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Assessing the feasibility of a green hydrogen economy in selected African regions with composite indicators

Amin Lahnaoui [a,*], Gianmarco Aniello [a], Stefano Barberis [b], Solomon Nwabueze Agbo [c], Wilhelm Kuckshinrichs [c]

[a] Forschungszentrum Jülich, Institute of Climate and Energy Systems - Jülich Systems Analysis (ICE-2), D-52425, Jülich, Germany
[b] Department of Mechanical Engineering – Thermochemical Power Group – University of Genova, Via Alla Opera Pia 15, 16100, Genova, Italy
[c] Forschungszentrum Jülich, Institute of Energy and Climate Research - Corporate Development (UE), D-52425, Jülich, Germany

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ABSTRACT

This study offers a comprehensive analysis of the feasibility of green hydrogen economies in Western and Southern African regions, focusing on the ECOWAS and SADC countries. Utilizing a novel approach based on composite indicators, the research evaluates the potential, readiness, and overall feasibility of green hydrogen production and export across these regions. The study incorporates various factors, including the technical potential of renewable energy sources, water resource availability, energy security, and existing infrastructure for transport and export. Country-specific analyses reveal unique insights into the diverse potential of nations like South Africa, Lesotho, Ghana, Nigeria, Angola, and Namibia, each with its unique strengths and challenges in the context of green hydrogen. The research findings underscore the complexity of developing green hydrogen economies, highlighting the need for nuanced, region-specific approaches that consider technical, socio-economic, geopolitical, and environmental factors. The paper concludes that cooperation and integration between countries in the regions may be crucial for the success of a future green hydrogen economy.

Nomenclature	
Abbreviations	
CI	Composite indicator
SDG	Sustainable development goals
LCOH	Levelized cost of green hydrogen
ECOWAS	Economic community of west african states
SADC	Southern african development community
BMBF	Federal ministry of education and research
EFP	Energy framework and policies
HFE	Hydrogen feasibility and export
EF	Energy framework
SP	Energy and SDG policies
HF	Hydrogen feasibility
HE	Hydrogen export
Indicators list and index	
EF1.0	Energy import dependency
EF2.0	Transformation efficiency
EF3.0	Dependency on traditional biomass
EF4.0	Use of renewable energy
EF5.0	Energy intensity per economic activity
SP1.0	Nationally determined contribution
SP2.0	Investments in renewable

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Nomenclature	
SP3.1	Access to electricity feasibility
SP3.2	Access to clean fuel feasibility
HF1.0	Technical potential
HF2.0	Cost of production
HF3.1	Groundwater
HF3.2	Desalination
HE4.0	Energy access and employment impact
HE1.1	Border trade
HE1.2	Harbors
HE2.1	Border regulation
HE2.2	Documentary compliance
HE3.1	Fuel exports
HE3.2	Export capacity
HE3.3	Regional export
HE4.1	Infrastructure score
HE4.2	Logistic score
HE.5.0	Ibrahim index
Symbols used in equation	
y	A specific year
c	A specific country

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* Corresponding author. author.
E-mail address: a.lahnaoui@fz-juelich.de (A. Lahnaoui).

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Nomenclature	
$I_{y,C}$	Indicator value for the year y and for country c
$I_{Ya,C}$	Historical weighted average indicator for the country c
NI_c	Normalized indicator for the country c
Min, Max	Minimum and maximum values for normalization
$Mean, Std.Dev$	Mean and standard deviation for standardization
w_i	Weight assigned to an indicator in aggregation
$Corr(X, Y)$	Correlation coefficient between two indicators

1. Introduction

1.1. Green hydrogen in Africa

The increasing global focus on mitigating climate change and achieving sustainable development has triggered a paradigm shift towards cleaner and renewable energy sources. Green hydrogen, produced through the electrolysis of water using renewable energy, has emerged as a promising solution to create an ecosystem where hydrogen serves as a primary energy carrier, facilitating the decarbonization of multiple sectors through its production, storage, transportation, and utilization. Essential components of thus ecosystem or what is referred to as the hydrogen economy, include abundant renewable energy sources, access to water for electrolysis, established infrastructure, supportive policy frameworks, and technological advancements in electrolysis and transport. Achieving economic viability through competitive hydrogen production costs compared to conventional fuels is a critical milestone for the development of such economies. Africa demonstrates strong potential to meet several of these prerequisites, particularly through its vast capacity for renewable energy generation and increasing international interest in hydrogen as a clean energy solution.

The European Union (EU) has been at the forefront of international initiatives focused on unlocking Africa's hydrogen potential, with the RePowerEU Plan outlining the goal of importing 10 million tons of green hydrogen annually by 2030 [1]. The EU's strategic interest in Africa's hydrogen resources is motivated by its ambition to decarbonize industries such as chemicals, steel, and heavy transport. These efforts need to align with Africa's opportunity [2] to develop export-driven green hydrogen markets while addressing its energy needs by leveraging its substantial renewable energy potential. Indeed, the African continent offers a huge untapped potential in terms of renewable energy, e.g., it accounts for 60% of the world's best solar resources, yet only 1% of global solar capacity is currently utilized [3]. This potential for cheap and abundant electricity generation has drawn a worldwide interest, positioning Africa at the crossroads of its own and global energy future in the development of a green hydrogen industry.

Many regions in Africa, with their expansive arid spaces along windy coastlines, offer significant potential for producing low-cost, competitive green electricity with minimal impact on ecosystems and biodiversity. Many African countries, where water could be also available thanks to desalination, could leapfrog to the new age of hydrogen technologies [4]. Africa has indeed a unique potential to harness low-cost renewable energy to produce green hydrogen for domestic and external markets [5]. Green Hydrogen could indeed propel the sustainable development of the continent, allowing African countries to reduce their environmental impact and make them less dependent on fossil fuels. This can enhance energy security and contribute to avoiding potential geopolitical issues.

Developing hydrogen economies in Africa would have indeed an impact on the continent's import/export economy: reducing the economic burden of importing costly refined fossil fuels, making African energy-intensive industries (e.g. fertilizer, chemicals, mining) more competitive, and generating revenue streams from exporting green hydrogen Additionally, such development could create employment, skills and generate wealth domestically [6]. African nations would also have the opportunity to meet their own decarbonization goals. Thanks to a renewable electricity cost, African hydrogen produced by electrolysis could be both, "renewable" or "low carbon" and competitive withing 2030. Despite these significant opportunities, Africa faces numerous challenges [7] including political, financial, economic, and regulatory, as well as the lack of required capabilities and capacity required for developing hydrogen industries, which need to be addressed [8].

Projects like JUST GREEN AFRH2ICA and H2Atlas-Africa are pivotal in advancing this agenda [9]. To form the most robust international alliance for harnessing Africa's hydrogen potential and creating markets and demand in Africa, collaboration between European and African hydrogen stakeholders is essential. This collaboration bridges governments, industries, technology providers, financial institutions, and large hydrogen consumers across continents. JUST GREEN AFRH2ICA, for example, seeks to create awareness and propose comprehensive solutions across technological, financial, and policy dimensions for the benefit of both Africa and the EU in developing green hydrogen economies. The JUST GREEN AFRH2ICA (JGA) project aims to promote a holistic, sustainable green hydrogen just transition in Africa, where all African nations can participate, and develop roadmaps that harmonize African and European hydrogen transition pathways. This ensures sustainability while preventing any form of " hydrogen colonization" in Africa. Instead, it promotes a mutually beneficial collaboration between the two continents towards the development of independent and collaborative hydrogen economies, R&D ecosystems, and value chains.

However, establishing a green hydrogen industry presents a vast array of challenges in terms of infrastructure (especially energy-related), political framework, geopolitical risk, as well as potential sustainability issues (e.g., water conflicts). To address these challenges and identify areas that could become early movers, an assessment of the feasibility of a green hydrogen industry is crucial. Clean energy planning and modeling activities are necessary for this purpose. This study builds upon experiences of JGA as well as of H2-Atlas-Africa, and leverages synergies between them to further enhance the understanding of energy and hydrogen modeling, as well as the gathering of local stakeholders' inputs in shaping effective and sustainable hydrogen strategies [2].

H2Atlas-Africa project investigated indeed the potential of generating green hydrogen from selected countries in East, West, and Southern Africa, considering technological, environmental, and socio-economic conditions prevailing in each country. This project funded by the German Federal Ministry of Education and Research (BMBF) accesses the available renewable energy, land, and water resources that are necessary for green hydrogen production, along with logistical and political framework conditions that can affect green hydrogen production, its utilization in Africa and export potential. In close consultation with partners from the target African regions, the project ensures that local energy scenarios, preferences, and peculiar contexts are factored in to avoid conflicts related to land, water, and energy resources. The project employs theoretical analysis using relevant analytical tools developed within the interdisciplinary team. The data required as input for the analysis include location information related to renewable energy resources, present and future local energy demands, and climate change scenarios and their impact, land and water use preferences among others. The H2Atlas-Africa project contributes towards a clear roadmap for enabling a green hydrogen-based economy in sub-Saharan Africa, making it highly relevant for policymakers, investors, researchers, and all stakeholders in the value chain. The results demonstrate that the potential for green hydrogen production and export in the investigated region is huge. The work done here leveraged the competence of an interdisciplinary team at the Forschungszentrum Jülich and the cooperation with African partners, including the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL), in Accra, Ghana, and the Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL), in Windhoek, Namibia, as well as support teams in the countries investigated.

These collaborations concluded that building a green hydrogen economy presents a multitude of challenges in terms of infrastructure (especially energy-related), political frameworks, geopolitical risks, as well as potential sustainability issues (e.g., water conflicts). To address these potential barriers and identify early movers' opportunities, assessing the feasibility of a green hydrogen economy is crucial. This article investigates the feasibility of a green hydrogen economy and its export potential. This analysis aims to summarize various results concerning hydrogen potential at technical, sustainability, and socio-economic levels and combine them into a unified indicator for policy-makers. It also gathers energy, policy, and regulatory frameworks that could be essential. The goal is not only to summarize feasibility at the national level but also to provide a standardized tool for assessing the status and attractiveness of countries in West and Southern Africa. This is particularly relevant as national policies for green hydrogen are still in their early stages and lack uniform measures. To achieve this, the analysis builds on model results and open-source data to construct a composite indicator for evaluating the feasibility of a green hydrogen economy in selected countries. Thus, a literature review covering the construction of composite indicators and their use in analyzing the feasibility of green energy projects is specified followed by a methodology adapted to the case of green hydrogen feasibility and framework in selected African regions.

1.2. Composite indicators literature review

The concept of composite indicators (CIs) emerged in the early '90s as a potent tool for addressing multifaceted development issues [10]. Notable global organizations like the United Nations, the World Bank, and the European Commission have played a pivotal role in formulating diverse CIs. Major used indicators included for instance: the Human Development Index (HDI) which assesses human well-being based on indicators such as life expectancy, education, and income; the Environmental Performance Index (EPI), which measures environmental performance and sustainability of countries based on various environmental factors; Gender Empowerment Measure (GEM) that focuses on gender disparities in political and economic empowerment; Quality of Life that aims to capture the overall quality of life experienced by individuals in a given society, encompassing aspects beyond economic indicators [11].

In recent years, the application of CIs has expanded, particularly in the realm of renewable energy. They offer a framework for understanding the socio-economic impacts of renewables, breaking down benefits into specific categories tailored to individual country needs. Their ability to simplify complex data, facilitate comparisons, assess outcomes, and track progress makes CIs invaluable for policymakers [12,13]. Thus, Sébastien et al. explored the significance of composite indicators in EU policymaking [14], and Gatto et al. measured renewable energy policy effectiveness using a composite indicator, exploring different perspectives across 230 countries [15].

Studies utilizing CIs have shed light on the feasibility of renewable energy technologies and investments. For example, Boie et al. highlighted the impact of economic and non-economic framework conditions in Germany focusing on the deployment of wind and photovoltaic energy [16], while Wang et al. emphasized the economic and technological efficiency of renewable energy technologies in the EU-27 [17]. In terms of investment feasibility, the Green Finance Index developed by Iqbal et al. evaluates energy, environmental, and financial variables [18], while the Renewable Energy Responsible Investment Index (RERII) by Lee et al. incorporates economic, environmental, social, and governance indicators [19].

Collectively, the literature research showed that many studies highlight the importance of a comprehensive approach considering economic, social, and environmental factors, pushing to underscore the potential of CIs from different dimensions in evaluating the feasibility and sustainability of renewable energy projects. Martchamadol et al. developed a performance indicator based on social, economic, and environmental dimensions [20]. Čeryová et al. utilized principal component analysis to assess the performance of the renewable energy sector in EU countries, emphasizing changes in indicators over time [21]. Androniceanu et al. applied multifactorial components analysis to the renewable energy sector in OECD countries, revealing correlations with economic development [22]. Pîrlogea studied macroeconomic indicators to evaluate the efficiency of investments in renewable energy, finding good economic efficiency but low social and environmental efficiency in European countries [23].

The importance of going beyond technology and investment analysis pushed us to further investigate the sustainability component of renewable energy. Thus, many articles focus on sustainability indicators [24–27], with Evans ranking wind power as the most sustainable and Cîrstea proposing a Renewable Energy Sustainability Index for European countries. Furthermore, Cuesta et al. emphasized the need to include social indicators like job creation and social acceptance [28]. It suggested enhancements for Hybrid Renewable Energy Systems optimization tools to better address socio-demographic aspects and local renewable resources. In this direction, other studies explored the relationship between energy and social development, Kelly et al. developed a scalable methodology for a composite index assessing the risk of energy poverty in home heating [29]. Lan et al. developed a multidimensional energy poverty index (EPI) for five Asian countries [30]. It assessed the impact of energy poverty indicators, revealing significant regional disparities in energy poverty and its relationship with electricity availability, clean energy access, and private investment in the energy sector. The exploration into the sustainability facets of renewable energy extends beyond technological and investment analyses, delving into the evaluation of the impact of energy efficiency on Sustainable Development Goals (SDGs) including mainly SDG9 [31] and SDG7 [32].

Further expanding the scope, the research investigated diverse aggregation and normalization techniques within sustainability analyses [10,33–35]. It revealed that proportionate normalization and hybrid aggregation techniques are suitable for developing CIs in the context of sustainability [10]. However, they cautioned that the fitting technique should be re-evaluated to suit individual cases, emphasizing the need for reflective CI research [35].

In essence, composite indicators are calculated based on a combination of a set of multidimensional sub-indicators that may lack a common unit [36]. This can be presented by a simple formulation as shown in Eq. (E.1) and Eq. (E.2):

$$CI = \sum_i w_i I_i \tag{E.1}$$

$$CI = \prod_i I_i^{w_i} \tag{E.2}$$

By far the most widespread linear aggregation is the linear additive aggregation (1), where I_i is the normalized variable, and w_i the weight attached to it so that the sum of the weights is equal to 1.

Although widely used, a drawback associated with additive aggregations is the implicit assumption of complete compensability, wherein poor performance in certain indicators can be offset by sufficiently strong performance in other indicators [36], so that a geometric aggregation (2) is used.

In sum, the use of composite indicators in assessing the feasibility and sustainability of renewable energy projects is important. They offer a nuanced understanding of the multi-layered challenges and opportunities in transitioning to a sustainable energy future. However, when it comes to green hydrogen technology in the context of Sub-Saharan Africa, there is limited use of composite indicators to address the complex dimensions of green hydrogen projects in this region. Feasibility has primarily been examined from technical and cost perspectives, often separately from the environmental dimension and the potential impacts of such projects.

Indeed, a range of studies have explored the feasibility and potential benefits of green hydrogen production in Sub-Saharan Africa from a techno-economic point of view. Ayodele [37] and Asaad [38] both highlight the technical and economic viability of green hydrogen production, with Ayodele specifically focusing on South Africa's wind energy resources and Asaad proposing the use of natural resources in North Africa for export to Europe. Separately, Hamukoshi [39] and Fopah-Lele [40] emphasize the potential socio-economic impacts and benefits of green hydrogen, including job creation and economic value in the energy export sector. However, Fopah-Lele also acknowledges the challenges and difficulties in implementing hydrogen technology in the region. These studies suggest that while there are significant opportunities for green hydrogen in Sub-Saharan Africa from technical and economic perspectives, there are also important considerations and challenges that need to be addressed at the local level.

To address these multidimensional aspects of implementing green hydrogen projects, the study aims to introduce a novel composite index for assessing green hydrogen feasibility specific to African contexts, integrating socio-economic, geopolitical, and environmental factors into the feasibility analysis. The use of composite indicators serves as a tool to merge various outcomes into a single feasibility study. Therefore, Chapters 2 and 3 will present the methodology and results behind the application of composite indicators in assessing the feasibility of green hydrogen in Africa. This approach will provide conclusions and practical recommendations in Chapters 4 and 5 for policymakers and investors to support the development of green hydrogen economies in these regions.

2. Methodology

The methodology for this study adheres to the constructive checklist developed by the OECD for building a composite indicator [36]. This comprehensive approach includes data selection, correction, normalization, weighting, aggregation, uncertainty and sensitivity analysis.

Data selection: Data was chosen based on its measurability, coverage, and relevance, ensuring that the indicators are interrelated and represent the study's objectives effectively.

Data correction: The primary challenge in the African context is often missing or low-quality data. To address this, historical data from 2000 to 2020 were used, improving indicator quality.

Normalization: Normalization makes diverse variables comparable. Two techniques were utilized: the Min-Max and standardization methods.

Weighting and aggregation: The importance of each indicator within the overall composite was determined based on their inter-correlations. Weighting was proportional to these correlations. The arithmetic mean was predominantly used for aggregation of composite indicators and sub-indexes, with geometric means employed in specific cases to address concerns related to interaction and compensability.

Uncertainty and sensitivity analysis: to assess the robustness of the composite and the correlation between them.

2.1. Index structure

The feasibility of investment in green hydrogen is performed using the Index (Ind) shown in Fig. 1. This Ind is decomposed into two categories Energy framework and policies (EFP) and Hydrogen feasibility and export (HFE). EFP includes two categories SP and EF, 7 sub-categories, and 9 indicators as described in Table 1, while HFE includes two additional categories HE and HF, 9 sub-categories, and 15 indicators as described in Table 2.

The two components of the index are analyzed separately, for different focus countries, the broad context of energy sector performance, and green hydrogen projects feasibility.

The first sub-index indicators are presented in Table 1 and analyze current energy framework (EF), and sustainable development goals (SDGs) policies to promote them (SP). The first one (EF) focuses on the performance of energy systems across different countries, considering aspects like energy security, efficiency, intensity, impacts on health, and the role of renewable energy sources. The second one (SP) quantifies the impact of various countries' and regions' policies on promoting renewable energy, mitigating climate change, and promoting energy access.

The second sub-index indicators are presented in Table 2 and reflect the feasibility of a hydrogen economy (HF), and export-based economy (HE). The first one (HF) synthetizes the key results of the H2Atlas project 49 at the national level, incorporating factors like hydrogen potential, cost, water constraints, and local impacts. The second one (HE)

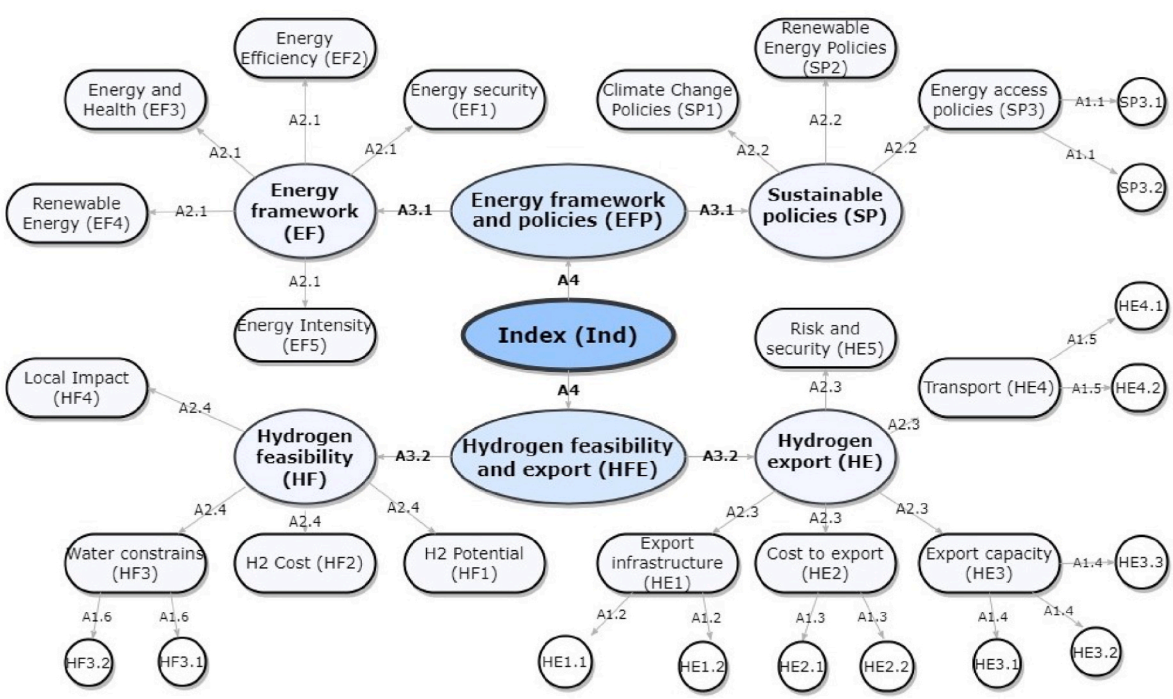

Fig. 1. Index structure.

Table 1
Dimensions, categories, sub-categories, and indicators of current energy framework and energy policies (EFP).

	Sub-category	Indicator		Components	Unit	Source
Energy framework EF	Energy security EF1	**EF1.0**	Energy import dependency	Total energy produced Total energy supply	%	[41]
	Energy efficiency EF2	**EF2.0**	Transformation efficiency	Total final energy demand Total energy supply	%	[41]
	Energy and health EF3.	**EF3.0**	Dependency on traditional biomass	Total final energy demand from traditional biomass Total energy demand	%	[41]
	Renewable energy EF4	**EF4.0**	Use of renewable energy	Total renewable electricity generation Total electricity generation	%	[41,42]
	Energy intensity EF5	**EF5.0**	Energy intensity per economic activity	Total energy supply Gross domestic product	kWh/USD	[43]
Sustainable development goal policies SE	Climate change policies SP1	**SP1.0**	Nationally determined contribution	NDCs means (conditional, unconditional) NDCs version (first, updated, or second) NDCs scope (energy, waste, AFOLU, IPPU)	–	[44]
	Renewable energy policies SP2	**SP2.0**	Investments in renewable	Financial flows for clean and renewable energy production	%	[43]
	Access to energy SP3	**SP3.1**	Access to electricity feasibility	Historical 2000–2020 electricity access change Electricity access targeted by national policies	–	[43–45]
		SP3.2	Access to clean fuel feasibility	Historical 2000–2020 clean fuel access change Clean fuel access targeted by national policies	–	[43–45]

Table 2
Dimensions, categories, sub-categories, and indicators of hydrogen production and export (HFE).

	Sub-category	Indicator		Components	Unit	Source
Hydrogen feasibility	H2 potential HF1	**HF1.0**	Technical potential	Total green hydrogen potential with 50 % energy potential expansion per km2	kWh/(yr*m^2)	[46–49]
	H2 cost HF2	**HF2.0**	Cost of production	Average cost of green hydrogen by 2020 with 50 % energy potential expansion	EUR/kg	[46–49]
	Water constrains HF3	**HF3.1**	Groundwater	Groundwater sustainable yield (medium) per year	mm/(yr)	[46–49]
		HF3.2	Desalination	Desalination potential proportional to coastline length	Km	[50]
	Local impact HF4	**HF4.0**	Energy access and employment impact	Maximum population directly impacted by green hydrogen projects	%	[46–49]
Export feasibility	Export infrastructure HE	**HE1.1**	Border trade	Trading across neighboring borders scores		[51,52]
		HE1.2	Harbors	Ports organized by size, and numbers		
	Cost to export HE2	**HE2.1**	Border regulation	Time to cost for compliance with customs regulations	USD	[51,52]
		HE2.2	Documentary compliance	Time to cost for documentary requirements	USD	
	Export capacity HE3	**HE3.1**	Fuel exports	Fuel exports (% of merchandise exports)	%	[51]
		HE3.2	Export capacity	Total merchandise export capacity HE3.2		
		HE3.3	Regional export	Share for export to developing economies	%	
	Transport infrastructure HE4	**HE4.1**	Infrastructure score	Transport composite index of africa infrastructure development index (AIDI) HE4.1		[53]
		HE4.2	Logistic score	Logistic index HE4.2		[51]
	Risk and security HE5	**HE.5.0**	Ibrahim index	Security and safety sub–Ibrahim index of african governance	–	[54]

quantifies the feasibility of exports, considering aspects such as export, transport, logistic infrastructure scores, and the cost of export, including constraints like security and risk.

2.2. Overview of datasets

Annex 2 gives a statistical summary of the main indicators. Energy security exhibits moderate values in the two regions, yet the wide range indicates substantial diversity between countries. Transformation efficiency suggests low variability. The high mean and median values indicate a considerable dependency on traditional biomass, showcasing high diversity among entities. The use of renewable energy is moderately distributed with wide-ranging diversity. Energy intensity's mean value suggests relatively high intensity, with a notable range among entities.

Both SP1.0 and SP2.0 mean values imply moderate and low focuses on climate change policies and the adoption of renewable energy policies, respectively. SP3.1's high mean and median values suggest a high feasibility of universal access to electricity in the region. However, achieving access to clean fuel targets is challenging on average, with high diversity among countries.

The hydrogen technical potential is very high, yet considerable diversity exists among countries. Conversely, the cost of production is relatively consistent. Concerning water constraints for hydrogen use, both groundwater uses and desalination potentials show wide ranges among countries. However, the mean values of HF3.2 indicate a high desalination potential. National energy access and the employment impact of hydrogen projects are moderate in the regions but with high variability, suggesting contrasted local impacts.

Export infrastructure indicators show low to medium variability, contrasting with the cost of infrastructure indicators exhibiting higher variability. The low mean and median values of export capacity indicators suggest relatively low scores, while transport and logistic infrastructure perform slightly better.

2.3. Data correction and normalization

Two types of data were used in the analysis of the indicators: qualitative and quantitative. Qualitative indicators, particularly those accounting for policies, are based on data gathered from various national, regional, and UN policy reviews. For SP.1.0, scores of −1, 0, and 1 were assigned based on the scope of NDCs (unconditional commitments receiving the highest score), the version (second revised NDC being the highest), and the end-user scope (all end-users covered by the NDC being the highest score).

For SP3.1 and SP3.2, changes in energy access over the last 10–20 years were averaged and compared to universal access national targets. The resulting ratio was ranked from low to high, proportional to the level of feasibility of reaching the targets set by regional policies.

Quantitative data primarily include model results for hydrogen feasibility and open-source data for energy framework and export feasibility. A primary challenge in data selection for the African context is missing or low-quality data. To address this, historical data from 2000 to 2020 were collected to improve the quality of indicators. A weighting methodology was employed to emphasize recent trends and improvements. The historical weighted average, described in Eq. (E.3), is calculated for indicators EF1.0, EF2.0, EF3.0, EF5.0, SP2.0, HE1.1, HE2.1, HE2.2, HE3.1, HE3.2, HE3.3, HE4.1, HE4.2, and HP.5. Trend correction was also applied to account only for the most recent five years, particularly for EF4.0.

The historical weighted average indicator $I_{Ya,C}$ is calculated as:

$$I_{Ya} = \sum_{y} \frac{I_y}{Y - y + 1} \Bigg/ \sum_{y} \frac{1}{Y - y + 1} \tag{E.3}$$

Where.

- $I_{Ya,C}$ represents the indicator calculated with a historical weighted average for country c.
- $I_{y,C}$ is the value of the indicator in year y for the country C
- Y represents the final year (2020 or the most recent recorded data year).

Various normalization techniques are available. Different techniques were applied to the set of indicators, and the most representative ones were selected to analyze the score for each country. The Min-Max method Eq. (E.4) was used for indicators EF1.0, EF2.0, EF3.0, EF4.0, EF5.0, SP2.0, HF2.0, HF3.2, HE1.1, and HE2.1, while the standardization method Eq. (E.5) was applied to indicators with high variation around the mean (Table 3) including HF1.0, HF3.1, HF4.0, HE3.1, HE3.2, HE3.3, HE4.1, HE4.2, HP.5.0.

Min-Max normalization is given by:

$$NI_C = \frac{I_{Ya.C} - \min_c I_{Ya.c}}{\max_c I_{Ya.c} - \min_c I_{Ya.c}} \tag{E.4}$$

Standardization normalization is given by:

$$NI_C = \frac{I_{Ya.C} - \mathrm{mean}_c I_{Ya.c}}{\mathrm{sdv}_c I_{Ya.c}} \tag{E.5}$$

Where.

- NI_C represents the normalized indicator for country c
- I_{Ya} represents the indicator calculated with a historical weighted average.
- $min_c I_{Ya.c}$, $max_c I_{Ya.c}$, $mean_c I_{Ya.c}$, and $sdv_c I_{Ya.c}$ represent the minimum, maximum, average, and standard deviation among the weighted indicators $I_{Ya.C}$ for the different sets of countries.

2.4. Weighting and aggregation

The final score and ranking of the composite indicators depend on the weighting of the normalized values of the indicators. Weighting reflects the importance of each indicator relative to the overall composite indicator. In this paper, since no other suitable means of weighting were identified [55], weighting was chosen equal at the first, third, and fourth aggregation levels. At the second aggregation level, the weights were based on the proportional correlation matrix between the indicators (**Annex 3**). **Annex 3** shows the absolute value of the correlation coefficients between the aggregated indicators at level one of the same sub-index.

For instance, SP, SP.3 (aggregated from SP3.1 and SP3.2), which represents access to energy policies, shows a strong correlation with renewable energy policies (SP2) but not as much with climate change policies (SP1). Therefore, we assign the highest weight to the least correlated indicator, SP1, followed by SP2, and then SP3. This is formulated mathematically for all level 2 aggregations as shown in Eq. (E.6), and the results are summarized in Table 3.

$$w_2{}^i = \frac{\left| \sum_{i,j} corr\left(AI_{C,1}{}^i, AI_{C,1}{}^j\right) \right|}{\sum_i n - \left| \sum_j corr\left(AI_{C,1}{}^i, AI_{C,1}{}^j\right) \right|} \tag{E.6}$$

Where.

- $AI_{C,1}{}^i$ is the i-th aggregated indicator for the same category (for instance, for SP, $NI_{C,1}{}^3$ correspond to SP.3)
- $w_2{}^i$ is the weight of the aggregated composite indicator $NI_{C,1}{}^i$ (for instance, for SP, $w_2{}^3$ is equal to 0.28 as shown in Table 3)

Table 3
Type and normalization method of the indicators, along with the weight at the second aggregation level.

Level 1 aggregated indicators $AI_{C,1}{}^i$	EF1	EF2	EF3	EF4	EF5	SP1	SP2	SP3
Corresponding indicators I_C	EF1.0	EF2.0	EF3.0	EF4.0	EF5.0	SP1.0	SP2.0	SP3.1, SP3.2
Type of indicators	QNT	QNT	QNT	QNT	QNT	QLT	QNT	Qnt, QNT
Normalization NI_C	(E.4)	(E.4)	(E.4)	(E.4)	(E.4)	–	(E.4)	–
Weight 2 $w_2{}^i$	0.21	0.22	0.19	0.20	0.18	0.37	0.35	0.28
Aggregation 2 A_2	A2.1					A2.2		

$AI_{C,1}{}^i$	HF1	HF2	HF3	HF4	HE1	HE2	HE3	HE4	HE5
I_C	HF1.0	HF2.0	HF3.1, HF3.2	HF4.0	HE1.1, HE1.2	HE2.1, HE2.2	HE3.1, HE3.2, HE3.3	HE4.1, HE4.2	HF.0
Type	QNT	QNT	QNT, QNT	QNT	QLT, QNT	QNT, QNT	QNT, QNT, QNT	QNT, QNT	QNT
NI_C	(E.5)	(E.4)	(E.5), (E.4)	(E.5)	-, (E.4)	(E.4), (E.4)	(E.4), (E.4), (E.5)	(E.5), (E.5)	(E.5)
$w_2{}^i$	0.22	0.21	0.31	0.27	0.2	0.2	0.18	0.21	0.2
A_2	A2.3				A2.4				

- $|corr(NI_{C,1}{}^{i}, NI_{C,1}{}^{j})|$ is the absolute correlation coefficient between $NI_{C,1}{}^{i}$ and $,NI_{C,1}{}^{j}$ of the same category (for instance for SP, $|corr(NI_{C,1}{}^{1}, NI_{C,1}{}^{3})|$ corresponds to the absolute correlation coefficient between SP.1 and SP.3, which is of 0.03 (**Annex 3**), and is symmetric to $|corr(NI_{C,1}{}^{3}, NI_{C,1}{}^{1})|$).
- n correspond to the number of aggregated indicators in the same category (for instance for SP, this corresponds to 3)

Arithmetic means were used for the aggregation of the different composite indicators and sub-indexes. However, a drawback associated with additive aggregations is the implicit assumption of complete compensability, wherein poor performance in certain indicators can be offset by sufficiently strong performance in other indicators [36]. In this case, geometric means were used to address these concerns related to interaction and compensability, particularly for A1.5. The methods used are also summarized in Table 3, following the index structure shown in Fig. 1.

3. Results

For all the results section, the results are presented separately for two regional blocs in Western and Southern Africa. The Economic Community of West African States (ECOWAS) encompasses 15 West African nations, focusing on regional economic integration and development. Similarly, the Southern African Development Community (SADC), comprising 16 countries in Southern Africa, emphasizes economic cooperation and sustainable development. These regions were chosen for their substantial renewable energy potential and the strategic importance of green hydrogen in addressing energy and socio-economic challenges.

3.1. General results

First, the general results of the index components are shown in Fig. 2 and detailed in Table 4. The results illustrate the total index score (Ind) for the ECOWAS and SADC regions, and the score for the different sub-categories (EF, HF, SP, and HE).

The index results are detailed in Table 4, along with the total score and countries ranking. Overall, South-Africa ranks first followed by Lesotho, Cabo Verde, Angola, Gambia, and Ghana. At the bottom, one can find Guinea-Bissau, Tanzania, and Congo DR. However, the final index ranking incorporates a very diverse set of results of all the composite indicators. Such sub-indicators are crucial to understanding the areas that can and/or ought to be improved, the potential for either a more export-oriented or domestic-oriented green hydrogen industry, as well as the potential complementarities and synergies between neighboring countries. Therefore, the next sub-sections will delve into a more detailed description of the composite indicators.

3.2. Energy framework and policies (EFP)

The detailed results of the Energy framework and policies (EFP) index components are shown in Fig. 3.

Fig. 3 summarizes the CIs regarding energy framework and policies (EFP) across the two regions, for which significant variation can be observed. A more detailed disaggregation of the scores is reported in Table 4. In **ECOWAS**, Ghana stands out with an overall EFP score of 0.70, followed by Cabo Verde (0.67) and Gambia (0.60). Guinea-Bissau, Niger, and Togo perform very poorly in terms of this sub-index with scores of 0.34, 0.40 and 0.41, respectively. When looking into the sub-components of EFP, Ghana confirms its first position with respect to the energy framework (0.79), followed by Côte d'Ivoire (0.68). Regarding energy policies (SP) Cabo Verde achieves the best score in the region (0.80), followed by Benin and Liberia (both at 0.71). While a moderate correlation between the EF and SP indicators can be noticed, EF and SP indicators do not necessarily go hand in hand: e.g., Togo has the worst performance in terms of EF (0.20) but an above-average score in SP (0.63). To better understand what is behind such divergent performance **Annex 4** reports the strengths and weakness of each country, namely the 5 indicators that have the most positive impact on the final index score, and the 5 indicators with the most negative impact. In this regard, Cape Verde, Gambia, and Benin rank low in terms of energy security, whereas, Ghana, ranks highest in terms of this indicator.

In SADC, Table 4 shows that Lesotho performs best in terms of EFP with a score of 0.69, followed by Angola (0.65), South-Africa and Mauritius (both at 0.63). In contrast, Madagascar (0.36), Congo DR, and Zimbabwe (both at 0.41) have the lowest scores in the region. With respect to the energy framework, Angola (0.77) and Malawi (0.70) hold the top positions. Regarding sustainable policies, Lesotho ranks first with a score of 0.78, followed by Comoros (0.65), Mauritius, and Eswatini (both at 0.65). Concerning the main weaknesses, Angola ranks low in terms of renewable energy policies, while Lesotho underperforms

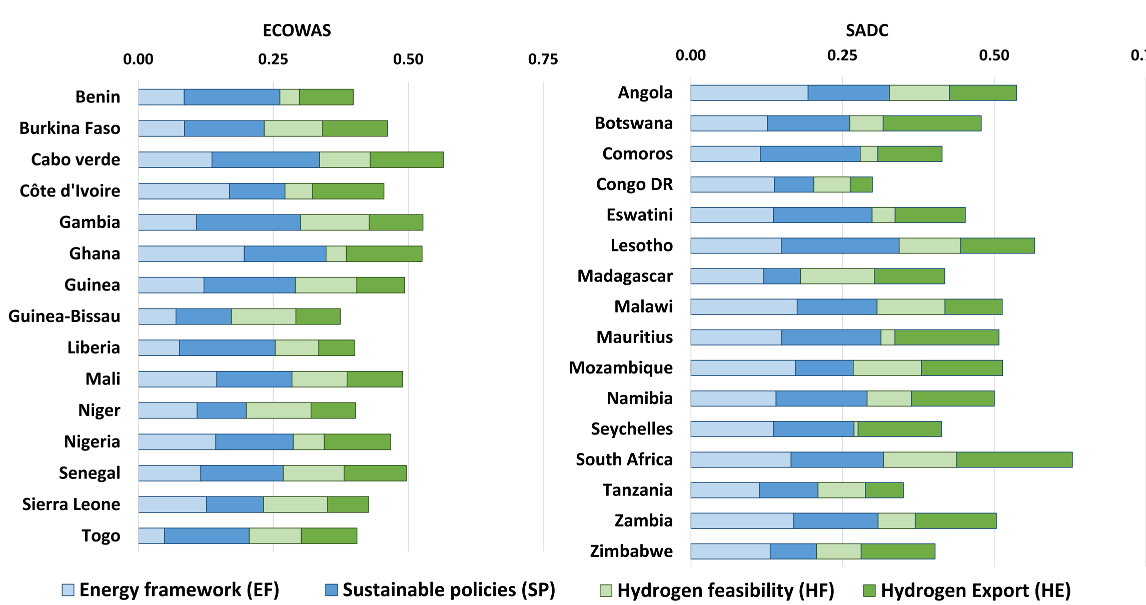

Fig. 2. Total index score for ECOWAS and SADC countries.

Table 4
Index (Ind), categories (EFP, HFE), and sub-categories (EF, SP, HF, HE) scores results for all countries.

Code	Country	Region	Rank	Ind	EFP	HFE	EF	SP	HF	HE
ZAF	South Africa	SADC	1	0.63	0.63	0.62	0.66	0.61	0.48	0.76
LSO	Lesotho	SADC	2	0.57	0.69	0.45	0.60	0.78	0.41	0.49
CPV	Cabo Verde	ECOWAS	3	0.57	0.67	0.46	0.55	0.80	0.38	0.54
AGO	Angola	SADC	4	0.54	0.65	0.42	0.77	0.54	0.40	0.44
GMB	Gambia	ECOWAS	5	0.53	0.60	0.45	0.43	0.77	0.51	0.40
GHA	Ghana	ECOWAS	6	0.53	0.70	0.36	0.79	0.61	0.15	0.56
MOZ	Mozambique	SADC	7	0.51	0.54	0.49	0.69	0.38	0.45	0.53
MWI	Malawi	SADC	8	0.51	0.61	0.41	0.70	0.53	0.45	0.38
MUS	Mauritius	SADC	9	0.51	0.63	0.39	0.60	0.65	0.09	0.68
ZMB	Zambia	SADC	10	0.50	0.62	0.39	0.68	0.56	0.25	0.54
NAM	Namibia	SADC	11	0.50	0.58	0.42	0.56	0.60	0.29	0.55
SEN	Senegal	ECOWAS	12	0.50	0.54	0.46	0.46	0.61	0.45	0.46
GIN	Guinea	ECOWAS	13	0.49	0.58	0.40	0.49	0.68	0.45	0.35
MLI	Mali	ECOWAS	14	0.49	0.57	0.41	0.58	0.56	0.42	0.41
BWA	Botswana	SADC	15	0.48	0.52	0.43	0.50	0.54	0.22	0.65
NGA	Nigeria	ECOWAS	16	0.47	0.57	0.36	0.57	0.57	0.23	0.49
BFA	Burkina Faso	ECOWAS	17	0.46	0.47	0.46	0.34	0.59	0.43	0.48
CIV	Côte d'Ivoire	ECOWAS	18	0.45	0.54	0.37	0.68	0.41	0.20	0.53
SWZ	Eswatini	SADC	19	0.45	0.60	0.31	0.54	0.65	0.15	0.46
SLE	Sierra Leone	ECOWAS	20	0.43	0.46	0.39	0.51	0.42	0.47	0.30
MDG	Madagascar	SADC	21	0.42	0.36	0.48	0.48	0.24	0.49	0.46
COM	Comoros	SADC	22	0.41	0.56	0.27	0.46	0.66	0.12	0.42
SYC	Seychelles	SADC	23	0.41	0.54	0.29	0.55	0.53	0.03	0.55
TGO	Togo	ECOWAS	24	0.40	0.41	0.40	0.20	0.63	0.39	0.41
NER	Niger	ECOWAS	25	0.40	0.40	0.41	0.44	0.36	0.48	0.33
ZWE	Zimbabwe	SADC	26	0.40	0.41	0.39	0.52	0.31	0.29	0.49
LBR	Liberia	ECOWAS	27	0.40	0.51	0.29	0.31	0.71	0.32	0.27
BEN	Benin	ECOWAS	28	0.40	0.52	0.27	0.34	0.71	0.15	0.40
GNB	Guinea-Bissau	ECOWAS	29	0.37	0.34	0.40	0.28	0.41	0.48	0.33
TZA	Tanzania	SADC	30	0.35	0.42	0.28	0.45	0.38	0.31	0.25
COD	Congo DR	SADC	31	0.30	0.41	0.19	0.55	0.26	0.24	0.15

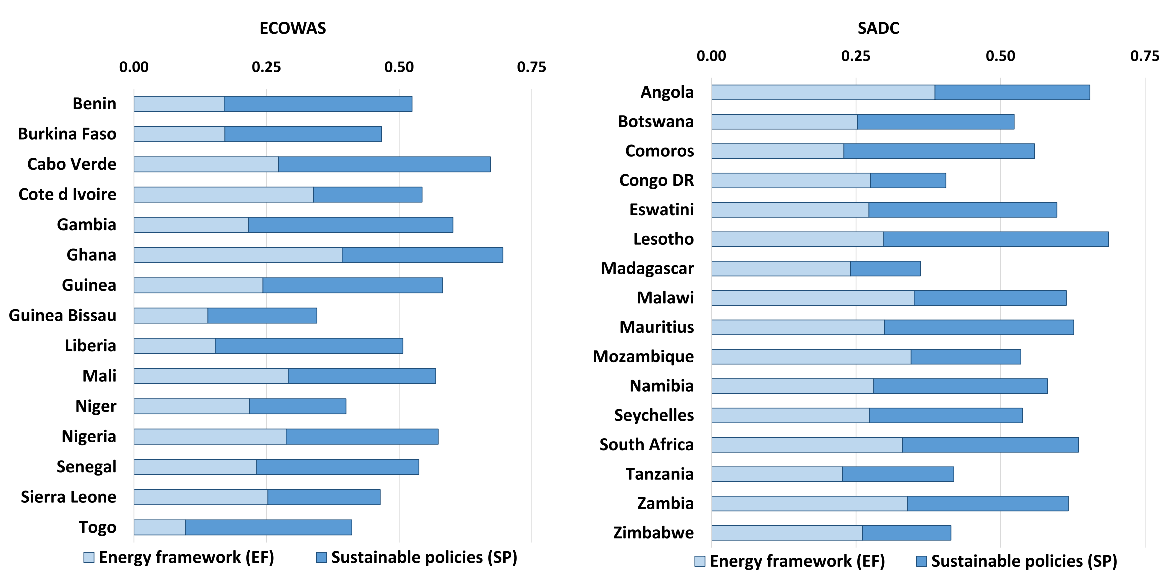

Fig. 3. Energy framework (EF) and sustainability policies (SP) composite indicators.

in terms of energy efficiency and intensity. South Africa performs poorly both in terms of renewable energy policies (indicator SP2.0) and renewable energy (indicator EF.4.0). The Comoros ranks lowest on renewable energy in the region and performs poorly on energy security.

Overall, both SADC and ECOWAS appear to have a few countries performing significantly better than the rest, especially Ghana and Lesotho which combine both the implementation of sustainability-oriented policies and a good energy framework and infrastructure.

3.3. Green hydrogen production and export (HFE)

The detailed results of the green hydrogen production and export (HFE) index components are shown in Fig. 4.

Fig. 4 reports the CIs regarding the feasibility of green hydrogen production and its export. Regarding the sub-index HFE, in ECOWAS, Table 4 shows that Cabo Verde, Senegal, and Burkina Faso rank joint first with a score of 0.46. ranks first with a score of 0.46. Benin and Liberia rank lowest with scores below 0.30. Regarding the sub-component on production feasibility HF, Gambia ranks first with 0.51, followed by Guines-Bissau and Niger (both at 0.48), as well as Sierra Leone at 0.47. Regarding the sub-component on export feasibility HE, Ghana (0.56), Cabo Verde (0.55), and Côte d'Ivoire (0.53) perform best. Weaknesses common to Cabo Verde, Guines-Bissau, and Gambia are export capacity, fuel exports, and regional export indicators. Ghana and Côte d'Ivoire underperform in terms of H2 cost and potential. Burkina Faso, Niger, and Sierra Leone rank low in terms of risk and security.

In SADC, Table 4 shows that South Africa stands out with a score of 0.62 in terms of HFE, followed by Mozambique (0.49) and Madagascar (0.48). Seychelles, Tanzania, Comoros, and Congo DR have the lowest scores. Madagascar and South Africa rank first (0.49) and second (0.48) in terms of HF, respectively. In terms of HE, South Africa ranks, by far, first with a score of 0.76, followed by Mauritius (0.68) and Botswana (0.65). The infrastructure score is a main weakness for both Mozambique and Madagascar. Mauritius ranks low on fuel exports, regional exports, and hydrogen potential, whereas Malawi and Botswana underperform in terms of documentary compliance and logistic score. Finally, both Botswana and South Africa rank low in terms of groundwater resources, yet the latter has desalination potential due to its sizable coastline.

Overall, while in terms of the sub-index on hydrogen feasibility, the best countries in the two regions perform similarly, in terms of export, SADC appears to perform better than ECOWAS, especially thanks to countries such as South Africa and Mauritius, which enjoy a higher level of integration in global trade.

3.4. Sensitivity analysis

The initial ranking of countries based on the indicators positions South Africa and Lesotho are at the top in the SADC region, with Cabo Verde and Ghana leading in the ECOWAS region. To assess the robustness of these rankings, a sensitivity analysis was conducted over 500 iterations by altering weights (random 15% variation), normalizing methods (Min-Max scaling, z-score standardization), and aggregation techniques (arithmetic mean, geometric mean).

The sensitivity analysis follows a structured methodology that examines how variations in the assumptions underlying the composite indicator construction influence the rankings. First, Monte Carlo simulations were used to generate random variations of 15% in the weights, ensuring the total weight always sums to 100%. Next, alternative normalization between the two preselected methods was applied to scale the data, testing whether differences in range standardization affect the comparability of indicators. Finally, aggregation techniques were alternated to explore how compensability (the ability of one indicator to offset another) influences the final rankings. For instance, the arithmetic mean assumes full compensability, while the geometric mean limits compensability, reflecting stricter trade-offs among indicators.

The results of the sensitivity analysis provide insights into the stability of the rankings and how changes in methodology affect each country's position. Only the ranking statistics were analyzed, as it is the only comparable metric across different composite indicator methodologies. For each iteration, ranking positions were recorded and Fig. 5 shows the order of the countries by their nominal ranks, and the median rank across the uncertainty analysis. Additionally, to explore further the central tendency and the range of variability in rankings, **Annex 5** provides a more comprehensive table of the sensitivity analysis results, including mean, median, Q5, and Q95.

The analysis shows that South Africa (ZAF) maintains its leading position in the majority of iterations, demonstrating relative stability in its ranking. Lesotho (LSO), Cabo Verde (CPV), Angola (AGO), Malawi (MWI), and Ghana (GHA) also exhibit relatively stable rankings, reinforcing their positions in the top tier. Among these countries, only ZAF and AGO had a higher variability of 5 and 6, respectively, compared to

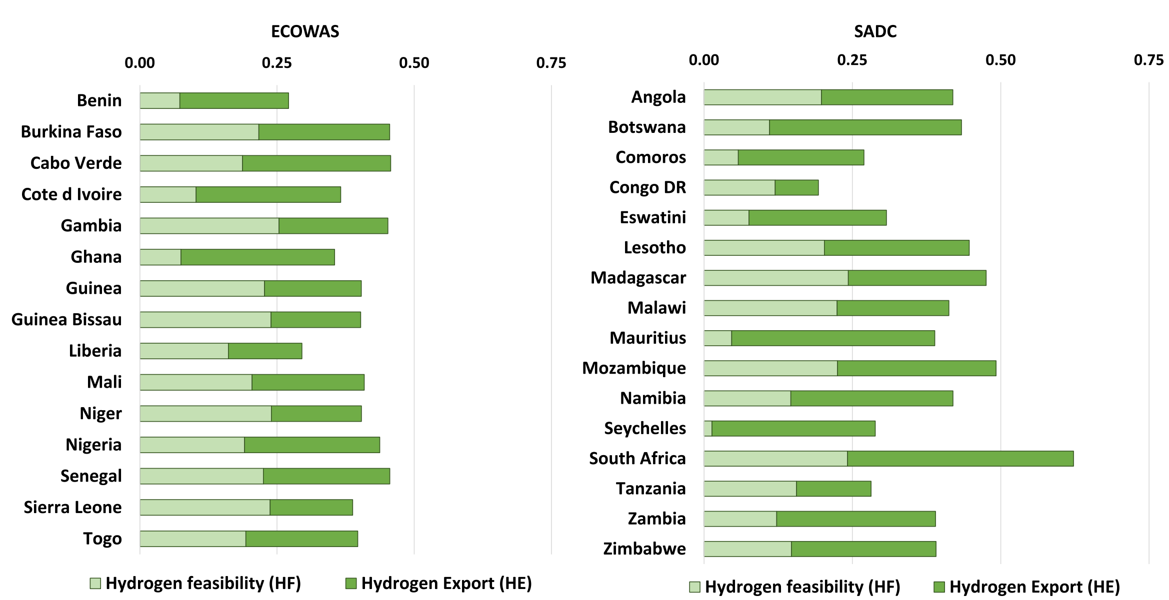

Fig. 4. Hydrogen feasibility (HF) and export (HE) composite indicators.

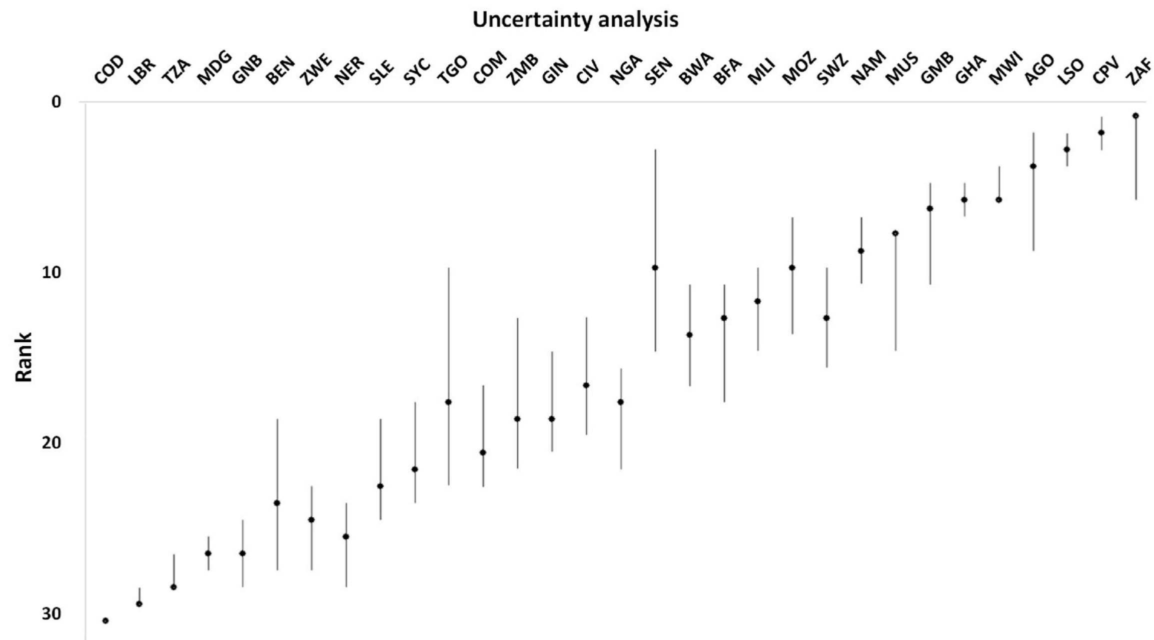

Fig. 5. *U*ncertainty analysis of the countries sorted by their nominal rank.

around 2 for the other countries.

Several countries, such as Mozambique (MOZ), Mali (MLI), and Burkina Faso (BFA), consistently maintain mid-range positions, indicating stability in their rankings across different iterations. Meanwhile, countries like Congo DR (COD), Liberia (LBR), Tanzania (TZA), and Madagascar (MDG) consistently rank toward the bottom in most iterations, reflecting their lower standing in terms of the different indicators.

However, some countries experience more significant variations in their rankings across iterations. For instance, Senegal (SEN) shows sensitivity to changes in methodology, with its ranking fluctuating notably. Togo (TGO) and Benin (BEN) also exhibit variability in their rankings, suggesting that their positions are influenced by the chosen weights, normalization, and aggregation methods. Looking at these countries' index scores separately, they are located at the first quartile for SEN and the third one for TGO. Thus, a small variation by$\pm$0.01 in the score leads to a change for Senegal in 8 positions and 7 positions for Togo.

4. Discussion

The results of this analysis have shown that there is a wide variability in terms of potential, readiness, and, more generally, feasibility of hydrogen economies across countries in West and South Africa. Technical potential, at least in terms of RES sources, is present in most of the countries: aside from some notable exceptions (e.g., Seychelles), even countries with a below-average score on HF1.0 may still have significant potential for green hydrogen production. This is especially true for large countries, whose national score averages vast areas with high production potential and areas less ideal for the deployment of RES capacity. In this regard, further research within the context of H2Atlas and JGA pays special attention to the spatial dimension of green hydrogen feasibility, by focusing on the assessment of sub-national territorial units, as well as of hydrogen hubs and valleys.

However, a major bottleneck for technical feasibility can be embodied by water resources: several countries have scarce groundwater resources, which cannot be compensated by access to the coastline for desalinated water. In such cases, the presence of a good power grid infrastructure, as well as cooperation and trade with neighboring countries with abundant water resources (also in terms of desalinated water) become crucial for the feasibility and sustainability of green hydrogen production. Another factor affecting feasibility is of course the estimated levelized cost of green hydrogen (LCOH) production, which is captured by the indicator HF2.0: this, however, shows rather low variability, meaning that cost does not seem a major driver for divergent levels of feasibility. Such an outcome is because: (i) as already discussed, most of the countries enjoy good conditions in terms of RES potential; (ii) the differences in LCOH depend exclusively on RES technical potential, rather than on differences in discount rates. In fact, country risk, and therefore discount rates, may vary considerably between countries across the two regions, impacting the economic assessment of hydrogen projects. Such a limitation is addressed in this study, as the composite indicator approach encompasses several indicators affecting the investment risk associated with green hydrogen projects, both directly (i. e., HE5.0) and indirectly (e.g., EF1.0). This approach allows to disentangle several aspects that may indeed impact the attractiveness of green hydrogen investment, thereby allowing for a more qualitative assessment of green hydrogen feasibility. For instance, in the case of the indicator EF1.0, a low level of energy security may be perceived to increase the risk of a secure energy supply for hydrogen production, as well as the risk of energy conflicts. On the other hand, a low performance in this indicator may also be an opportunity, in that local governments could adopt green hydrogen as a strategy to increase energy security and possibly electricity access. Therefore, indicators on sustainable policies (including the indicators SP3 on improvement in energy access) point to the commitments and progress made towards sustainable development goals, which would go hand in hand with a national green hydrogen strategy.

The presence of a fossil fuel industry can also be seen as a further double-edged sword. On the one hand, this industry correlates with a good score on the energy framework and export feasibility indicators. On the other hand, in countries reliant on fossil fuel exports, decarbonization policies might be less politically appealing: further investment in the fossil fuel industry may result in technological lock-in, whereas production of blue and even grey hydrogen may be preferred over green one. Ghana, for instance, appears to overcome this, as its good performance on energy framework and export infrastructure, due in part to an important fossil fuel industry, is combined with a political framework oriented towards sustainability.

Adding to the broader analysis, examining specific countries reveals unique insights that explain the divergence in general or sub-index scores. For instance, despite a seemingly low potential score, Ghana demonstrates considerable promise for a hydrogen economy, particularly in the context of the ECOWAS region's future export-based economy. The country's overall potential, accounting for 25% of energy potential expansion, amounts to 560 TWh. This is equivalent to one-fifth of its current final energy consumption. Ghana's case underscores that a low potential score does not necessarily preclude the development of a viable hydrogen economy.

Nigeria and Angola, as major oil, and natural gas exporters, possess transport and export infrastructures that could be advantageous for hydrogen and its derivatives. Existing natural gas pipelines might be repurposed for blended green hydrogen, while oil terminal infrastructures are suitable for liquid organic hydrogen carriers. However, Angola scores higher than Nigeria, primarily due to its significant hydropower generation, which positively influences indicators related to the use and willingness to adopt renewable energy resources.

Namibia stands out for its active involvement in current hydrogen projects, yet it only achieves an average score. This can be attributed to two main factors. Firstly, within the H2-Atlas assessment, vast high-potential regions are assumed to be ineligible for project development due to their status as protected areas. However, this assumption may not hold in the Namibian context: several planned projects in the Tsau Khaeb National Park would be deemed infeasible because of land eligibility within the H2-Atlas analytical framework. Secondly, Namibia's low population density makes it less attractive in terms of local impact: this also indicates that Namibian green hydrogen production would be highly export-oriented. Furthermore, the country's energy security indicator is low, largely because it relies on energy imports from South Africa. However, as discussed before, this dependency could also be interpreted as an incentive to invest in green hydrogen as a mean to enhance energy autonomy.

A further caveat concerns this last point: although low energy security may negatively affect green hydrogen feasibility, (inter)dependence on neighboring countries should not be necessarily considered a downside, nor it should negatively affect green hydrogen feasibility. As a matter of fact, countries' strengths might complement each other and/or operate in synergy, creating new opportunities for regional cooperation and trade. In this regard, preexisting interdependences could be the foundation for regionally integrated green hydrogen economies. The coordinated effort to build green hydrogen economies across the region through the so-called green hydrogen diplomacy, as well as the resulting economic integration, might in turn increase regional institutional and economic stability, thereby triggering a positive feedback loop around green hydrogen feasibility.

5. Conclusions

Focusing on green hydrogen export potential and domestic applications, this study presents a detailed assessment using composite indicators to evaluate the feasibility of a green hydrogen economy within the ECOWAS and SADC regions of West and Southern Africa. It shows the complex dimensions affecting the socio-economic, political, and technical feasibility of a green hydrogen industry in West and Southern Africa. The use of composite indicators allows for a first preliminary assessment of the strengths and weaknesses of the countries under analysis. Such a cross-country, multi-dimensional comparison helps to identify the aspects in which countries have more potential, as well as the barriers that need to be addressed by policymakers and/or potential investors.

5.1. Key findings

The main findings reveal considerable variation across countries, highlighting unique strengths and challenges. For instance, South Africa emerges as a leader in the SADC region, showcasing strong potential in both hydrogen production and export capabilities, underpinned by robust infrastructure and policy frameworks. In contrast, countries like the Congo DR face significant challenges due to limited infrastructure and high geopolitical risks, despite having considerable potential for green hydrogen production. In West Africa, Ghana stands out with its advanced energy framework and commitment to sustainable policies, positioning it well prepared for both domestic and international hydrogen markets. Challenges in countries like Guinea-Bissau, primarily in infrastructure and policy, underscore the need for tailored strategies to unlock their green hydrogen potential.

However, such an assessment is not meant to rank countries against one another but rather aims to support innovation among potential first movers, which may pave the way for countries with current low levels of feasibility.

Moreover, country-specific strengths may be complementary in terms of technical potential (renewable electricity potential vs water resources), infrastructure (grid, roads, and ports), as well as policies. Regarding this last aspect, mutual, trade-related interest may help the development of joint H2 policies, whereby green-hydrogen-friendly political frameworks may spill over into neighboring trade partners. One the one hand, cooperation among (neighboring) countries might be crucial for a cost-efficient and therefore more feasible green hydrogen industry. On the other hand, a transnational green hydrogen industry would generally boost the energy and economic integration of countries in West and Southern Africa, thereby enhancing shared prosperity across the region.

All the results presented in this paper would be beneficial for the next steps of both H2-ATLAS and JUST-GREEN AFRH2ICA Projects which are continuously collaborating to assess the most relevant strategies and approaches to promote African renewable hydrogen transition. This paper could be also a basis to compare its results with other energy/hydrogen modeling and planning approaches to be proposed by the authors in the future in the context of these two projects and leveraging local stakeholders' inputs and literature data to further refine their analysis.

Additionally, an extension will be needed to address aspects not addressed by the current composite indicator analysis, particularly the regulatory and political framework for implementing a hydrogen economy in the region. Furthermore, the analysis of the four sub-indexes is done separately and underscores the need to explore potential correlations. There may be also some connections between for instance renewable energy policies and the development of green hydrogen projects. Conducting the sensitivity analyses to account for varying weights of sub-indicators influenced by correlations mitigated this limitation, however, a more comprehensive comparison with future studies is essential.

Finally, composite indicators often have limitations such as compensability issues, where poor performance in one area can be offset by good performance in another. Moreover, poor performance does not necessarily imply infeasibility; challenges such as stability and lack of infrastructure, often significant barriers to energy project investment in the continent, can be addressed through project implementation and stakeholder engagement, including community involvement from the start of the project.

5.2. Policy analysis

If the analysis shows that there is potential for green hydrogen development in various regions, the feasibility of the hydrogen economy will be dependent on the investment feasibility, which will likely come from a mix of international financial institutions, private sector investors, and public sector contributions. There has been an increasing interest in funding renewable energy projects in Africa and providing the necessary capital and technical assistance to kickstart hydrogen projects. Additionally, private sector companies, especially those in the energy and industrial sectors, are keen to invest in green hydrogen as part of their sustainability strategies and to capitalize on new market opportunities. This, however, must be complemented by public sector support. The framework and policy indicator analysis suggest that, despite economic challenges, African governments are increasingly committed to investing in renewable energy and green hydrogen to diversify energy sources, reduce dependence on fossil fuels, and achieve sustainable development goals.

A major outcome of the analysis is the need for regional collaboration, this along with the importance of foreign investment and external funds to stimulate investments creates a complex ecosystem that will rely on international relations and trade agreements. The success of a green hydrogen economy in the regions will depend not only on technological and economic factors but also on political and diplomatic relationships between producing and consuming countries. Bilateral and multilateral trade agreements, such as the African Continental Free Trade Area (AfCFTA), on the one hand, will facilitate export collaboration on green hydrogen in Africa, reducing trade barriers and enhancing economic cooperation. On the other hand, partnerships between African countries and the European Union (EU), supported by the EU's Green Deal, will provide regulatory and financial frameworks for green hydrogen trade.

This international cooperation is also essential to facilitate knowledge sharing, technology transfer, and financial resource allocation. Several successful examples of international cooperation have already been established in this regard. For instance, Germany's partnership with Namibia to develop a green hydrogen facility in the Namib Desert, supported by German funding and technology will surely enhance the sustainability of green hydrogen economies, creating job opportunities and ensuring long-term project viability.

Finally, the analysis shows that water availability could be a bottleneck for hydrogen development in the region, and scaling up green hydrogen production can pose potential environmental impacts. To mitigate these impacts, sustainable practices are essential and should be implemented from the start of hydrogen projects. These include implementing water recycling and conservation techniques and using non-potable water sources for electrolysis. In this regard, desalination could be a key strategy to unlock the potential of green hydrogen while mitigating water stress and improving water access by oversizing production capacities.

CRediT authorship contribution statement

Amin Lahnaoui: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Gianmarco Aniello:** Writing – original draft, Validation, Investigation, Data curation, Conceptualization. **Stefano Barberis:** Writing – review & editing, Resources, Project administration, Funding acquisition, Conceptualization. **Solomon Nwabueze Agbo:** Writing – original draft, Resources, Project administration, Funding acquisition, Conceptualization. **Wilhelm Kuckshinrichs:** Writing – review & editing, Supervision, Resources, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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ANNEX.

Annex 1
Summary of the inputs used to assess hydrogen feasibility [46–49].

Code	LCOH in €/kg	Potential in TWh/yr	Groundwater in mm/yr	Area in km^2	Coastline in km	local impact in %
AGO	4.41	16531.24	16.77	1246700	1600	0.00
BEN	4.49	31.49	12.10	110622	121	12.75
BWA	4.19	4510.51	2.05	566730	0	0.00
BFA	4.41	2663.26	7.06	273800	0	71.46
CPV	3.75	46.16	0.00	4033	965	2.49
COM	4.64	1.80	6.42	2235	340	0.00
COD	4.63	8565.80	15.42	2344858	169	20.80
CIV	4.66	86.26	10.58	318003	515	23.22
SWZ	4.77	85.65	0.36	17204	0	21.66
GMB	4.31	90.19	25.46	10120	80	61.87
GHA	4.65	560.21	8.25	227533	539	0.00
GIN	3.79	16.54	78.92	245717	320	28.75
GNB	4.56	162.80	91.21	28120	350	59.81
LSO	4.06	117.27	12.17	30355	0	53.88
LBR	4.95	65.31	114.80	96320	579	41.13
MDG	4.19	2677.86	44.07	581540	2828	0.00
MWI	4.47	637.24	6.91	94080	0	90.33
MLI	4.07	27676.58	7.83	1220190	0	0.07
MUS	4.61	4.11	0.00	2030	177	0.00
MOZ	4.52	10712.72	12.80	786380	2470	13.78
NAM	4.17	5091.20	1.82	823290	1572	0.57
NER	3.98	28235.22	20.14	1266700	0	0.03
NGA	4.50	7755.04	55.11	910768	853	5.18
SEN	4.31	1850.39	25.46	196722	531	32.31
SYC	5.00	0.02	0.00	455	491	0.00

(continued on next page)

Annex 1 (*continued*)

Code	LCOH in €/kg	Potential in TWh/yr	Groundwater in mm/yr	Area in km^2	Coastline in km	local impact in %
SLE	4.83	194.82	114.00	71740	402	82.81
ZAF	4.05	20729.22	1.43	1219912	2798	0.00
TZA	4.62	5667.28	8.15	885800	1424	24.01
TGO	4.72	639.36	11.31	56785	56	59.28
ZMB	4.39	7336.09	10.19	752614	0	0.05

Annex 2
Indicators raw statistical values.

Indicator	Min	Max	Mean	Median	Q25	Q75	IQ-Range	Std.dev
EF1.0	0	1	0.41	0.23	0.04	0.84	0.8	0.4
EF2.0	0.87	1	0.95	0.97	0.95	0.98	0.03	0.04
EF3.0	0.01	0.96	0.55	0.61	0.35	0.77	0.42	0.27
EF4.0	0	1	0.42	0.34	0.05	0.71	0.66	0.36
EF5.0	2.41	15.02	6.55	5.33	3.34	8.61	5.28	3.67
SP1.0	0.14	1	0.55	0.5	0.38	0.75	0.38	0.21
SP2.0	0	0.02	0	0	0	0	0	0
SP3.1	0.4	1	0.84	0.96	0.73	1	0.27	0.2
SP3.2	0.01	1	0.39	0.25	0.04	0.67	0.63	0.37
HF1.0	0.04	22.68	7.34	6.4	2.59	9.92	7.34	6.05
HF2.0	3.75	5	4.42	4.47	4.19	4.64	0.44	0.31
HF3.1	0	177.64	25.42	10.58	4.98	22.8	17.82	39.84
HF3.2	0	2828	618.71	340	0	716	716	832.23
HF4.0	0	90.33	23.55	13.78	0	36.72	36.72	27.86
HE1.1	0	1	0.54	0.57	0.45	0.66	0.21	0.26
HE1.2	0	7	1.5	1	0.5	1.75	1.25	1.77
HE2.1	98.08	1580.56	528.7	422.6	300.81	674.35	373.53	358.62
HE2.2	25	347.5	151.06	133	93	189.62	96.62	82.1
HE3.1	0	0.95	0.1	0.01	0	0.07	0.07	0.23
HE3.2	0	1	0.25	0.14	0.05	0.3	0.25	0.3
HE3.3	0	0.95	0.1	0.01	0	0.07	0.07	0.23
HE4.1	0.01	1	0.53	0.46	0.18	0.97	0.8	0.37
HE4.2	0	0.7	0.41	0.46	0.4	0.5	0.1	0.15
HE5.0	37.5	92.5	79.49	84.1	78	87	9	12.4

Annex 3
Indicators correlation matrix

	EF.1	EF.2	EF.3	EF.4	EF.5	SP.1	SP.2	SP.3	HP.1	HP.2	HP.3	HP.4	HE.1	HE.2	HE.3	HE.4	HE.5
EF.1		0.06	0.08	0.25	0.20												
EF.2	0.06		0.22	0.08	0.06												
EF.3	0.08	0.22		0.20	0.53												
EF.4	0.25	0.08	0.20		0.37												
EF.5	0.20	0.06	0.53	0.37													
SP.1							0.08	0,03									
SP.2						0.08		0,25									
SP.3						0,03	0,25										
HP.1										0,49	0,07	0,17					
HP.2									0,49		0,07	0,22					
HP.3									0,07	0,07		0,05					
HP.4									0,17	0,22	0,05						
HE.1														0,04	0,35	0,07	0,27
HE.2													0,04		0,35	0,3	0,13
HE.3													0,35	0,35		0,11	0,23
HE.4													0,07	0,3	0,11		0,13
HE.5													0,27	0,13	0,23	0,13	

Annex 4
Main strengths and weaknesses of the country's indicators.

Strengths				Weaknesses			
Country	Code	Name	Rank	Country	Code	Name	Rank
AGO	EF1.0	Energy security	1	AGO	SP2.0	Renewable Energy Policies	29
AGO	HE3.1	Fuel exports	1	AGO	HE2.1	Border regulation	28
AGO	HE3.2	Capacity export	1	AGO	HE1.1	Border Trade	27
AGO	HE3.3	Regional export	1	AGO	HE2.2	Documentary compliance	27
AGO	SP1.0	Climate Change Policies	2	AGO	HE4.1	Infrastructure score	27
BEN	SP1.0	Climate Change Policies	2	BEN	HE5.0	Risk and Security	29
BEN	HE4.2	Logistic score	3	BEN	EF4.0	Renewable Energy	28
BEN	HE2.2	Documentary compliance	6	BEN	HF1.0	H2 Potential	28
BEN	SP2.0	Renewable Energy Policies	6	BEN	EF1.0	Energy security	27
BEN	HE1.1	Border Trade	8	BEN	EF2.0	Energy Efficiency	25
BFA	SP1.0	Climate Change Policies	2	BFA	HE5.0	Risk and Security	25
BFA	HF4.0	Local Impact	3	BFA	EF1.0	Energy security	24
BFA	HE4.2	Logistic score	4	BFA	EF2.0	Energy Efficiency	24
BFA	HE2.2	Documentary compliance	7	BFA	EF3.0	Energy and Health	24
BFA	HE2.1	Border regulation	8	BFA	EF.4	Renewable Energy	22
BWA	HE2.1	Border regulation	1	BWA	HE4.2	Logistic score	28
BWA	HE4.1	Infrastructure score	1	BWA	EF2.0	Energy Efficiency	27
BWA	SP3.1	Access to Electricity	1	BWA	SP1.0	Climate Change Policies	27
BWA	HE1.1	Border Trade	3	BWA	HF3.1	Groundwater	25
BWA	HE5.0	Risk and Security	4	BWA	HE2.2	Documentary compliance	23
CIV	EF1.0	Energy security	1	CIV	HF1.0	H2 Potential	29
CIV	EF2.0	Energy Efficiency	2	CIV	HF2.0	H2 Cost	26
CIV	HE4.2	Logistic score	2	CIV	SP3.1	Renewable Energy Policies	26
CIV	HE3.1	Fuel exports	5	CIV	HE1.1	Border Trade	24
CIV	HE3.2	Capacity export	5	CIV	SP1.0	Climate Change Policies	20
COD	EF1.0	Energy security	1	COD	SP3.1	Access to Electricity	30
COD	EF4.0	Renewable Energy	3	COD	SP1.0	Climate Change Policies	28
COD	HE3.2	Capacity export	6	COD	HE3.1	Fuel Export	23
COD	HE1.2	Harbors	9	COD	HE3.3	Regional export	23
COD	HF3.1	Groundwater	11	COD	HF2.0	H2 Cost	23
COM	HE4.1	Infrastructure score	1	COM	EF4.0	Renewable Energy	30
COM	SP3.1	Access to Electricity	1	COM	EF1.0	Energy security	26
COM	EF5.0	Energy Intensity	2	COM	HF1.0	H2 Potential	26
COM	HE4.2	Logistic Score	7	COM	HE2.1	Border regulation	25
COM	SP3.2	Access to Clean fuel	4	COM	HF2.0	H2 Cost	24
CPV	HE4.1	Infrastructure score	1	CPV	HE3.1	Fuel exports	30
CPV	HF2.0	H2 Cost	1	CPV	HE3.2	Capacity export	30
CPV	SP3.1	Access to Electricity	1	CPV	HE3.3	Regional export	30
CPV	SP1.0	Climate Change Policies	2	CPV	HE2.1	Border regulation	24
CPV	EF5.0	Energy Intensity	3	CPV	EF1.0	Energy security	23
GHA	EF1.0	Energy security	1	GHA	HF2.0	H2 Cost	25
GHA	SP3.1	Access to Electricity	1	GHA	HF1.0	H2 Potential	24

	Strengths				Weaknesses			
Country	**Code**	**Name**	**Rank**	**Country**	**Code**	**Name**	**Rank**
GHA	HE3.1	Fuel exports	4	**GHA**	HE1.1	Border Trade	23
GHA	HE3.2	Capacity export	4	**GHA**	SP1.0	Climate Change Policies	19
GHA	HE3.3	Regional export	4	**GHA**	EF.4	Renewable Energy	19
GIN	HF2.0	H2 Cost	2	**GIN**	HF1.0	H2 Potential	30
GIN	SP1.0	Climate Change Policies	2	**GIN**	SP3.2	Access to Clean fuel	28
GIN	HF3.1	Groundwater	4	**GIN**	HE1.1	Border Trade	26
GIN	HF4.0	Local Impact	10	**GIN**	HE2.1	Border regulation	26
GIN	EF4.0	Renewable Energy	11	**GIN**	EF3.0	Energy and Health	23
GMB	SP1.0	Climate Change Policies	1	**GMB**	EF4.0	Renewable Energy	29
GMB	HF3.1	Groundwater	7	**GMB**	HE3.1	Fuel exports	29
GMB	HF4.0	Local Impact	4	**GMB**	HE3.2	Capacity export	29
GMB	EF5.0	Energy Intensity	7	**GMB**	HE3.3	Regional export	29
GMB	EF.4	Renewable Energy	1	**GMB**	EF1.0	Energy security	28
GNB	HF3.1	Groundwater	3	**GNB**	EF1.0	Energy security	30
GNB	HF4.0	Local Impact	5	**GNB**	EF3.0	Energy and Health	30
GNB	EF2.0	Energy Efficiency	9	**GNB**	HE3.1	Fuel exports	28
GNB	HE4.2	Logistic score	10	**GNB**	HE3.2	Capacity export	28
GNB	SP1.0	Climate Change Policies	14	**GNB**	HE3.3	Regional export	28
LBR	SP3.1	Access to Electricity	1	**LBR**	HF2.0	H2 Cost	30
LBR	SP1.0	Climate Change Policies	2	**LBR**	SP3.2	Access to Clean fuel	30
LBR	HF3.1	Groundwater	1	**LBR**	EF5.0	Energy Intensity	29
LBR	EF2.0	Energy Efficiency	8	**LBR**	HE1.1	Border Trade	29
LBR	SP2.0	Renewable Energy Policies	3	**LBR**	HE2.1	Border regulation	29
LSO	EF4.0	Renewable Energy	1	**LSO**	EF2.0	Energy Efficiency	26
LSO	SP3.1	Access to Electricity	1	**LSO**	EF5.0	Energy Intensity	25
LSO	HE1.1	Border Trade	2	**LSO**	HE3.2	Capacity export	23
LSO	EF3.0	Energy and Health	5	**LSO**	HE4.2	Logistic score	21
LSO	SP2.0	Renewable Energy Policies	5	**LSO**	HF1.0	H2 Potential	21
MDG	HF3.2	Desalination	1	**MDG**	HE4.1	Infrastructure score	25
MDG	HE3.1	Fuel exports	3	**MDG**	SP2.0	Renewable Energy Policies	24
MDG	HE3.3	Regional export	3	**MDG**	HE5.0	Risk and Security	23
MDG	HE1.2	Harbors	6	**MDG**	EF3.0	Energy and Health	22
MDG	HF3.1	Groundwater	6	**MDG**	HE2.1	Border regulation	21
MLI	HF1.0	H2 Potential	1	**MLI**	SP3.2	Access to Clean fuel	29
MLI	SP3.1	Access to Electricity	1	**MLI**	HE4.1	Infrastructure score	28
MLI	HE2.2	Documentary compliance	2	**MLI**	HE3.1	Fuel exports	22
MLI	EF2.0	Energy Efficiency	3	**MLI**	HE3.3	Regional export	22
MLI	HE1.1	Border Trade	5	**MLI**	HF3.1	Groundwater	20
MOZ	EF1.0	Energy security	1	**MOZ**	EF5.0	Energy Intensity	30
MOZ	EF2.0	Energy Efficiency	1	**MOZ**	HE4.1	Infrastructure score	29
MOZ	HF3.2	Desalination	3	**MOZ**	HE4.2	Logistic score	29
MOZ	HE1.2	Harbors	4	**MOZ**	SP1.0	Climate Change Policies	28

	Strengths				Weaknesses			
Country	Code	Name	Rank	Country	Code	Name	Rank	
MOZ	HF1.0	H2 Potential	4	**MOZ**	SP3.2	Access to Clean fuel	23	
MUS	EF5.0	Energy Intensity	1	**MUS**	HE3.1	Fuel exports	25	
MUS	HE4.1	Infrastructure score	1	**MUS**	HE3.3	Regional export	25	
MUS	HE.5	Risk and Security	3	**MUS**	HF1.0	H2 Potential	25	
MUS	EF3.0	Energy and Health	2	**MUS**	SP2.0	Renewable Energy Policies	22	
MUS	SP3.2	Access to Clean fuel	3	**MUS**	HF2.0	H2 Cost	21	
MWI	HF4.0	Local Impact	1	**MWI**	HE2.2	Documentary compliance	30	
MWI	SP3.1	Access to Electricity	1	**MWI**	HE3.2	Capacity export	24	
MWI	HE2.1	Border regulation	3	**MWI**	HE4.2	Logistic score	23	
MWI	EF4.0	Renewable Energy	3	**MWI**	HE4.1	Infrastructure score	21	
MWI	EF2.0	Energy Efficiency	5	**MWI**	SP3.2	Access to Clean fuel	20	
NAM	HE4.1	Infrastructure score	1	**NAM**	EF2.0	Energy Efficiency	30	
NAM	SP1.0	Climate Change Policies	2	**NAM**	HE4.2	Logistic score	27	
NAM	EF3.0	Energy and Health	3	**NAM**	HF3.1	Groundwater	26	
NAM	EF4.0	Renewable Energy	4	**NAM**	SP3.1	Access to Electricity	25	
NAM	HE2.1	Border regulation	4	**NAM**	HF4.0	Local Impact	20	
NER	HF1.0	H2 Potential	2	**NER**	HE4.1	Infrastructure score	30	
NER	HE2.2	Documentary compliance	3	**NER**	HE5.0	Risk and Security	30	
NER	HF2.0	H2 Cost	3	**NER**	EF2.0	Energy Efficiency	29	
NER	EF1.0	Energy security	8	**NER**	SP3.1	Access to Electricity	27	
NER	HE3.1	Fuel exports	8	**NER**	SP3.2	Access to Clean fuel	26	
NGA	EF1.0	Energy security	1	**NGA**	SP2.0	Renewable Energy Policies	30	
NGA	HE3.2	Capacity export	1	**NGA**	HE1.1	Border Trade	28	
NGA	HE1.2	Harbors	2	**NGA**	HE2.2	Documentary compliance	28	
NGA	HE3.1	Fuel exports	2	**NGA**	EF3.0	Energy and Health	27	
NGA	SP1.0	Climate Change Policies	2	**NGA**	HE2.1	Border regulation	27	
SEN	SP3.1	Access to Electricity	1	**SEN**	EF4.0	Renewable Energy	23	
SEN	HE3.1	Fuel exports	6	**SEN**	HE4.1	Infrastructure score	23	
SEN	HE3.3	Regional export	6	**SEN**	EF1.0	Energy security	22	
SEN	HE1.2	Harbors	7	**SEN**	HE2.1	Border regulation	19	
SEN	HF3.1	Groundwater	7	**SEN**	HE1.1	Border Trade	18	
SLE	HF4.0	Local Impact	2	**SLE**	HF2.0	H2 Cost	29	
SLE	SP1.0	Climate Change Policies	2	**SLE**	SP3.1	Access to Electricity	28	
SLE	HF3.1	Groundwater	2	**SLE**	HE3.1	Fuel exports	27	
SLE	EF4.0	Renewable Energy	8	**SLE**	HE3.3	Regional export	27	
SLE	SP2.0	Renewable Energy Policies	13	**SLE**	HE5.0	Risk and Security	27	
SWZ	HE1.1	Border Trade	1	**SWZ**	HF2.0	H2 Cost	28	
SWZ	SP3.1	Access to Electricity	1	**SWZ**	HE3.1	Fuel exports	24	
SWZ	EF4.0	Renewable Energy	2	**SWZ**	HE3.3	Regional export	24	
SWZ	HE2.1	Border regulation	2	**SWZ**	SP2.0	Renewable Energy Policies	24	
SWZ	SP1.0	Climate Change Policies	2	**SWZ**	HE3.2	Capacity export	20	
SYC	EF3.0	Energy and Health	1	**SYC**	EF1.0	Energy security	29	

	Strengths				Weaknesses			
Country	Code	Name	Rank	Country	Code	Name	Rank	
SYC	HE4.1	Infrastructure score	1	**SYC**	EF4.0	Renewable Energy	27	
SYC	SP3.1	Access to Electricity	1	**SYC**	HE3.1	Fuel exports	26	
SYC	SP3.2	Access to Clean fuel	1	**SYC**	HE3.2	Capacity export	26	
SYC	HE5.0	Risk and Security	2	**SYC**	HE3.3	Regional export	26	
TGO	HE2.2	Documentary compliance	1	**TGO**	EF2.0	Energy Efficiency	28	
TGO	SP3.1	Access to Electricity	1	**TGO**	EF5.0	Energy Intensity	28	
TGO	SP1.0	Climate Change Policies	2	**TGO**	HE5.0	Risk and Security	28	
TGO	SP2.0	Renewable Energy Policies	5	**TGO**	HF2.0	H2 Cost	27	
TGO	HE2.1	Border regulation	6	**TGO**	EF1.0	Energy security	25	
TZA	HE1.2	Harbors	3	**TZA**	HE1.1	Border Trade	30	
TZA	HF3.2	Desalination	6	**TZA**	HE2.1	Border regulation	30	
TZA	HE3.1	Fuel exports	7	**TZA**	HE2.2	Documentary compliance	29	
TZA	HE3.3	Regional export	7	**TZA**	EF3.0	Energy and Health	28	
TZA	HE3.2	Capacity export	10	**TZA**	SP2.0	Renewable Energy Policies	28	
ZAF	EF1.0	Energy security	1	**ZAF**	HF3.1	Groundwater	27	
ZAF	HE1.2	Harbors	1	**ZAF**	SP2.0	Renewable Energy Policies	25	
ZAF	HE3.2	Capacity export	1	**ZAF**	EF4.0	Renewable Energy	25	
ZAF	HE4.1	Infrastructure score	1	**ZAF**	EF5.0	Energy Intensity	23	
ZAF	SP3.2	Access to Clean fuel	1	**ZAF**	HE2.1	Border regulation	23	
ZMB	EF2.0	Energy Efficiency	4	**ZMB**	SP1.0	Climate Change Policies	28	
ZMB	HE5.0	Risk and Security	5	**ZMB**	EF5.0	Energy Intensity	24	
ZMB	EF4.0	Renewable Energy	7	**ZMB**	HE2.2	Documentary compliance	24	
ZMB	HE3.2	Capacity export	7	**ZMB**	SP3.1	Access to Electricity	23	
ZMB	SP2.0	Renewable Energy Policies	4	**ZMB**	HE1.1	Border Trade	22	
ZWE	HE4.1	Infrastructure score	1	**ZWE**	SP3.1	Access to Electricity	29	
ZWE	HF1.0	H2 Potential	8	**ZWE**	EF5.0	Energy Intensity	27	
ZWE	EF1.0	Energy security	10	**ZWE**	HF3.1	Groundwater	24	
ZWE	HE5.0	Risk and Security	10	**ZWE**	SP2.0	Renewable Energy Policies	23	
ZWE	HE3.1	Fuel exports	11	**ZWE**	HE4.2	Logistic score	22	

Annex 5
Sensitivity analysis results.

Code	Nominal	Mean	Median	Q5	Q95	IQ-Range
ZAF	1	2.05	1	1	6	5
CPV	2	2.15	2	1	4	3
LSO	3	2.75	3	2	4	2
AGO	4	4.62	4	2	8	6
MWI	5	5.26	5	4	6	2
GHA	6	6.19	6.5	4.95	7	2.05
GMB	7	7.24	7	5	11	6
MUS	8	8.71	8	8	15	7
NAM	9	8.94	9	7	12	5
SWZ	10	12.97	13	9	17	8
MOZ	11	10.3	10	7.95	14	6.05
MLI	12	12.4	12	10	15	5
BFA	13	13.91	13	11	18	7
BWA	14	14.54	14	11	17.05	6.05
SEN	15	10.67	10	3	16	13
NGA	16	17.92	18	15	21	6
CIV	17	16.71	17	12	19.05	7.05
GIN	18	20.56	19	13	21	8
ZMB	19	20.23	19	14	22	8
COM	20	21.05	21	18	23	5
TGO	21	17.06	17	10	24	14
SYC	22	21.93	22	18	24	6
SLE	23	22.71	23	19.95	25	5.05
NER	24	25.87	25	23.95	29	5.05
ZWE	25	25.79	26	23	28	5
BEN	26	23.97	24	19	28	9
GNB	27	26.91	26	25	29	4
MDG	28	26.82	27	26	28	2
TZA	29	28.54	29	27	30	3
LBR	30	29.93	30	29	30	1
COD	31	31	31	31	31	0

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