hydrogen production becomes very high, and thus there is likely to be a conflict with SDG 6 on water security unless the projects are carefully managed. On the other hand, $WF_{adjusted}$ is low for countries with low WSI values, meaning green hydrogen in such places would contribute to SDG 7 (clean energy) with limited impacts on SDG 6.

Summed up, findings from the volumetric water footprint and $WF_{adjusted}$ data provide evidence that aligning green hydrogen with both SDG 6 (mainly SDG 6.4.2 – level of water stress) and SDG 7 in Africa requires a focus on wind power and a preference for low water stress locations.

5.3 Interpretation of the most suitable power source to power the green hydrogen production in each country by comparing $WF_{adjusted}$ and FLH

When comparing the FLH of solar and wind power in each country with the scarcity-adjusted water footprint of solar-powered hydrogen production and wind-powered hydrogen production, it is possible to have an idea about which power method will be most suitable for each area. Although the wind-powered hydrogen production is the best option for water-scarce areas, as it has a lower water footprint, the FLH can affect it. For this comparison, the assumptions mentioned in the materials and methods section were used.

For Algeria, Botswana, Burkina Faso, Cabo Verde, Chad, Djibouti, Egypt, Kenya, Libya, Mali, Mauritania, Mauritius, Morocco, Niger, Senegal, Somalia, South Africa, Sudan, Tunisia, Zambia and Zimbabwe the wind FLH is much higher (>>20%) than the solar FLH (due to the higher wind turbine CF), as well as the wind powered hydrogen production has the better water footprint. Therefore, wind energy is the most suitable to power the hydrogen production in those countries.

For Benin, Comoros, Eswatini, Gambia, Ghana, Guinea-Bissau, Lesotho, Madagascar, Malawi, Mozambique, Namibia, Nigeria, Sao Tome and Principe, South Sudan, and Togo have a relative difference of ± 0%-20% between the wind FLH and solar FLH. Therefore, the determining factor is the $WF_{adjusted}$. As the scarcity-adjusted water footprint for wind-powered hydrogen production is lower than solar solar-powered hydrogen production; wind energy is the most suitable energy source for those countries.

Angola, Burundi, Cameroon, Central African Republic, Democratic Republic of Congo, Equatorial Guinea, Eritrea, Gabon, Guinea, Liberia, Sierra Leone, and Uganda have a >>20% higher solar FLH than wind FLH, and also the $WF_{adjusted}$ of solar powered hydrogen production is not higher than 5 m^3/tH_2 for those countries. Therefore, solar-powered hydrogen production is recommended according to the assumptions made in this study.

For Ethiopia and Rwanda, the solar FLH is higher than the wind FLH. But the $WF_{adjusted}$ for solar-powered hydrogen production is greater than 5 m^3/tH_2. Therefore, according to the assumptions made in the study, a single technology is not forced. Both solar and wind power can be combined when powering the hydrogen production. It will reduce the weighted water footprint while sustaining high yield. Study by Staab and Dickinson (2023) shows that hybrid wind-solar generation increases the electrolyser usage efficiency by 10% when compared with the normal wind power generation system (Staab & Dickinson, 2023).

These findings also align with key SDGs by minimizing water stress and analysing energy yield. Countries with high wind FLH and low WFadjusted can produce hydrogen efficiently with minimal water impact, strongly supporting SDG 6 (clean water and sanitation); SDG 6.4 on water use efficiency, SDG 7 (clean energy); SDG 7.2 (renewable energy) and SDG 13 (climate action) enabling low carbon hydrogen without increasing pressure on scarce water resources.

5.4 Social Implications of Green Hydrogen Production

The triangulated survey findings (n=8), in combination with the literature review, were used to interpret the idea of society towards green hydrogen production in Africa. As half of the respondents work in academia/ research, a quarter in energy production, and lower percentages in government/ NGO, with most respondents being Kenya and Nigeria-based, these results can be identified as informed stakeholder opinion rather than general public opinion.

5.4.1 General awareness of green hydrogen

Survey responses showed a good level of awareness (around 50%) and high positivity (around 75%) towards the roles and applications of green hydrogen (transport, industrial feedstocks, storage, exports and etc.). This is only to be expected from a sample mainly drawn from sectors already close to technology and research. By contrast, the literature refers to low familiarity at the community level in most of the African/ Global South contexts, with acceptance being strongly governed by good communication and visible local benefits, and by youth skills gaps being filled. The difference between the survey sample and the literature

review reflects the expert composition of the sample. The issue is in the mechanisms that generate acceptance (communication, noticeable benefits, skills development).

Therefore, programmatic investments in awareness, vocational training, and targeted communication are compulsory for a broad social acceptance even when expert stakeholders are already on board.

5.4.2 Water use and sustainability concerns

Water is the main issue according to section 2 of the survey, which tested the levels of concern, source preferences and trade-off choices. More than half of the respondents were concerned about the water requirements (around 62.5%). Also, seawater with desalination was the most-preferred water source (around 50%) for green hydrogen production in water-scarce regions. Also, the respondents expressed that equal priority should be given for water utilization with other uses.

Literature findings quantify the constraint; electrolysis needs 9 litre of water per kg H_2 and notes that a huge part of Africa is already water-stressed, and additional freshwater withdrawals further risk the scarcity. While desalination can decouple projects from freshwater in inland locations, it demands energy costs and hypersaline brine risks; accordingly, wastewater recycling and /or desalination are recommended with the aim of avoiding conflict with human and agricultural needs, but only when paired with low-carbon power and stable brine disposal. Policy evidence also warns that poor water energy governance will create zero-sum competition between hydrogen and fundamental uses, which means the gain of one side is exactly matched by the loss of another side.

Therefore, designing projects to be water-neutral, avoiding new intakes in stressed basins, focusing on treated wastewater and/ or renewable energy-powered desalination, and including brine controls and integrated water-energy permitting from the start can be identified as solutions for sustainable water use in hydrogen production.

5.4.3 Social and Economic impacts

According to section 3, the respondents showed job creation (87.5%) as the most promising benefit of green hydrogen production. Also, energy independence, economic development, and reduced carbon emissions were also accepted by the respondents as noticeable benefits. High cost (87.5% of the respondents) was identified as the most significant risk of hydrogen production and water scarcity (37.5% of the respondents) was also mentioned. The respondents showed that investments in water efficient technologies (50%) and government regulations on industrial water use (50%), mandatory water sharing agreements (37.5), and community-led water management (25%) as the convenient fairness mechanisms of water by green hydrogen projects.

Triangulation with literature, therefore, supports a twofold message: the economic opportunity is real, but its social acceptability depends on the distribution of costs and benefits at the local level. The emphasis given by respondents on inclusion and equity is reflected in the literature's demand for community-level impartiality. As implications government can tie investment approval to benefit sharing and equity protection, community benefit agreements for jobs and training, and water equity protocols for drought or scarcity periods can be mentioned.

5.4.4 Policy and sustainable development alignment

Section 4 responses linked hydrogen to SDG 6, 7, 9, 13, 15, with most of the respondents voted for SDG 7: affordable and clean energy (75%). The open questions specifically called for water sustainability policy that empowers on-site stakeholders and draws in communities as decision makers, with the preference for desalination to avoid pressure on current supplies.

Triangulation with literature indicates tight alignment between stakeholder perception and policy proposals and the gap is implementation speed and instrument development against market force.

The implication is a two-track approach: firstly, a fast-tracking procedural clarity which is integrated water energy permitting, community approval and water source regulations

(desalination/ wastewater). Secondly, structural market development which is demand-led market structure, proper financing and research and development. These will help realize SDG benefits without creating water conflict.

5.4.5 Participation and trust

According to section 5, regular information sharing (75%), public consultation meetings (62.5%), and employment opportunities (62.5%) can be found as most important community participation methods for green hydrogen production. Also, government agencies (37.5%) and international organizations (37.5%) are mostly trusted by the respondents in managing hydrogen projects.

Triangulating these results with the literature, the opportunity is clear but depends on some factors. Trust is based on reliability, compulsory mechanisms, not just targets. In practice, agreements must be conditioned upon community benefit commitments, local hiring and training targets, routes to co-ownership, independent monitoring/ certification with open criticism channels. So, voice, value and verifiability are established and will be constant throughout the project.

6 Conclusion

This thesis was intended to quantify the water footprint of green hydrogen production, identify the impacts related to water scarcity, identify country specific low stress renewable energy options to power hydrogen production and assess social implications of water use for green hydrogen, particularly in water stressed regions. The findings relate directly to three research questions concerning the water footprint of green hydrogen production, its alignment with water and energy related SDGs, and the social implications of increased water use in vulnerable communities. To respond the first research question, two methods were applied; the water footprint method on a volumetric basis and the water stress adjusted water footprint method to present complete and regionally based estimates of water use for solar and wind powered hydrogen production in Africa. To respond the second research question, water footprint, FLH and survey triangulation with literature were used. To address

the third research question, a survey-based analysis of stakeholder perceptions, issues and priorities; triangulated with literature data was used.

The results show that the volumetric water footprint of solar-powered hydrogen production (34.7 m^3/tH_2) is far higher than wind-powered hydrogen production (9.2 m^3/tH_2), consistent with the literature that justifies the PV panel manufacturing stage as water-intensive due to polysilicon and wafer production. According to the breakdown, 57.7% of the water footprint of solar powered hydrogen production is for the construction, while 42.3% is for the operation. 1.7% of the water footprint of wind powered hydrogen production is for construction, while 98.3% is for operation, which means solar dominates by construction and wind dominates by operation. These results demonstrates that the water footprint of green hydrogen production is not a fixed value but strongly depend on the technology used, while wind showing roughly one-quarter of the water demand of solar powered hydrogen production. Upon consideration of the country-level water stress index, high spatial variety becomes visible. Libya (8.1714), Algeria (1.4481), Egypt (1.4117) and Sudan (1.1866) appear with the highest $WF_{adjusted}$ values, indicating where hydrogen production would apply a huge pressure on water resources. The study also shows cases where low volumetric water usage is still connected to high scarcity-adjusted water footprint, highlighting the significance of integrating local water scarcity into planning rather than depending totally on volumetric water footprints. These finding align green hydrogen production with SDG 6 (clean water and sanitation); SDG 6.4 (water use efficiency) and SDG 6.4.2 (level of water stress). Also, the $WF_{adjusted}$ to country-level renewable energy FLHs made it possible to establish the most suitable energy source to power the hydrogen production in each country. The choice of wind power is best for nearly 2/3 of the African countries due to both its lower adjusted water footprint and higher FLH, whereas solar power is best suited mostly for Central and Western African nations with intense solar resources. In Ethiopia and Rwanda, a solar-wind hybrid approach is recommended to balance the energy and water efficiency with optimal utilization of the electrolyser. These findings align green hydrogen production with SDG 7 (clean energy); SDG 7.2 (renewable energy) and SDG 13 (climate action).

The social implications survey part in this study adds richness to the output as well. Stakeholder survey response (n=8) revealed high positivity but modest awareness for green hydrogen, with the most significant benefits mentioned as creating employment, energy independence, economic development and carbon emission reduction. However, high costs

and water shortage were identified as major threats, and the responses consistently emphasized the significance of desalination, wastewater treatment, and reuse and regulatory approaches to fair water allocation. The perspectives were justified in literature triangulation, quoting that while Africa offers huge potential to become a leading exporter of hydrogen, securing social acceptance requires community participation, transparent benefit sharing, and integration of water energy governance. The respondents closely linked green hydrogen production with SDG 7 (affordable and clean energy) and also with SDG 6 (clean water and sanitation), SDG 9 (Industry, Innovation and Infrastructure), SDG 13 (climate action), and SDG 15 (life on land), reasoning that green hydrogen can be used for climate action, industrial transition and access to improved water if desalination is responsibly practiced. The policy implications are clear; governments must speed up hydrogen-specific regulations, integrate water energy licensing, and provide incentives, funding, and training programs that enable equal access and speed up the deployment without contributing to water conflicts.

This thesis adds value to multiple fields. The findings can be useful for energy planners and policy makers, pointing out that only technical feasibility is insufficient to ensure sustainable deployment. Also, the need to integrate water availability and water stress into hydrogen siting and technology selection is highlighted. The social acceptance and equity considerations must be addressed in infrastructure planning.

In spite of this, the thesis has limitations. Application of national scale water stress indices potentially can mask sub national heterogeneity, and data gaps for four countries (Republic of the Congo, Ivory Coast, Seychelles and Tanzania) limit the full comparability. Another limitation in this thesis is the assumption that solar panel construction occurs within each assessed country, even though most of the solar panels are imported from other countries. This can make an overestimation of the $WF_{adjusted}$ associated with solar powered hydrogen production. The small, expert-biased sample (n=8), majorly concentrated in Kenya and Nigeria, is appropriate to surfacing informed signals but not to estimate population level ideas or generalization across Africa. Despite value-labelled graphs, the small n and question level aggregation limit the fine-grained statistics. Results are thus descriptive and hypothesis generating in the readers' minds.

Future research must consist of sub national WSI data to better identify regional variability, rather than depending on national averages. Updated data sets in the future will help to cover

the current data gaps. Also, future analysis could separate domestic and imported construction water footprints, allowing the construction related water use of solar panels to be allocated to the actual production country rather than assuming to occur locally. Carrying out larger scale, stratified public opinion surveys by regions; coupling this with community workshops and case studies in targeted landing zones, carrying out longitudinal follow ups to track the changes as the projects are progressing, integrating the surveys works with government audit data of water-energy licensing can be the best options for future research with more accurate results.

Lastly, this thesis demonstrates that coordination of green hydrogen production with African water facts and socio-economic necessities is possible and necessary. The move towards wind-powered or hybrid-powered hydrogen production in water-scarce countries, complemented with good governance frameworks and renewable-powered desalination, can minimize water issues and maximize energy security, climate action, and sustainable development. This study helps to build a fair roadmap for Africa's water-efficient hydrogen development.

References

1. 7newsMorocco, 2025. *Morocco accelerates green hydrogen ambitions with €30 million ammonia plant.* [Online] Available at: https://en.7news.ma/morocco-accelerates-green-hydrogen-ambitions-with-e30-million-ammonia-plant/ [Accessed 18 August 2025].

2. Agyekum, E. B., 2024. Is Africa ready for green hydrogen energy takeoff? - Amulti-criteria analysis approach to the opportunities and barriers of hydrogen production on the continent. *international journal of hydrogen energy,* Issue 49, pp. 219-233. Available at: https://doi.org/10.1016/j.ijhydene.2023.07.229

3. Barradas, S., 2023. *HySHiFT renewable hydrogen project, South Africa – update.* [Online] Available at: https://www.engineeringnews.co.za/article/hyshift-renewable-hydrogen-project-south-africa-update-2023-09-01 [Accessed 22 August 2025].

4. Bartell, J., 2024. *A first look at water demand for green hydrogen and concerns and opportunities with desalination,* s.l.: International PtX Hub.

5. Bhandari, R., 2022. Green hydrogen production potential in West Africa e Case of Niger. *Renewable Energy,* Issue 196, pp. 800-811. Available at: https://doi.org/10.1016/j.renene.2022.07.052

6. Brown, F. & Roberts , D., 2021. *Green, blue, brown: the colours of hydrogen explained.* [Online] Available at: https://www.csiro.au/en/news/all/articles/2021/may/green-blue-brown-hydrogen-explained [Accessed 09 September 2025].

7. Chigbu, U. E. & Eze, C. N., 2023. Green Hydrogen Production and Its Land Tenure Consequences in Africa: An Interpretive Review. *land,* Issue 12. Available at: https://doi.org/10.3390/land12091709

8. Cleveland, C., 2025. *What methods of electricity generation use the most water?*. [Online]
Available at: https://visualizingenergy.org/what-methods-of-electricity-generation-use-the-most-water
[Accessed 04 September 2025].

9. Dash, S. K., Chakraborty, S. & Elangovan, D., 2023. A Brief Review of Hydrogen Production Methods and Their Challenges. *energies,* 16(3). Available at: https://doi.org/10.3390/en16031141

10. Datawrapper, 2011. *Datawrapper (online data visualization platform).* [Online] Available at: https://www.datawrapper.de/
[Accessed 16 09 2025].

11. DOE, U. D. o. E., 2022. *Technical Targets for Liquid Alkaline Electrolysis.* [Online] Available at: https://www.energy.gov/eere/fuelcells/technical-targets-liquid-alkaline-electrolysis
[Accessed 09 September 2025].

12. Dokso, A., 2023. *Africa's First Large-Scale Green Hydrogen Project to Revolutionize Energy Landscape.* [Online] Available at: https://energynews.biz/africas-first-large-scale-green-hydrogen-project-to-revolutionize-energy-landscape/
[Accessed 18 August 2025].

13. Du, L. et al., 2024. Water scarcity footprint and water saving potential for large-scale green hydrogen generation: Evidence from coal-to-hydrogen substitution in China. *Science of the Total Environment,* Issue 940. Available at: https://doi.org/10.1016/j.scitotenv.2024.173589

14. Elgowainy, A. et al., 2015. *Life-Cycle Analysis of Water Consumption for Hydrogen Production,* s.l.: 2015 U.S. DOE Hydrogen and Fuel Cells Program and Vehicle Technologies Office Annual Merit Review and Peer Evaluation Meeting.

15. FAO, 2021. *Progress on level of water stress,* Rome: FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS AND UNITED NATIONS WATER. Available at: https://doi.org/10.4060/cb6241en

16. FAO, 2022. *AQUASTAT Dissemination System.* [Online] Available at: https://data.apps.fao.org/aquastat/?lang=en
[Accessed 25 09 2025].

17. Flourish , 2018. *Flourish (Online data visualization platform).* [Online] Available at: https://flourish.studio/
[Accessed 15 09 2025].

18. Franke, K., Garcia, J. F., Kleinschmitt, C. & Sensfuß , F., 2024. Assessing worldwide future potentials of renewable electricity generation: Installable capacity, full load hours and costs. *Renewable Energy,* Issue 226. Available at: https://doi.org/10.1016/j.renene.2024.120376

19. Gevaert, S., Pause, L., Cezne, E. & Otsuki, K., 2022. *Green Hydrogen in the Global South; A literature review.* s.l., Utrecht University. Available at: https://www.researchgate.net/publication/366809109

20. gh2namibia, 2022. *Daures Green Village.* [Online] Available at: http://gh2namibia.com/wp-content/uploads/2022/09/Daures-Green-Village.pdf
[Accessed 18 August 2025].

21. Gunawan, D., 2022. Unlocking the Potential of Hydrogen in Indonesia. In: H. Ardiansyah & P. Ekadewi, eds. *Indonesia post-pandemic outlook: Strategy towards net-zero emissions by 2060 from the renewables and carbon-neutral energy perspectives.* s.l.:Overseas Indonesian Student's Association Alliance & BRIN Publishing, pp. 209-235. Available at: DOI:10.55981/brin.562.c11

22. Hamukoshi, S. S., Mama, N., Shimanda, P. P. & Shafudah, N. H., 2022. An overview of the socio-economic impacts of the green hydrogen value chain in Southern Africa. *Journal of Energy in Southern Africa,* 33(3), pp. 12-21. Available at: https://doi.org/10.17159/2413-3051/2022/v33i3a12543

23. Hasan, E., Tarhule, A., Hong, Y. & III, B. M., 2019. Assessment of Physical Water Scarcity in Africa Using GRACE and TRMM Satellite Data. *Remote sensing,* Issue 11. Available at: https://doi.org/10.3390/rs11080904

24. HDF, 2022. *Swakopmund Renewstable.* [Online] Available at: https://www.renewstable-swakopmund.com/the-project [Accessed 18 August 2025].

25. Henriksen, M. S. et al., 2024. Tradeoffs in life cycle water use and greenhouse gas emissions of hydrogen production pathways. *international journal of hydrogen energy,* Issue 49, pp. 1221-1234. Available at: https://doi.org/10.1016/j.ijhydene.2023.08.079

26. HIVEENERGY, 2024. *Coega Green Ammonia Project.* [Online] Available at: https://www.hiveenergy.co.uk/clean-futures/green-hydrogen/coega-green-ammonia-project/ [Accessed 22 August 2025].

27. Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M. & Mekkonen, M. M., 2011. *The Water Footprint Assessment Manual,* London: Earthscan.

28. Hollands, C., 2021. *EnergyCapital&Power.* [Online] Available at: https://energycapitalpower.com/namibia-to-develop-first-ever-large-scale-green-hydrogen-project/ [Accessed 18 August 2025].

29. Hyphen, 2025. *Hyphen Hydrogen Energy Project Status Update.* [Online] Available at: https://hyphenafrica.com/hyphen-hydrogen-energy-project-status-update-2/# [Accessed 18 August 2025].

30. IEA, 2025. *Global hydrogen demand by sector in the Net Zero Scenario, 2020-2030.* [Online] Available at: https://www.iea.org/data-and-statistics/charts/global-hydrogen-demand-by-sector-in-the-net-zero-scenario-2020-2030-2 [Accessed 14 08 2025].

31. Imasiku, K., Farirai, F., Olwoch, J. & Agbo, S. N., 2021. A Policy Review of Green Hydrogen Economy in Southern Africa. *Sustainability,* Issue 13. Available at: https://doi.org/10.3390/su132313240

32. ISO 14046, 2014. *Environmental management — Water footprint — Principles, requirements and guidelines.* [Online] Available at: https://www.iso.org/standard/43263.html [Accessed 15 07 2025].

33. Komorowski, P. & Grzywacz, M., 2024. Green hydrogen in Africa: opportunities and limitations. *Journal of Management and Financial Sciences,* XVI(50), pp. 61-79.

34. Lin, N., Arzumanyan, M., Calzado, E. R. & Nicot, J. P., 2025. Water Requirements for Hydrogen Production: Assessing Future Demand and Impacts on Texas Water Resources. *Sustainability,* 17(2). Available at: https://doi.org/10.3390/su17020385

35. Madsen, H. T., 2022. *Water treatment for green hydrogen: what you need to know.* [Online]
Available at: https://hydrogentechworld.com/water-treatment-for-green-hydrogen-what-you-need-to-know?
[Accessed 25 05 2025].

36. Mekonnen, . M. M., Leenes, G. P. W. & Hoekstra, A. Y., 2015. The consumptive water footprint of electricity and heat: a global assessment. *Environmental Science Water Research & Technology,* 1(3), pp. 255-396. Available at: DOI: http://10.1039/c5ew00026b

37. Mika, L. et al., 2024. Seawater Treatment Technologies for Hydrogen Production by Electrolysis - A Review. *Energies,* Issue 17. Available at: https://doi.org/10.3390/en17246255

38. Ministry of Energy and Mineral Resources, 2024. *Technology ta forthe Indonesian power sector,* Jakarta: Directorate General of Electricity. Available at: https://gatrik.esdm.go.id/echnology-data-for-the-indonesian-power-sector-2024

39. NamibiaToday, 2025. *Namibia's Daures Village Pioneers Africa's First Net Zero Green Hydrogen and Farming Hub.* [Online]
Available at: https://namibiatoday.com/namibias-daures-village-pioneers-africas-first-net-zero-green-hydrogen-and-farming-hub/
[Accessed 18 August 2025].

40. Njovu, G., 2024. *OCP & Fortescue: hydrogen and ammonia production in Morocco.* [Online]
Available at: https://ammoniaenergy.org/articles/ocp-fortescue-hydrogen-and-ammonia-production-in-morocco/
[Accessed 18 August 2025].

41. NREL, 2025. *National Renewable Energy Laboratory - Capacity Factor.* [Online] Available at: https://samrepo.nrelcloud.org/help/mtp_capacity_factor.html
[Accessed 23 September 2025].

42. Olaitan, D., Bertagni, M. & Porporato, A., 2024. The water footprint of hydrogen production. *Science of the Total Environment,* Issue 927. Available at: https://doi.org/10.1016/j.scitotenv.2024.172384

43. Patel, G. H. et al., 2024. Climate change performance of hydrogen production based on life cycle assessment. *The Royal Society of Chemistry 2024,* Issue 26, pp. 992-1006. Available at: DOI: http://10.1039/d3gc02410e

44. Patrick, 2023. *Tsau-Khaeb National Park green hydrogen plant, largest of its kind in sub-Saharan Africa, to be developed in Namibia.* [Online] Available at: https://constructionreviewonline.com/construction-news/namibia-oks-construction-of-largest-green-hydrogen-project-in-sub-saharan-africa-situated-in-the-tsau-khaeb-national-park-namib-desert/
[Accessed 18 August 2025].

45. Pfenninger, S. & Staffell, L., 2024. *Renewables.ninja.* [Online] Available at: https://www.renewables.ninja/
[Accessed 04 10 2025].

46. Pinto, M. C., Simoes, S. G. & Fortes, P., 2024. How can green hydrogen from North Africa support EU decarbonization? Scenario analyses on competitive pathways for trade. *International Journal of Hydrogen Energy ,* Issue 79, pp. 305-318. Available at: https://doi.org/10.1016/j.ijhydene.2024.06.395

47. Rai, S., Habil, M. & Massey, D. D., 2021. A Review on Green Hydrogen: An Alternative of Climate Change Mitigation. *Indian Journal of Advances in Chemical Science,* 4(9), pp. 340-345. Available at: DOI: http://10.22607/IJACS.2021.904016

48. Snousy, M. G. et al., 2025. The Potential Role of Africa in Green Hydrogen Production: A Short-Term Roadmap to Protect the World's Future from Climate Crisis. *Water,* 17(3). Available at: https://doi.org/10.3390/w17030416

49. Staab, H. & Dickinson, A., 2023. *Producing green hydrogen from wind and solar energy: case study,* s.l.: natural power. Available at: https://www.naturalpower.com/mediaLibrary/other/english/4700.pdf

50. SustainabilityDirectory, 2025. *How Does Solar Energy Reduce Water Usage?*. [Online]
Available at: https://energy.sustainability-directory.com/question/how-does-solar-energy-reduce-water-usage
[Accessed 04 September 2025].

51. Tonelli, D. et al., 2023. Global land and water limits to electrolytic hydrogen production using wind and solar resources. *nature communications,* Issue 14. Available at: https://doi.org/10.1038/s41467-023-41107-x

52. UNSD, U. N. S. D., 2025. *Standard country or area codes for statistical use (M49).* [Online]
Available at: https://unstats.un.org/unsd/methodology/m49/
[Accessed 10 10 2025].

53. Uzoagba, . C. E. J. et al., 2025. Development of the Hydrogen Market and Local Green Hydrogen Offtake in Africa. *hydrogen,* 43(6). Available at: https://doi.org/10.3390/hydrogen6030043

54. Vassileva, A., 2022. *H2-Industries to build 1 GW waste-to-hydrogen hub in Egypt.* [Online]
Available at: https://renewablesnow.com/news/h2-industries-to-build-1-gw-waste-to-hydrogen-hub-in-egypt-771847/
[Accessed 18 August 2025].

55. Wang, Y. B., Wu, P. T., Engel, B. A. & Sun, S. K., 2015. Comparison of volumetric and stress-weighted water footprint of grain products in China. *Ecological Indicators,* Issue 48, pp. 324-333. Available at: https://doi.org/10.1016/j.ecolind.2014.08.014

56. World Resources Institute, 2025. *Aqueduct - Using cutting-edge data to identify and evaluate water risks around the world.* [Online] Available at: https://www.wri.org/aqueduct [Accessed 24 07 2025].

57. World Resources Institute, 2025. *AQUEDUCT Water Risk Atlas.* [Online] Available at: https://www.wri.org/aqueduct [Accessed 14 08 2025].

58. Yano, S., Hanasaki, N., Itsubo, N. & Oki, T., 2015. Water Scarcity Footprints by Considering the Differences in Water Sources. *Sustainability,* Issue 7, pp. 9753-9772. Available at: https://doi.org/10.3390/su7089753

59. Younis, A. & Onsa, M., 2022. A brief summary of cleaning operations and their effect on the photovoltaic performance in Africa and the Middle East. *Energy Reports,* Issue 8, pp. 2334-2347. Available at: https://doi.org/10.1016/j.egyr.2022.01.155

Appendix 1. Questionnaire

Dear Participant,

Thank you for taking the time to participate in this survey about green hydrogen production in Africa. I am Ruvini Tissera, a master's student at Lappeenranta-Lahti University of Technology, Finland. This research is part of my master's thesis project which is carried out under the supervision of Professor (tenured) Jouni Havukainen and Junior researcher Husain Patel, focusing on the water footprint, water scarcity and social implications of green hydrogen production. Your responses will help to identify key factors influencing social acceptance and concerns related to green hydrogen projects in Africa.

The survey will take approximately 5 - 10 minutes to complete. All responses will remain confidential and will only be used for academic research purposes. Your company's name will only be mentioned in the thesis if you explicitly consent to it below.

Section 1: General awareness of Green Hydrogen

1. How much familiar are you with green hydrogen production technologies?
   - Not at all familiar
   - Slightly familiar
   - Moderately familiar
   - Very familiar
   - Extremely familiar
2. In general, how would you describe your idea towards green hydrogen production in Africa?
   - Very negative
   - Somewhat negative
   - Neutral
   - Somewhat positive
   - Very positive

3. How important do you think green hydrogen will be for Africa's future energy targets?

- o Not important at all
- o Slightly important
- o Moderately important
- o Very important
- o Extremely important

4. What do you see as the most promising application of green hydrogen in Africa? (Select up to 3)

- o Transportation (e.g., fuel-cell vehicles)
- o Industrial processes (e.g., steel, ammonia production)
- o Energy storage & grid balancing
- o Power generation (e.g., hydrogen turbines)
- o Export for global clean energy markets
- o Other : _____

Section 2: Water use and sustainability concerns

5. How concerned are you with the water requirements for green hydrogen production in your region?

- o Not at all concerned
- o Slightly concerned
- o Moderately concerned
- o Very concerned
- o Extremely concerned

6. What type of water source you think should be prioritized for green hydrogen production in water-scarce regions? (Select all that apply)

- Seawater (with desalination)
- Wastewater (after treatment)
- Brackish groundwater
- Surface water (rivers, lakes)
- Other: ____

7. How to balance water utilization for green hydrogen production with other needs in your area?

- Hydrogen production should have priority
- Equal priority with other uses
- Other uses should have priority
- No opinion

Section 3: Social and Economic Impacts

8. What do you believe to be the most significant possible BENEFIT of green hydrogen production in your region? (Select up to 3)

- Job creation
- Energy independence
- Economic development
- Reduced carbon emissions
- Technology transfer
- Improved energy access
- Other: _____

9. What do you believe to be the most significant possible RISK of green hydrogen production in your region? (Select up to 3)

- Water scarcity
- Land use conflicts
- High costs
- Safety concerns
- Environmental impacts
- Displacement of communities
- Other: _____

10. How can green hydrogen projects provide fair access to water for local communities? (Select all that apply)

- Mandatory water-sharing agreements
- Investments in water-efficient technologies
- Community-led water management
- Government regulations on industrial water use
- Other: _____

Section 4: Policy & Sustainable Development Alignment

11. In which categories do you think green hydrogen production aligns with the UN Sustainable Development Goals (SDGs)? (Select relevant SDGs)

- SDG 6 (Clean Water & Sanitation) – if water use is managed responsibly
- SDG 7 (Affordable & Clean Energy) – decarbonizing energy
- SDG 9 (Industry, Innovation & Infrastructure) – new tech & jobs
- SDG 13 (Climate Action) – reducing emissions
- SDG 15 (Life on Land) – if land/water impacts are minimized

- Other: _____

12. What policies or regulations are required to ensure sustainable use of water for green hydrogen production? (Open) _____

Section 5: Participation and Trust

13. What kind of community participation do you think is most important for green hydrogen projects? (Select all that apply)

- Regular information sharing
- Public consultation meetings
- Community representation in decision-making
- Financial participation (e.g., community ownership)
- Employment opportunities

14. Which group do you trust the most in managing green hydrogen projects responsibly?

- Government agencies
- Private companies
- International organizations
- Local communities

Section 6: Demographic Information

15. Which country are you based in? _____

16. What is your primary sector of work?

- Energy production
- Government/policy
- Academia/research

- NGO/community organization
- Other: ____

17. How long has your organization been involved in hydrogen-related activities?

- Not involved yet
- Less than 1 year
- 1-3 years
- 3-5 years
- More than 5 years

Section 7: Consent to mention company name in Thesis

18. May we include your company's name in our thesis and research publication (e.g., in a list of participating organizations or as part of analysis)?

- Yes, you may include our company name.
- No, please keep our company name confidential.

19. If yes, please confirm the name as you'd like it to appear (optional): _____

20. Do you like to receive a summary of the research after completing my work?

- Yes
- No
- Maybe

Thank you for your participation! Your responses will contribute valuable insights into the social dimensions of green hydrogen production in Africa.

LUT University

Appendix 2: Country codes

Country	Country code
Algeria	DZ
Angola	AO
Benin	BJ
Botswana	BW
Burkina Faso	BF
Burundi	BI
Cabo Verde	CV
Cameroon	CM
Central African Republic	CF
Chad	TD
Comoros	KM
Democratic Republic of the Congo	CD
Republic of the Congo	CG
Djibouti	DJ
Egypt	EG
Equatorial Guinea	GQ
Eritrea	ER
Eswatini	SZ
Ethiopia	ET

Gabon	GA
Gambia	GM
Ghana	GH
Guinea	GN
Guinea-Bissau	GW
Ivory Coast	CI
Kenya	KE
Lesotho	LS
Liberia	LR
Libya	LY
Madagascar	MG
Malawi	MW
Mali	ML
Mauritania	MR
Mauritius	MU
Morocco	MA
Mozambique	MZ
Namibia	NA
Niger	NE
Nigeria	NG
Rwanda	RW
Sao Tome and Principe	ST

Senegal	SN
Seychelles	SC
Sierra Leone	SL
Somalia	SO
South Africa	ZA
South Sudan	SS
Sudan	SD
Tanzania	TZ
Togo	TG
Tunisia	TN
Uganda	UG
Zambia	ZM
Zimbabwe	ZW