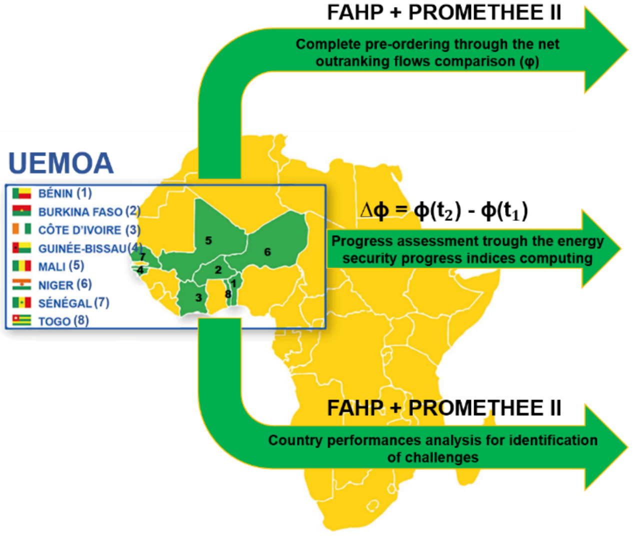
Assessing energy security within the electricity sector in the West African economic and monetary union: inter-country performances and trends analysis with policy implications

Article

Accepted Version

Energy security assessment within the electricity sector in the UEMOA (2010-2019)



MCDA methods

- Fuzzy AHP (FAHP)
- PROMETHEE II

Energy security performances ranking (2019)

1. Côte d'Ivoire
2. Senegal
3. Togo
4. Mali
5. Benin
6. Burkina Faso
7. Niger

Long term energy security progress (2010-2019)

↑ Progression
↓ Regression

↑ Côte d'Ivoire
↑ Senegal
↑ Burkina Faso
↑ Togo
↓ Benin
↓ Mali
↓ Niger

Energy security challenges

- Poor governance
- Lack of competition and collaboration
- Unaffordable and instable services
- Inadequate financing
- Lack of sector policy & regulation
- Poor diversity
- High dependency on imports

Policy Implications

- Governance enhancement
- Sector liberalization
- Promotion of private sector investment
- Implementation of proper energy policies and measures
- Generation capacity increasing with priority to renewables sources
- Off-grid generation and individual solutions
- Power system improvement and maintenance
- Implementation of environmental policies and education
- Energy audit and energy efficiency initiatives

Assessing energy security within the electricity sector in the West African Economic and Monetary Union: Inter-country performances and trends analysis with policy implications

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Abstract

This paper assesses the energy security performance of the electricity sectors of the West African Economic and Monetary Union (UEMOA) countries using Multiple-criteria Decision Analysis. First, it establishes a five-level framework incorporating the dimensions: availability and diversity; affordability and equality; efficiency and reliability; regulation and governance; and environmental sustainability to conceptualize energy security. 18 metrics characterizing these dimensions are then used to assess the energy security performance of the UEMOA countries during the 2010-2019 period. The results indicate that Côte d'Ivoire was the most secure country of the Union, followed by Senegal and Togo in 2019, while the worst-performing country was Niger. Furthermore, Mali, Benin and Niger were found to have regressed the most concerning energy security from 2010 to 2019, whereas Senegal had improved greatest, followed by Togo, Cote d'Ivoire and Burkina Faso. In addition, none of the countries were found to perform well in all the indicators of energy security. Therefore, common actions such as improving governance, increasing generation capacity with priority to renewable sources, improving energy efficiency, upgrading power systems and encouraging R&D and paying more attention to environmental concerns could enhance energy security throughout the electricity sectors of all the UEMOA countries.

Keywords: UEMOA, Electricity Sector, Energy Security, Multiple Criteria Decision Analysis, Energy Policy.

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Abbreviations and acronyms

A	Availability and diversity
AHP	Analytical Hierarchy Process
APERC	Asian Pacific Energy Research Centre
B	Affordability and Equality
C	Efficiency and Reliability
D	Regulation and Governance
E	Environmental Sustainability
ES	Energy Security
ESI	Energy Security Index
FAHP	Fuzzy Analytical Hierarchy Process
FCFA	Franc of the African Financial Community
MCDA	Multiple-Criteria Decision Analysis
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluations
R&D	Research and development
TFN	Triangular Fuzzy Number
UEMOA	West African Economic and Monetary Union

1. Introduction

Access to electricity is a prerequisite for providing essential services and economic growth (Tarekegne and Sidortsov, 2021) and has reached the point where its availability, accessibility and secure supply are perceived as significant development indicators.

17.2% of the world's population live in Africa, however the continent consumes only 3.14% of global electricity use (United Nations, 2019), the lowest of all the world's regions. Access to electricity, defined as the percentage of the total population with access to electricity (World Bank, 2021a), is also the weakest in Africa, with a divide between North Africa and Sub-Saharan Africa. North Africa had reached, almost universal access to electricity by 2019, whereas the electrification rate in sub-Saharan Africa was 48% in the same year (IEA, 2021a, 2019) as a result almost three-quarters of people without access to electricity in the world today live in sub-Saharan Africa (IEA, 2021a). Therefore, the region has the most exposed electricity sector as performances in terms of access, affordability and security of supply remain very low compared to other parts of the world, (Blimpo et al., 2018, 2020; Streatfeild, 2018).

The consequences of such deficiency in the sector include social and economic poverty, under-development, unemployment, a high level of illiteracy and increased migration (Ajayi, 2013; Blimpo and Cosgrove-davies, 2019; Sarkodie and Adams, 2020). In addition, environmental and health concerns must also be considered, due to the lower share of electricity use (**Fig.1**), populations strongly rely on subsidy fuels such as biomass burning for energy, which causes pollution and emissions of harmful gases (Ajayi, 2013; Leite et al., 2021). Thus, the electricity sector, and especially the universal access to electricity, has become a significant priority for most Sub-Saharan

African countries and as a result have revised their development goals to achieve it (Tarekegne and Sidortsov, 2021).

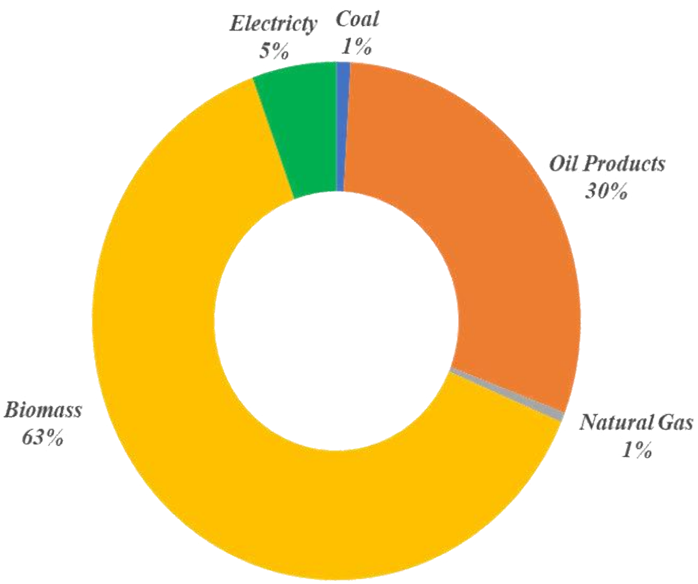

Fig. 1. Share of the different sources for the total energy consumed in UEMOA 2018 (UEMOA, 2020).

The UEMOA countries are not excluded by the deficiency concerning this sector. The region contains some of the least electrified countries in West Africa, as well as the country with the lowest consumption of electricity per capita: Guinea Bissau (IEA, 2021a; IndexMundi, 2021). Therefore, the need to improve the electricity sector is crucial for many of the governments in the UEMOA, forming a critical axis of their development plans. However, success most of the time requires financial investment, which is often beyond the financial capacity of individual countries. Consequently, countries typically rely on financial assistance from international aid and donor organizations (Tarekegne and Sidortsov, 2021), furthermore, lack of proper planning, poor governance, and adverse actions such as corruption and injustices have also caused many failures for initiatives targeting sustainable energy for all in the region (Boamah et al., 2021; Gregory and Sovacool, 2019).

Energy security assessment is one of the critical parameters used to determine the current position and future prospects for the development of all countries and regions (Radovanović et al., 2017; Winzer, 2012) and therefore is a suitable tool to assess the electricity sectors of the UEMOA countries. However, despite the significant amount of literature existing on the topic of energy security, to-date studies have generally focused on the global North. In their review of the factors characterizing energy security in West Africa, Ofosu-Peasah et al. (2021) previously noted the lack of studies on energy security in the global South, especially related to West Africa and tried to fill the gap by characterizing energy security in the region in a general manner rather than focusing on a specific element of energy security. Ofosu-Peasah et al. (2021) defined energy security using nine factors: one region-specific factor (investment); five cross-sector factors (governance, sustainability, reliability, affordability and regional energy pools); and three sector-specific factors (energy demand-side management for the electricity sub-sector; and availability and security for the oil and gas sub-sectors).

Furthermore, this lack of studies on energy security is more critical for quantitative studies, as qualitative approaches were used by most of the studies related to energy security in Sub Saharan Africa (Alemzero et al., 2021). Previously, Acquah and Sarpong (2015), based on the dimensions of the composite energy security index (CESI) proposed by Sovacool et al. (2011) conducted a comparative analysis for energy security between Ghana and 34 countries, including 17 (non-West) African, ASEAN and Global North countries. Also, Alemzero et al. (2021) recently formulated a 13 variables composite index of energy security and evaluated its impacts and trends by using a principal composite factor analysis (PCA) for a sample of 28 African countries. There is, therefore, a gap in research to perform a quantitative analysis of the energy security situation in Sub Saharan Africa, especially for a common characteristics-group of economies that constitutes the UEMOA countries. This paper aims to fill this gap by undertaking an energy security assessment to answer the following research questions:

1) How can energy security be assessed and analyzed for the electricity sectors of the UEMOA countries?
2) What are the current performances and trends of the UEMOA countries in terms of energy security for the electricity sector?
3) What reasons explain such trends for the countries?
4) How can energy security be improved in the electricity sectors of the UEMOA countries?

For this purpose, this study first presents, in section 2 the five-level framework proposed to assess energy security in the electricity sector in the UEMOA. Then in section 3, through the Fuzzy Analytical Hierarchy Process (FAHP) and the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), it assesses the energy security performances of the countries. Next, in Section 4, the paper presents the results and discusses the countries' energy security performances and trends and the possible reasons for such performances. Finally, in section 5, the paper gives the policy implications suggested by the results for the countries and draws conclusions.

2. Conceptualization of the energy security framework

After reviewing the literature on the conceptual aspect of energy security, this section proposes a framework for assessing energy security in the electricity sector in the UEMOA.

2.1. Literature review

Despite a significant body of literature existing on the energy security concept, it remains challenging to find a universal definition and consensus on its precise interpretation (Kruyt et al., 2009). Definitions and interpretations vary, from authors, to places, and also over time (AIT, 2010; APERC, 2007; ENDA, 2009; ERC, 2009; Goldemberg et al., 2009; IEA, 2007; TERI, 2008). Since the first oil crisis in the 1970s, energy security was primarily concerned with issues related to primary source disruption (APERC, 2007), thereby defining energy security as the reliable supply of energy at reasonable prices to support the economy and industry (Asif and Muneer, 2007; Bielecki, 2002; Dorian et al., 2006; IEA, 2001; Yergin, 1988). However, this definition does not consider additional social and environmental dimensions of the concept (Yergin, 2006; Zhang et al., 2017). Therefore it appeared to be narrow over the years. Aiming to capture these various dimensions of energy security and distil them into categories that can be tested and measured as part of an energy security index, Sovacool et al. (2011) defined energy security as "how to equitably provide available, affordable, reliable, efficient, environmentally benign, proactively governed and socially acceptable energy services to end-users". Based on this definition and using interviews, surveys and a workshop with global energy experts, they established a five-level framework broken into 20 components correlated to 20 metrics to set up a comprehensive energy security index. The framework also complies with the "4A" framework (availability, accessibility, acceptability and affordability) developed by the Asia Pacific Energy Research Centre (APERC, 2007), which is common to various studies in the literature (Hughes, 2012; Le and Nguyen, 2019; Ren and Sovacool, 2014a; Winzer, 2012).

This approach of developing an energy security index that aggregates a defined number of energy-related indicators can be used to rank various jurisdictions such as provinces, countries or regions based on the absolute performances concerning energy security (Li et al., 2016; Sovacool et al., 2011; Zhang et al., 2017). The same approach can be used to establish the most or least improved or to evaluate the speed of change or the trends of a jurisdictions' energy security level (Antanasijević et al., 2017; Li et al., 2016; Radovanović et al., 2017; Sovacool, 2011). For example, Li et al. (2016) developed a three-dimension resource-poor economies tailored index to measure energy security performances (of Japan, Korea, Singapore and Taiwan) using principal component analysis. In addition, at a country level, Zhang et al. (2017) developed a five-dimension energy security index broken into 20 components correlated to 20 metrics to measure the energy security performance of 30 Chinese provinces, divided into eight regions. Some of the studies that have developed multi-dimensional frameworks for energy security assessment however did not test their instruments (Vivoda, 2010; Von Hippel et al., 2011).

Instead of a comparative approach concerning energy security, other studies have focused only on analyzing a jurisdiction's energy security level using energy-related indicators that reflect the condition of the energy sources used (APERC, 2007; Bellos, 2018; Hughes, 2012). For example, Hughes (2012) used the IEA's definition of energy security, combined with structured systems analysis techniques to generate a three-indicator framework and a process-flow energy systems model which could apply to any energy system expressed in terms of energy chains and processes.

Finally, a limited number of previous studies have focused only on the security of the components of an energy system, most often electricity or oil and gas supply (Cabalu, 2010; Cohen et al., 2011; Grubb et al., 2006; Moore, 2017). For example, Moore (2017) used a four-level energy security framework to evaluate electricity integration in Morocco by analyzing perceptions of the energy security for shallow and deep electricity integration. Grubb et al. (2006) assessed the diversity of electricity generation in the UK and explored its relationship with the low carbon objectives of the country for the forthcoming decades using a quantified analysis. Based on a four-set of security indicators, Cabalu (2010) computed a composite index—gas supply security index (GSSI) to assess the relative vulnerability to natural gas supply disruptions of seven gas-importing countries in Asia.

2.2. Dimensions and metrics of the index

The UEMOA (**Fig. 2**) consists of eight coastal and Sahel states, linked by a common currency, the FCFA, and benefiting from common characteristics and cultural traditions: Benin, Burkina Faso, Côte d'Ivoire, Guinea-Bissau, Mali, Niger, Senegal and Togo. Created on January 10, 1994, in Dakar, it covers 3,506,126 km^2 with a global population of 123.6 million (UEMOA, 2021). The UEMOA zone has a tropical climate that varies from the typical semi-arid climate to the Sahel climate in the north of the union (Mali, Niger, Burkina Faso and Senegal) and from the sub-humid climate to the humid climate in the south of the zone, where the coastal countries are present (Benin, Côte d'Ivoire, Guinea Bissau and Togo) (BOAD, 2010).

Due to their similarities in the economy, traditions, society, and energy import dependence (UEMOA, 2021, 2020), the UEMOA countries should be treated as a unique and common category. However, to the authors' knowledge, no previous study in the literature has either tried to assess energy security individually for one of the economies or treat them all as a unique category for an energy security assessment. Therefore, this study develops a conceptual framework to specifically evaluate energy security within the electricity sector for this category of economies.

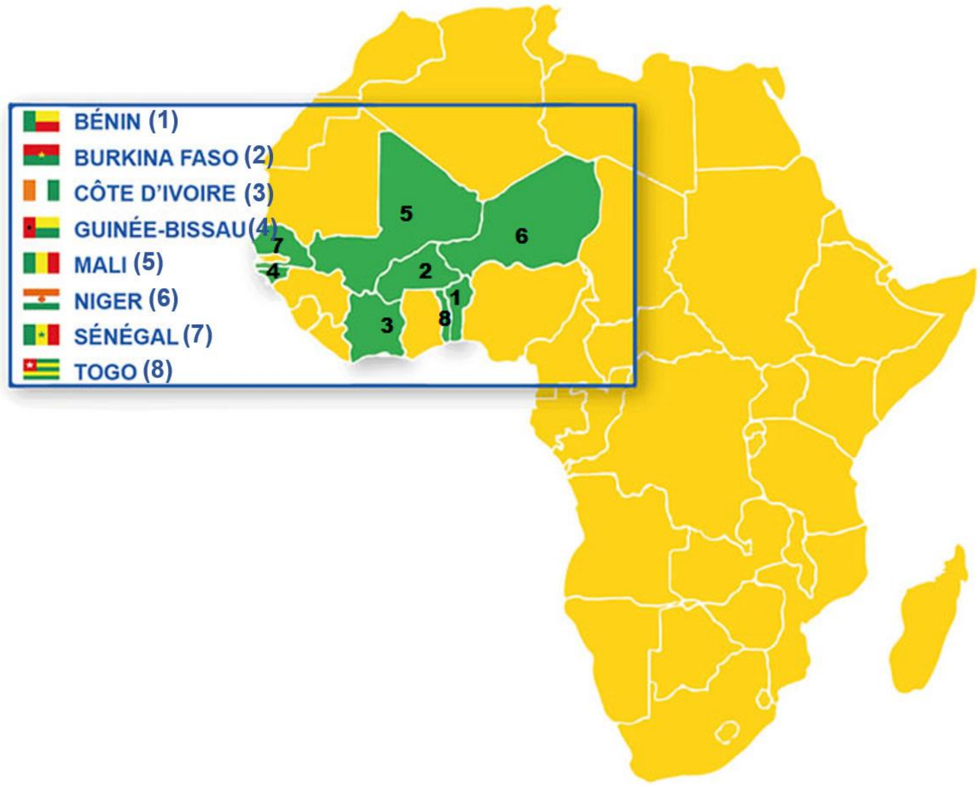

Fig. 2. Location of the UEMOA countries (Adapted from UEMOA, 2021a).

From the literature review, which included books and reports (APERC, 2007; IEA, 2007) and studies using: quantitative and qualitative assessments of energy security (Ofosu-Peasah et al., 2021; Ren and Sovacool, 2014a); qualitative research with energy experts (Sovacool et al., 2011; Sovacool and Mukherjee, 2011); focus groups and workshops (Sovacool, 2013; Sovacool et al., 2011; Sovacool and Mukherjee, 2011) ; and energy security perception comparisons at the international level (Sovacool, 2016; Sovacool et al., 2012), this paper proposes a five-dimension framework to measure the energy security within the electricity sector in the UEMOA. The five dimensions are 'availability and diversity', 'affordability and equality', 'efficiency and reliability', 'regulation and governance' and 'environmental sustainability' and these were further divided into 18 components correlated to 18 metrics (**Table 1**). The factors were chosen with consideration of the characteristics of the countries in the Union.

2.2.1. Availability and diversity

The first dimension chosen for the energy security index was *availability and diversity*. Four indicators were used to reflect it: *security of supply, diversity, dependency, and capacity factor*. Indeed, either due to poor industrialization and, therefore, lack of exploitation of individual countries' resources or resource-poor situation, most of the UEMOA countries spend a significant portion of their national budget on oil and gas imports for electricity generation and the transport sector (Ofosu-Peasah et al., 2021; UEMOA, 2020). This high dependency on imports exposes the countries to supply disruption and, therefore, vulnerable as they have established the basis of their development on the application of energy-demanding technologies while having no energy sources or exploitation technology of their own (Radovanović et al., 2017). The *dependency* indicator was therefore chosen to assess such a vulnerability.

Also, as a proxy indicator of the life quality of citizens, the *security of supply* (final electricity consumption per capita) was chosen. Indeed, the countries' vulnerability may translates into differences in quality of life and electricity use as different stages of development can be particularly noticeable within the countries due to their exposure to any disruption in the energy market (Radovanović et al., 2017). *Security of supply* was chosen therefore as an adapted indicator for this study.

The *diversity* indicator was selected because promoting a diversified collection of different energy sources and technology is fundamental for being energy secure (Sovacool et al., 2011). Indeed, diversity reduces vulnerability in case of disruption, even when the country is highly dependent. As a complex but accurate metric of diversity, the Shannon-Winner index (SWI) was used to reflect diversity for the countries regarding energy security (Sovacool and Mukherjee, 2011).

Finally, *capacity factor* of the power plants was selected to reflect the technology's availability, which is crucial for energy security as it consists of one of the most important upstream part of the security of energy supply. Indeed, in its own definition, energy security included the need to provide available energy services to end-users. *Capacity factor* was deemed adapted for this study.

2.2.2. Affordability and equality

The second dimension chosen for the energy security assessment in the UEMOA was *affordability and equality*, and again, it comprises four indicators: *access, affordability, stability and equality*. The *access* and *affordability* indicators were chosen to underline the social dimension that energy security needs to encompass. Indeed, the West African region consists of some of the poorest countries in the world (Ofosu-Peasah et al., 2021). Therefore, the countries' economic and financial situation translates into high tariffs for energy services and price volatility as they are highly dependent on fossil fuels (Guo et al., 2020), which are the primary sources of electricity generation. This situation does not help the population access or afford electrical services (Blimpo et al., 2018, 2020).

Furthermore, the volatility of the prices faced by the union's countries also translates into changes in the proposed tariffs for energy services. Therefore, the 'stability' indicator was chosen as having predictable prices for energy services, and fuels are fundamental for energy security (Sovacool and Mukherjee, 2011). Finally, UEMOA, located in the sub-Saharan part of Africa, still has many people who have no access to modern energy and rely on subsidies. Therefore, the 'equality' indicator was chosen as promoting equitable access to (modern) energy services is crucial for economic growth, global development, and poverty eradication (Martchamadol and Kumar, 2012;

Oyedepo, 2012; Sovacool and Mukherjee, 2011; Tarekegne and Sidortsov, 2021) and therefore fundamental for energy security.

2.2.3. Efficiency and reliability

Efficiency and reliability was chosen as the third dimension, and the index relies on three components for this dimension: *energy intensity, grid efficiency* and *grid reliability*. The electric systems of the UEMOA economies still consist of old materials in exploitation, which causes frequent disruption of the electricity services and questionable efficiency. As a response, Demand Side Management (DSM) and efficiency programs have been initiated in the Union (IFDD and UEMOA, 2020) to upgrade the electric systems and curtail the growing demand, and such actions can help by increasing energy security (Ang et al., 2015; Hughes, 2009). The *grid efficiency* and the *grid reliability* indicators were therefore, deemed essential for this study as they reflect the effectiveness of the energy-delivering technology (Sovacool et al., 2011). Indeed, having a suitable infrastructure, practicing good maintenance, and delivering high-quality and reliable energy services are essential for maintaining energy security (Sovacool and Mukherjee, 2011). Finally, global development is a priority for the UEMOA countries, and energy security (specifically efficient use of energy here) will play a crucial role in achieving sustainable development. The *energy intensity* was therefore chosen to reflect the efficient use of energy to produce (economic) development as this indicator shows simply the extent to which energy resources are consumed for the production of a unit of gross domestic product (Radovanović et al., 2017). This characteristic make this indicator a good measure for tracking changes in energy consumption over time (Sovacool and Mukherjee, 2011).

Table 1. Dimensions, components and metrics of the energy security index for the electricity sector in UEMOA.

Dimensions	Indicators	Metrics	Definition / explanation	Unit	Preference
A. Availability and diversity	A1. Security of supply	I1. Total electric energy supplied per capita	Includes all domestic production – thermal, hydroelectricity, solar, wind and other renewables and imports fewer exports	kWh/capita	Greater
	A2. Diversity	I2. Diversity in electricity consumption	Shannon-Winner Index (SWI) for diversity in electricity consumption: $\mathrm{SWI} = -\sum_{i=1}^{n} p_i \ln(p_i)$	-	Greater
	A3. Dependency	I3. Self-sufficiency	Percentage of electric energy demand met by the domestic production	%	Greater
	A4. Capacity factor	I4. Utilization rate of generation units	Actual total production in MWh / total nameplate capacity in MW times 8,760 hours	%	Greater
B. Affordability and Equality	B1. Access	I5. Share of population with high-quality connections to the electricity grid	Percentage of combined urban and rural electricity customers with reliable connections compared to the total population in the country	%	Greater
	B2. Stability	I6. Stability of electricity prices	Percentage that retails electricity prices have changed every year	%	Smaller
	B3. Affordability of electricity	I7. Quantity of electricity bought with GDP	Local GDP per capita divided by the average electricity price for a given year	kWh/capita	Greater

	B4. Equality	I8. Share of electricity in total energy consumption	Annual electricity consumed divided by local total energy consumption	%	Greater
C. Efficiency and Reliability	C1. Energy efficiency	I9. Energy Intensity	Electricity consumption per dollar of GDP	kWh/US$ (2010)	Smaller
	C2. Grid efficiency	I10. Share of total electricity losses	Total power losses (transmission and distribution including pilferage) divided by the total electricity output	%	Smaller
	C3. Grid Reliability	I11. Average blackout hours per household	Annual average blackout hours experienced per households	Hours/year	Smaller
D. Regulation and Governance	D1. Governance	I16. Worldwide governance rating	Mean score given for the six categories of accountability, political stability, government effectiveness, regulatory quality, rule of law, and corruption	-	Greater
	D2. Competition and markets	I18. Provision from IPPs	Percentage of generation capacity owned by the independent power providers (IPPs)	%	Greater
	D3. Information access	I19. Quality of information	Percentage of data points complete for this index out of all possible data points	%	Greater
E. Environment and sustainability	E1. Climate Change	I12. Per capita electricity-related emissions	Annual tons of electricity-related carbon dioxide emissions divided by the national population	$kgCO_2$/capita	Smaller

E2. Carbon-energy intensity	I13. Electricity-related emissions per electricity consumption	Annual tons of carbon dioxide electricity-related emissions divided by the total electricity consumption	gCO_2/kWh	Smaller
E3. Carbon-economy intensity	I14. Electricity-related emissions per GDP	Annual tons of carbon dioxide electricity-related emissions divided by total national GDP	$gCO_2/US\$$ (2010)	Smaller
E4. Sustainability	I15. Share of fossil fuels-related electricity in total output	The output of electricity produced based on fossil fuels divided by the total electricity output	%	Smaller

2.2.4. Regulation and governance

The fourth dimension chosen for the energy security is *regulation and governance* and four indicators were here also use to reflect it: *governance, competition and market and information access*. First, the *governance* indicator was chosen as it encompass the political aspect of energy security (Zhang et al., 2017). Indeed, having a stable, transparent, and participatory political system is very important for energy security (Sovacool and Mukherjee, 2011). Also, a competitive market and promotion of trade of energy technology and fuels are essential for enhancing energy security in the UEMOA. Although the energy demand is proliferating, the electricity sector, relays often on only one or a few energy providers, which makes the countries less secure. As a result, countries in the union have recently opened the gate to independent producers, and extended interconnections are also expected (Tractebel Engineering and GDF Suez, 2011). Therefore, a consistent regulatory system encouraging competitiveness and trade market is necessary. Therefore, the *competition and market* indicator was selected to reflect this regulatory aspect needed for energy security.

Finally, the last indicator, *information access*, was selected to reflect the quality or availability of energy information. Indeed, enhancing social and community knowledge about education and energy issues is crucial for maintaining a sound and sustainable energy security level.

2.2.5. Environmental sustainability

Environmental sustainability, the fifth dimension of the energy security index, was chosen considering the environmental aspect that energy security needs to achieve for sustainability. Again here, four indicators were chosen to reflect the dimension: *climate change*, *carbon-economy intensity*, *carbon-energy intensity*, and *sustainability*. Indeed, the high dependence on fossil resources in the electricity sector combined with the demand expected to grow in the coming years requires safer and cleaner energy resources with greener energy production and consumption to be implemented (Yao and Chang, 2014) in order to enhance and maintain a sustainable level of energy security. Furthermore, the indicator of *climate change* was chosen as minimizing ambient and indoor pollution, mitigating GHG emissions associated with climate change, and adapting to climate change are essential for enhancing energy security (Sovacool and Mukherjee, 2011). In addition, the environmental component must be incorporated in all the Union's governments' development programs, which aim at achieving sustainable development for their respective countries. Thus, the dimension relies on the *sustainability* and *carbon-intensity* (carbon-energy and carbon-economy) indicators. Indeed, they are good indicators of energy security, especially for long-term considerations, as they indicate, to some extent, the reduction of fossil fuel import (Radovanović et al., 2017).

The dimensions, components, indicators and metrics of the energy security index built for this study are synthetized in **Table 1**.

3. Methodology

3.1. Data collection and processing

Data were collected and processed for the UEMOA countries from 2010 to 2019. Data on the scoring values of the countries were computed mainly from data collected in the national activities and statistics yearbooks and the UEMOA energy report (UEMOA, 2020). Other data was drawn from IEA databases (IEA, 2021a, 2021b), World Bank databases (World Bank, 2021b, 2021c) and reports (SE4ALL, 2019a, 2019b). Due to a wide range of unavailable data, Guinea Bissau was excluded from the study, which left seven UEMOA countries investigated: Benin, Burkina Faso, Côte d'Ivoire, Mali, Niger, Senegal and Togo.

3.2. Theory / Calculations

Assessment of security within the electricity sector for the UEMOA countries was performed using two MCDA methods - Fuzzy Analytical Hierarchal Processes (FAHP) and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE). This section presents the two methods in terms of theory and calculations.

3.2.1. The Fuzzy AHP method

The AHP is an additive weighting process based multi-criteria method for analysis in which several relevant attributes are represented through their relative importance (Sun, 2010). Therefore, such a method is a powerful tool for solving complex problems involving several alternatives, criteria, and decision-makers as the problems can be decomposed into sub-problem represented by a set of criteria or attributes (Aczel and Saaty, 1983; Sun, 2010). The AHP is used to capture the decision-makers knowledge of a preference and represent the attributes through their relative importance using a pairwise comparison process (Sun, 2010; Zhang et al., 2017). The decision-makers can specify preferences either in the form of natural language or numerical values about the importance of each performance attribute (Güngör et al., 2009).

However, some shortcomings, including an unbalanced scale of judgment and uncertainty associated with human perceptions, have been pointed out for the conventional AHP method (Sun, 2010; Yang and Chen, 2004). Therefore, the Fuzzy set theory was introduced into the conventional AHP to overcome these problems, as such a mathematical tool is used to address the imprecision and uncertainty inherent to human judgments in the decision-making process (Ren and Sovacool, 2014b; Sun, 2010). Such a theory uses a membership function to calculate a grade of membership that a given variable belongs to (Ren and Sovacool, 2014b; Zhang et al., 2017). Several types of membership functions exist in the literature, with the triangular and trapezoidal functions usually used in fuzzy logic because of their simplicity and accuracy (Ren and Sovacool, 2014b).

Following the steps below, we implemented the FAHP method with fuzzy triangular numbers, for which definition and standards operations are given in **Appendix 1**.

Step 1: determining the generalized pairwise comparison matrix.

In this first step, the numerical generalized pairwise comparison matrices of the factors are constructed, first using linguistic terms in the same level of hierarchy structure and then converting them into fuzzy numbers (as presented in **Table 2**). The generalized pairwise comparison matrix is given by **Eq. (1)** (Zhang et al., 2017).

$$\tilde{A} = \begin{bmatrix} \tilde{1} & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & \tilde{1} & \dots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & \tilde{1} \end{bmatrix} = \begin{bmatrix} \tilde{1} & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & \tilde{1} & \dots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{n2} & \cdots & \tilde{1} \end{bmatrix} \tag{1}$$

Where $\tilde{a}_{iJ} = \left(a_{ij}^{l}, a_{ij}^{m}, a_{ij}^{u}\right)$, with a_{ij}^{l}, a_{ij}^{m} and a_{ij}^{u} standing respectively for the lower, middle, and upper values of the fuzzy number corresponding to the comparison of the i-th factor to the j-th factor.

As preferences of the dimensions and metrics are given by a committee of n decision-makers (see **Appendix B**), the generalized pairwise comparison matrix is synthesized from the pairwise comparison matrices of the n stakeholders using the geometric mean method (given by **Eq. (2)**) as suggested by (Buckley, 1985) and used by (Lee et al., 2021; Sun, 2010).

Table 2. The linguistic terms and corresponding fuzzy scales (for example)

Linguistic	Abbreviation	Scale	Triangular Fuzzy corresponding scales
Main values			
Equal importance	E	1	(1, 1, 1)
Moderate importance	M	3	(2, 3, 4)
Strong importance	S	5	(4, 5, 6)
Very strong importance	VS	7	(6, 7, 8)
Absolute/extreme importance	A	9	(8, 9, 10)
Intermittent values			
Weak/slight importance	W	2	(1, 2, 3)
Moderate plus importance	M +	4	(3, 4, 5)
Strong plus importance	S +	6	(5, 6, 7)
Very, very strong importance	VS +	8	(7, 8, 9)
Reciprocal values			Reciprocal of the fuzzy numbers

$$\tilde{a}_{iJ} = \left(a_{ij}^{l}, a_{ij}^{m}, a_{ij}^{u}\right) = \left(\prod_{k=1}^{n} \tilde{a}_{ij}^{k}\right)^{1/n} \quad (2)$$

With n the number of stakeholders of the decision committee.

Step 2: determining the fuzzy weights of the factors.

The first procedure of this step is to determine the geometric mean concerning each factor using **Eq. (3)**. Then, with this computed, the fuzzy weights concerning the factors are determined using the geometric means as given by **Eq. (4)** (Lee et al., 2021; Sun, 2010).

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \tilde{a}_{iJ}\right)^{1/n} = \left(r_i^{l}, r_i^{m}, r_i^{u}\right) \quad (3)$$

$$\widetilde{w}_i = \tilde{r}_i / \sum_{i=1}^{n} \tilde{r}_i \quad (4)$$

Where $\tilde{r}_i$ is the geometric mean of fuzzy comparison value of criterion i to each criterion and $\tilde{w}_i$ the fuzzy weight of the i-th criterion.

Step 3: locating the BNP (Best Non-fuzzy Performance) values of the weights of the factors.

This operation is also known as defuzzification and consists of transforming the factors' fuzzy weights into crisp numbers. To do so, Talon and Curt, (2017) identified no less than 29 methods within which the Center of Area method. This study uses this method, expressed by **Eq. (5)**, to defuzzify the factors' weights.

$$w_i = \left(w_i^u - w_i^l\right) + (w_i^m - w_i^l)/3 + w_i^l \tag{5}$$

With w_i^l, w_i^m and w_i^u standing respectively for the lower, middle, and upper values of the fuzzy number corresponding to the weight of the i-th factor.

3.2.2. The PROMETHEE method

The PROMETHEE method is one of the recent MCDA techniques. It is based on a pairwise comparison of alternatives along with each recognized criterion and has been used in the literature by several authors since its development (Albadvi et al., 2006; Anand and Kodali, 2008; L'Eglise et al., 2001; Macharis et al., 2004; Zhang et al., 2017). The alternatives are evaluated, therefore, according to different criteria, which are minimized or maximized. Such a method is advantageous because it presents several benefits, including ease of application, efficiency and interactivity (Brans et al., 1986; L'Eglise et al., 2001).

Several extensions of the PROMETHEE method, including the PROMETHEE family for outranking methods (PROMETHEE I and II) exist in the literature (Behzadian et al., 2010). The PROMETHEE II was used in this study because it offers a complete preordering of the alternatives through a comparison of net outranking flows. The procedure used to complete this method is given as follow:

Step 1: determining the normalized decision matrix

The decision matrix is represented with the alternatives, the criteria/factors, and the performance values that stand for the alternatives' scores over criteria. However, such a matrix presents the issue that all the criteria have different units. Therefore, it is indispensable to find a standard scale for all the factors by normalizing the performance values. Thus, the performance values are normalized here using the linear scale transformation (**Eq. (6)** for benefit attributes and **Eq. (7)** for cost attributes) (Çelen, 2014). The normalized decision matrix is then obtained as given by **Eq. (8)**.

$$r_{ij} = x_{ij} - \min_{j} x_{ij} / \max_{j} x_{ij} - \min_{j} x_{ij} \qquad (6)$$

$$r_{ij} = \max_{j} x_{ij} - x_{ij} / \max_{j} x_{ij} - \min_{j} x_{ij} \qquad (7)$$

Where r_{ij} is the normalized performance value of the i-th alternative over the j-th factor, x_{ij} is the original performance value and $\min_{j} x_{ij}$ and $\max_{j} x_{ij}$, are respectively the minimum and the maximum performance values of all the alternatives over the j-th factor.

$$C = \begin{vmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{vmatrix} \qquad (8)$$

Step 2: determining the deviations based on pairwise comparisons

The deviation translates the preference of an alternative over another concerning a criterion. Deviations are computed using **Eq. (9)** (Behzadian et al., 2010) as follows:

$$\mathrm{d_j(a,b) = \ g_j(a) - g_j(b)} \tag{9}$$

Where $d_j(a,b)$ refers to the difference between the evaluations of alternatives (a and b) over the j-th criterion or factor.

Step 3: determining the preference functions for the criteria

The preference function translates the difference between the evaluations of two alternatives into a preference degree ranging from 0 to 1 for each criterion (Behzadian et al., 2010). Six types of generalized preference function are usually found in the literature: the usual criterion, the quasi or U-shape criterion, the V-shape criterion, the level criterion, the V-shape with indifference criterion, and the Gaussian criterion (Brans et al., 1986; Brans and Vincke, 1985). The linear preference function (V-shape criterion) expressed by **Eq. (10)** was used in this study. Such criterion is the more widely used (Zhang et al., 2017).

$$\mathrm{P(d)} = \begin{cases} \mathrm{1 \ if \ d > p \ or \ d < -p} \\ \mathrm{d/p \ if - p \leq d \leq p} \end{cases} \tag{10}$$

Where $\mathrm{P(d)}$ refers to the preference of an alternative a with regard to alternative b on each criterion, as a function of $\mathrm{d_j(a,b)}$ and p, a preference threshold.

Step 4: computing the multi-criteria preference index

The multi-criteria or global preference index (**Eq. (11)**) expresses the weighted sum of the preference functions for each criterion (Behzadian et al., 2010).

$$\pi\ (a,b) = \sum_{j=1}^{k} P_j(d) \times w_j \tag{11}$$

Step 5: computing the positive and negative outranking flows

The outranking concept expresses how an alternative is given a preference over another considering the criteria. Positive and negative outranking flows are computed using **Eqs. (12) and (13)** below (Behzadian et al., 2010).

$$\phi^{+}(a) = 1/(m-1)\sum_{i=1}^{m}\pi\,(a,i) \tag{12}$$

$$\phi^{-}(a) = 1/(m-1)\sum_{i=1}^{m}\pi\,(i,a) \tag{13}$$

With $\phi^{+}(a)$ and $\phi^{-}(a)$ respectively, the positive and negative outranking flows for the alternative a, and m the number of alternatives.

Step 6: determining the net outranking flows and ranking alternatives

The net outranking flow is finally determined for each alternative, thanks to **Eq. (14)** (Behzadian et al., 2010).

$$\phi(a) = \phi^{+}(a) - \phi^{-}(a) \tag{14}$$

Where $\phi(a)$ denotes the outranking flow for the alternative a.

In this study, The PROMETHEE method was performed using the *Visual PROMETHEE* software, a complete and up-to-date software implementation of the PROMETHEE method. The analyses were performed at the aggregated and dimensional scales in absolute and temporal terms to know who is the most or least secure and who improved the most or least within a given period. Such later analysis was performed by computing energy security progress indices (**Eq (15)**), which were determined for periods ranging from t_1 to t_2 ($t_1 < t_2$) as:

$$\Delta\phi = \phi(t_2) - \phi(t_1) \tag{15}$$

Values obtained applying such expression are comparable between different periods and countries to determine change in energy security since the rankings were performed simultaneously for all studied years (Antanasijević et al., 2017).

4. Results and discussion

With the security framework set up with its dimensions and indicators, the Fuzzy AHP was first applied to compute the weights of the dimensions and the metrics. Several stakeholders' judgments determined the pairwise comparisons concerning the five dimensions and their components, first into linguistic terms (**Appendix B: Tables B1-B6**). The linguistic terms were then converted into fuzzy scales and aggregated (**Tables B7-B12**) using **Eq. (2)**. Using **Eqs. (3) and (4),** the fuzzy weights of the dimensions and the components/indicators in each dimension were determined. The global weight of each indicators could then be computed as shown in **Table 3**, as it corresponds to the product of the indicator's weight in the hierarchy and the weight of its belonging dimension.

Then, with the different weights computed and data collected on the performance of the countries concerning the metrics, we used the *Visual PROMETHEE* software to evaluate the security performance within the electricity sector in the UEMOA.

4.1. Energy security performances

Table 4 presents the final results of the security performance evaluation for the electricity sector in the UEMOA during the 2010-2019 period. The value of Phi (ϕ) represents the net outranking flows with respect to the countries, and the greater the value is, the more energy secure the country will be with respect to the others.

Table 3. Weights of the dimensions and metrics of the energy security index

Dimensions weights		Components weights		Global weights	
Dimensions	**Weights**	**Metrics**	**Weights**	**Metrics**	**Global Weights**
Availability and diversity	0.3003	A1	0.346	I1	0.104
		A2	0.180	I2	0.054
		A3	0.228	I3	0.069
		A4	0.245	I4	0.074
Affordability and equality	0.2103	B1	0.368	I5	0.077
		B2	0.253	I6	0.053
		B3	0.273	I7	0.057
		B4	0.106	I8	0.022
Efficiency and reliability	0.1843	C1	0.222	I9	0.041
		C2	0.320	I10	0.059
		C3	0.459	I11	0.085
Regulation and governance	0.1632	D1	0.500	I12	0.082
		D2	0.218	I13	0.036
		D3	0.282	I14	0.046
Environmental Sustainability	0.1420	E1	0.370	I15	0.053
		E2	0.183	I16	0.026
		E3	0.198	I17	0.028
		E4	0.249	I18	0.035

On the one hand, data in **Table 4** suggests, for example, in 2019 that Côte d'Ivoire (0.52) ranked first in terms of energy security in the UEMOA, followed by Senegal (0.22), Togo (0.04), Mali (-0.04), Benin (-0.09), Burkina Faso (-0.11) and Niger (0.47). On the other hand, averaging the energy security net flows over the study period can give us a decent sense of which country is most and worst energy secure within the UEMOA.

Table 4. Energy security performances (expressed as the net flow: ϕ and the country's rank: Rk) in the electricity sector in the UEMOA.

Countries	**2010**		**2011**		**2012**		**2013**		**2014**		**2015**		**2016**		**2017**		**2018**		**2019**	
	ϕ	**Rk**	**ϕ**	**Rk**	**ϕ**	**Rk**	**ϕ**	**Rk**	**ϕ**	**Rk**	**ϕ**	**Rk**	**ϕ**	**Rk**	**ϕ**	**Rk**	**ϕ**	**Rk**	**ϕ**	**Rk**
Benin	-0.01	4	-0.11	5	0.05	4	-0.02	5	-0.11	5	-0.08	5	-0.07	5	0.01	4	-0.06	4	-0.09	5
Burkina Faso	-0.12	6	-0.15	6	-0.24	6	-0.15	6	-0.20	6	-0.26	6	-0.17	6	-0.17	6	-0.12	6	-0.11	6
Cote d'Ivoire	0.26	1	0.28	1	0.25	1	0.29	1	0.38	1	0.35	1	0.46	1	0.43	1	0.41	1	0.45	1
Mali	0.14	2	0.23	2	0.13	2	0.06	3	0.10	2	0.11	3	0.00	4	0.00	5	-0.11	5	-0.03	4
Niger	-0.30	7	-0.25	7	-0.29	7	-0.30	7	-0.31	7	-0.34	7	-0.35	7	-0.41	7	-0.46	7	-0.47	7
Senegal	0.03	3	-0.02	4	0.12	3	0.11	2	0.10	3	0.11	2	0.09	2	0.11	2	0.18	2	0.22	2
Togo	-0.02	5	0.02	3	-0.03	5	0.01	4	0.05	4	0.11	4	0.08	3	0.06	3	0.17	3	0.04	3

By doing so, it was found that Cote d'Ivoire (0.35) was the most energy secure, followed by Senegal (0.10), Mali (0.06), and Togo (0.05). At the same time, Niger (-035) was the worst energy secure, preceded by Burkina Faso (-0.17) and Benin (-0.05), respectively.

On the other hand, another picture emerges when the temporal path is explored as shown in **Fig. 3**. Indeed, one can analyses which country has improved the most or least in terms of energy security by computing the change from 2010 to 2019 for all countries (**Eq. (15)**). Doing so it was found that Senegal demonstrated most significant positive change with respect to 2010 (520%) by improving from 0.03 in 2010 to 0.22 in 2019, followed by Togo (297%), Cote d'Ivoire (74%) and Burkina Faso (10%). On the other hand, other countries, including Niger (-36%), Benin (-89%), and Mali (604%), demonstrated a decline in energy security, with Mali performing the worst.

Based on the values obtained in 2019 for the net outranking flow of energy security for the countries, a review of the energy security trend was performed by grouping the countries. Indeed, two groups were formed based on the values recorded for the net flow of the energy security index (ESI):

Group 1: ESI greater than 0 (Senegal, Cote d’Ivoire, Togo)

Group 2: ESI lower than 0 (Benin, Burkina Faso, Niger, Mali)

As shown in **Figure 4a**, within the countries of group 1, Cote d'Ivoire and Senegal generally displayed an increasing pattern, with, on the one hand, two significant increases recorded for Cote d'Ivoire in 2014 and 2016. Senegal also recorded a significant increase after 2011, followed by a relatively stable pattern from 2012 to 2017 and another significant increase following 2017. On the other hand, Togo displayed a more fluctuating pattern, including significant increases from 2012 to 2015 and in 2018 and a significant decrease in 2019, preceded by relatively slight decreases from 2015 to 2017.

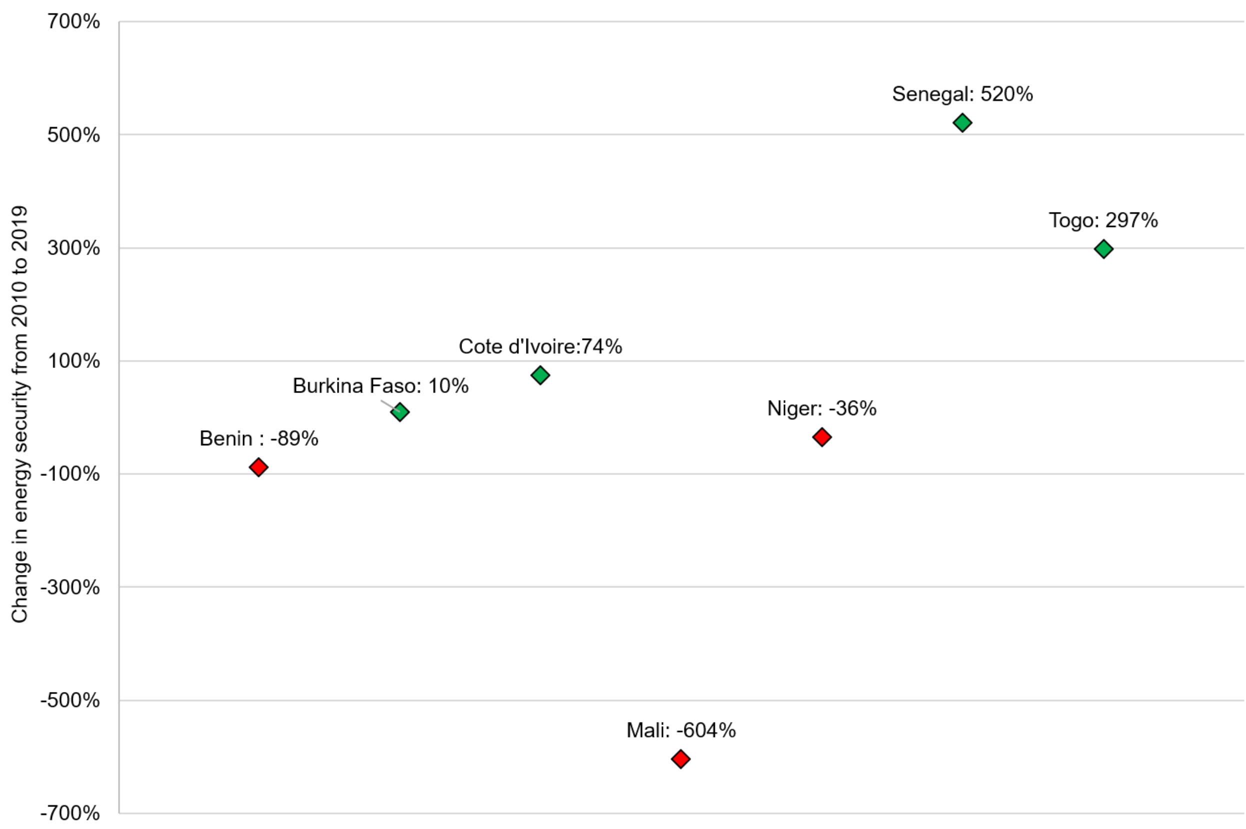

Fig. 3. Energy security improvement for the UEMOA countries (% change from 2010 to 2019).

In **Figure 4b**, countries in group 2 demonstrated two tendencies, with Niger and Mali showing a generally decreasing pattern over the study period and Benin and Burkina Faso showing more fluctuating patterns. Indeed, on the one hand, despite an early increase in 2011, Niger's performance decreased year by year for the study period with respect to the other countries. The same trend was recorded for Mali, with some more periodically slight increases recorded early in 2011, from 2013 to 2015, and in 2019. On the other hand, Benin and Burkina registered fluctuating patterns, with Benin facing a general decrease in energy security and Burkina Faso recording a general increase in energy security with respect to the other countries.

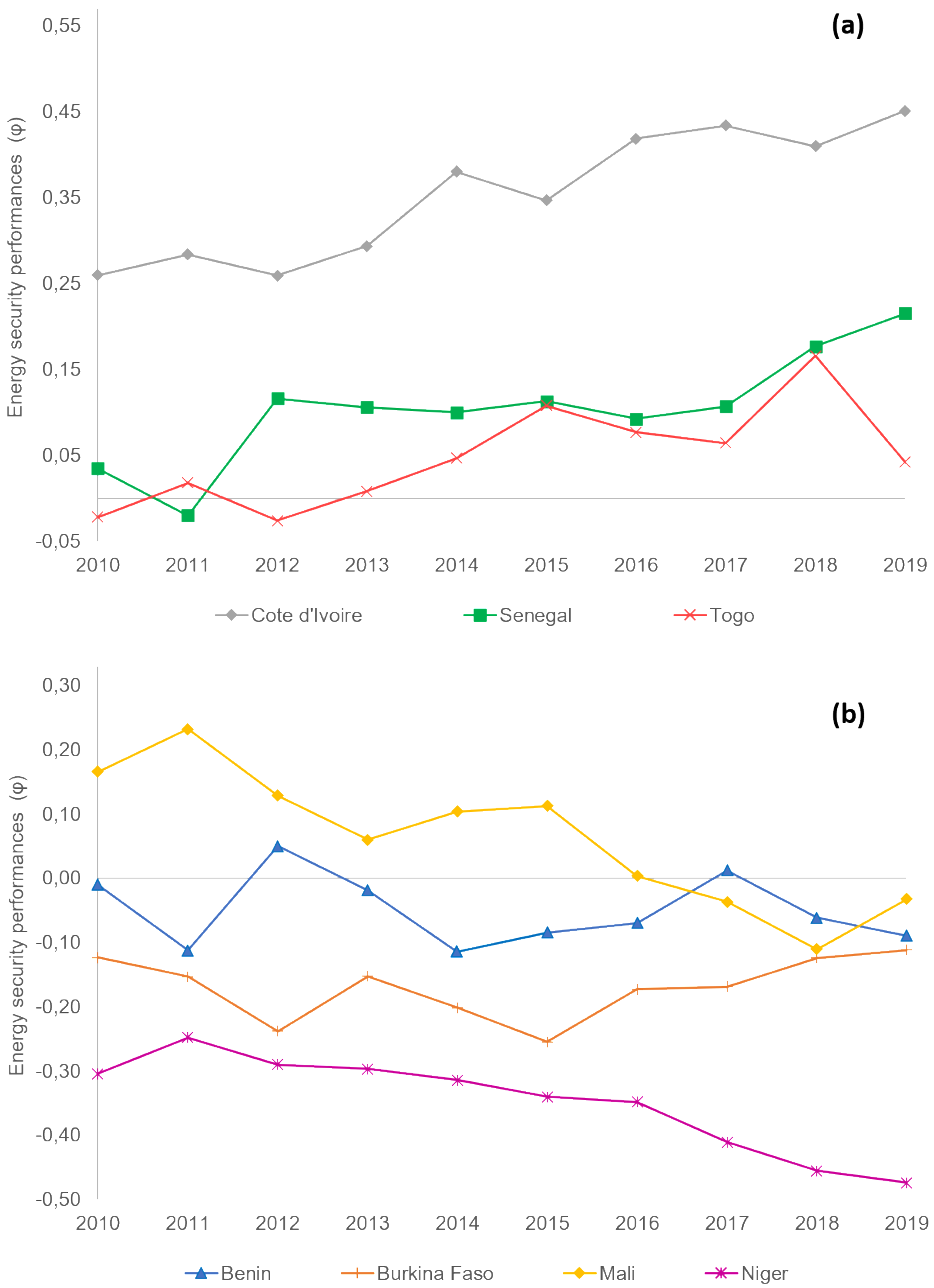

Fig. 4. Trends in overall energy security performances (expressed as ϕ) in the UEMOA (2010-2019)

All previous analyses are made on a comparative basis, which means that, for example, sometimes countries' best and worst performance is related not to the improvement in the indicators' metric but to an overall deterioration in some metrics

(Sovacool et al., 2011). As an illustration, **Table 5** on the trends in performance for the energy security indicators for the study period can demonstrate that any country performed well in all the indicators. Therefore, to analyze the policy implications of the country-level findings and channel future research, the indicators' performance trends (**Table 5**) were analyzed for each country below.

Table 5. Trends in performance for the energy security indicators for the study period in UEMOA

Indicators / components	Benin	Burkina Faso	Cote d'Ivoire	Mali	Niger	Senegal	Togo
A1. Security of supply	↑	↑	↑	↑	↑	↑	↑
A2. Diversity	↓	↑	↓	↑	↑	↑	↓
A3. Dependency	↑	↓	-	↓	↑	-	↑
A4. Capacity factor	↓	↑	↑	↑	↑	↓	↑
B1. Access	↑	↑	↑	↑	↑	↑	↑
B2. Stability	-	-	ʍ	-	-	ʍ	-
B3. Affordability of electricity	↑	↑	↑	↑	↓	↓	↑
B4. Electricity equality	↓	↑	↑	↑	↑	↑	↑
C1. Energy efficiency	↑	↓	↓	↓	↑	↓	↓
C2. Grid efficiency	↑	↑	↑	↑	↓	↑	↑
C3. Grid Reliability	↑	↑	↑	↓	↓	↑	↓
D1. Governance	↓	↓	↑	↓	↓	↑	↓
D2. Competition and market	↑	↑	↑	↓	↓	↑	↓
D3. Information access	↑	-	-	↓	↑	↓	↑
E1. Climate Change	↓	↓	↑	↓	↓	↓	↓
E2. Carbon-energy intensity	↓	↑	↑	↓	↓	↓	↑
E3. Carbon-economy intensity	↓	↓	↑	↓	↓	↑	↑
E4. Sustainability	↓	↑	↑	↓	↓	↑	↓

↑ indicates progression, ↓ indicates regression, – indicates stability and ʍ indicates instability.

4.1.1. Benin

Eight indicators for the country of Benin, including *diversity, capacity factor, electricity equality, governance*, and all the *environmental and sustainability* indicators, recorded an overall decline within the study period. In comparison, *stability* remains stable, and the lasting nine indicators recorded an overall increase.

On the one hand, the declining indicators' metrics, *diversity, climate change, 'carbon-energy intensity,* and *sustainability*, recorded notable drops in their trends with at least a decrease of 30% in performance. For example, the Shannon-Winner Index (SWI) used as the metric of the diversity indicator showed a fluctuating and decreasing pattern with a corresponding drop of 31% in performance, showing the poor diversity of the country in terms of primary energy sources for electricity generation. Indeed, from already a fairly poor energetic mix for electricity generation consisting only of hydroelectricity (49%), natural gas (40%), and oil (11%) in 2010, the country saw a progressive decline in diversity which resulted in global domination of natural gas (75%) in 2019 (ARSE-TG, 2019). As a result, this progressive increase in the use of fossil fuels resulted in a drop in performance in the *environmental sustainability* indicators. Indeed, the per capita electricity-related emissions and the per kWh electricity-related emissions grew respectively from 29.83 kgCO2 /capita and 0.33 kgCO2 /kWh in 2010 to 44.47 kgCO2 /capita and 0.44 kgCO2 /kWh in 2019, corresponding to drops of 43% and 39% for the *climate change* and *carbon-energy intensity*.

On the other hand, some increasing indicators showed a notable boost over the study period, including *dependency* and *affordability*. Indeed, even with a reasonably fluctuating pattern, the country's self-sufficiency (ability to meet its domestic electricity demand) increased by 78% due to the contribution from IPPs after 2015 and the launching of a 129 MW power plant in 2019. Also, due to a notable increase in GDP, *electricity affordability* increased by 33%.

4.1.2. Burkina Faso

For Burkina Faso, five indicators failed to increase within the study, including *dependency, energy efficiency, governance, climate change,* and *carbon-economy intensity*. After an increase in the early years, the country's self-sufficiency started declining at a 9% rate per year since 2015 due to its dependency on imports from Cote d'Ivoire and Ghana to satisfy the demand. Such a situation translates into a drop in performance of 24% for the study period. The dependence on Ghana and Cote d'Ivoire, which have fossil fuel shares increasing in their energetic mix over the study period, also translates into decreasing performance for the environmental indicators. The electricity emission per capita increased, for example, by 37% within the study period. Also, mainly due to the country's political instability, *governance* performances keep dropping for the period study at a rate of 12% per year until 2019, resulting in an overall decrease of 112%.

On the other hand, even if they have recorded a non-negligible boost over the period, the values of some indicators' metrics, including the *security of supply*, *access to electricity, electricity affordability,* and *grid reliability*, remain low for energy security. For example, from 60.88 kWh supplied per capita in 2010, the country reached 97.08 kWh in 2019, corresponding to a 50% change within the study period. However, even with such an increase, the electricity supplied per capita remained low with respect to the other countries of UEMOA and compared to that in the world. The same can be said for the *electricity access* indicator, which grew by 39% with respect to 2010 but remains insufficient as only 23% of people had access to electricity in 2019. Similarly, even though a fluctuating pattern was found for the *grid reliability*, a global increase of

51% (with respect to 2010) was recorded. However, it remains insufficient as users experienced 86 hours of blackout in 2019, far from the objectives of less than 50 hours set (ARSE-BF, 2019).

4.1.3. Côte d'Ivoire

The Cote d'Ivoire, which was demonstrated to be the most energy secure with respect to the other countries, revealed a drop in performance for two indicators' metrics, including *diversity* and *energy efficiency*. Indeed, with already a poor energetic mix for electricity generation consisting of the majority of natural gas (62%), followed by hydroelectricity (29%) and oil (9%), the country the Shannon-Winner index dropped by 28% from 2010 to 2019 due to a reduced diversity (natural gas rose to 67%, while oil almost disappeared). Also, with a more stable but increasing GDP produced per capita and quasi-constantly increasing electricity supplied per capita (38% in the study period), *energy efficiency* drops as energy intensity increases by 7%.

Also, although an increase was recorded for some indicators' metrics, they still need to be considered for energy security enhancement. For example, despite an increase in the performances of the *governance* indicator, which saw its metric (Worldwide governance rating) increase by 55% within the period study, the value of the latter is still at -0.56, indicating presence of corruption, poor regulatory system, political instability or government ineffectiveness. For example corruption increased by 24% between 2014 and 2019 (Keulder, 2021).

4.1.4. Mali

Numerous indicators' metrics demonstrated decreasing trends, which translated probably in the country being the worst performer in terms of energy security change over the study period. Indeed, as seen in **Table 5**, ten indicators saw their metrics showing decreasing trends from 2010 to 2019, including all the *regulation and governance* and *environmental sustainability* indicators. For example, to supply the constantly increasing demand (electricity supplied per capita increased by 69%), the country switched from hydroelectricity, representing 57% of the offer in 2010, to imports from Cote d'Ivoire which electricity mix is dominated by natural gas (67%). As a result, the country's self-sufficiency dropped by 20%. Moreover, this increased the environmental indicators' metrics. For example, emissions per capita increased by 133% over the period study, and carbon-energy intensity increased by 109%.

On the other hand, although they demonstrate increasing trends, numerous indicators' metrics remain low for energy security. For example, *security supply* and *electricity access*, whose metrics increased the most (by 69% and 88% respectively), still show lower energy security performances as only 48% of the population had access to electricity in 2019, with electricity supplied per capita still at 136.23 kWh. These values remain low compared to the rest of the world and some of the countries of the Union.

4.1.5. Niger

Probably being the cause of Niger remaining the worst energy security performer with respect to the others country, half of the indicators have seen their metrics showing declining trends within the period study. The notable declines were recorded for the efficiency and reliability indicators and those of environmental sustainability. Indeed, with the demand keeps increasing (supplied electricity per capita increased by 52%) over the study period, the performances of the grid, on the other hand, demonstrated deteriorating trends, with losses in the electric system increasing from 19% in 2010 to 24% in 2019 corresponding to a drop in efficiency by 26%. Furthermore, the reliability also drops by 19% from 2017 to 2019. This can be explained by the inability of the material/technology of the grid to follow the increasing demand for many reasons, including lack of good management, poor planning or lack of investment, or poor maintenance of the material. Also, with a high penetration of fossil fuels on the mix of primary energy used to generate electricity: 77% (ARSE-NE, 2019), all the metrics of the environmental indicators demonstrated declining trends with, for example, the per capita electricity-related emission of CO_2 increasing by 65% over the study period.

Despite demonstrating increasing trends, the other indicators' metrics still indicate lower energy security performance. Indeed, supplied electricity per capita and access to electricity increased by 52% and 56%, respectively, over the study period. However, in 2019, such values of 58.63 kWh/capita and 13.60% remained the Union's and the World's lowest. Efforts are therefore needed in this way for energy security. The country's self-sufficiency in satisfying the domestic demand increased by 91% with respect to 2010. However, the country remains dependent at 70% from the neighboring countries, including Nigeria, in 2019 (NERC, 2019).

4.1.6. Senegal

For the trends in performance for the indicators in Senegal, on the one hand, five indicators saw their metrics recording a decrease in their trends, including capacity factor, affordability of electricity, 'energy efficiency, and 'climate change. Indeed, despite the decline in the use of fossil fuels (4% from 2010 to 2019), Senegal remains the country with the most significant share of primary fossil energy for electricity generation (86%). This translates into Senegal being the country with the most considerable emissions in the Union, resulting in decreasing trends for climate change and carbon-energy intensity as the carbon emissions per capita and per kWh increased by 8% and 21%, respectively, for example, over the study period.

On the other hand, some indicators recorded performance boost over the study period, including, for example, governance, diversity, grid reliability, and 'electricity equality. For example, from a poor primary energy mix (oil 90% and hydroelectricity 10%) in 2019, the country switched to a more diverse mix (oil, photovoltaic solar, coal, and hydroelectricity) in 2019. This helps increase the Shannon-Winner index by 105% over the study period. Also, 'electricity equality' increased by 39% for the period study, and the value of 11.47%, representing the share of electricity use in the total energy consumed in the country in 2019, demonstrated to be the best performance of the UEMOA as electricity use still have very low shares in energy consumption for the Union's countries.

4.1.7. Togo

For Togo, metrics of seven indicators recorded decreasing trends during the study period, including diversity, energy efficiency, grid reliability, governance, competition and market, climate change, and sustainability. For example, with a constantly increasing demand (supply of electricity per capita), the grid reliability showed fluctuating but overall decreasing patterns, with users shifting from experiencing 24.80 hours of blackout in 2010 to 78 hours in 2019, indicating a drop in grid reliability at a rate of 215% within the study period. In addition, poor diversity was also recorded as the SWI dropped by 37% within the study period. Indeed, Togo, like many countries in UEMOA, Togo still demonstrates a poor mix of primary energy sources for electricity generation (hydroelectricity: 28% and natural gas: 71%).

Also, even though some indicator metrics showed increasing trends, they still do not indicate good performances for energy security. For example, the country's worldwide governance rating keeps a quasi-increasing trend at a rate of 14%, with its value switching from -0.87 in 2010 to -0.75 in 2019. However, such a value still indicates poor governance, with corruption, for example, recording an increase of 21% since 2014 (Keulder, 2021).

4.2. Limitations of the study

In order to fill the gap of insufficient quantitative analyses on the energy security situation in Sub Saharan Africa, especially for a common characteristics-group of economies that constitutes the UEMOA countries, this study undertakes an energy security assessment to provide insights on the current performances and trends of the UEMOA countries in terms of energy security for the electricity sector. However, due to numerous factors, the findings are limited by some restrictions given below.

First, the conceptualized framework encompasses a fairly complete set of critical dimensions and indicators of energy security which are adapted to the energy situation of the countries. However, these were chosen taking into account the availability of data, which was crucial for completing the analysis. Indeed, some of potential indicators were omitted due to unavailability of data for the UEMOA countries. Other future studies should therefore upgrade the current framework, when more data is available for the countries.

Also, the Fuzzy AHP in this study helps giving weights to the dimensions and indicators, which are considered in some extent a subjective approach by the literature. To overcome this limitation, more objective approaches such as the use of factor analysis tools such as principal component analysis (PCA) can be used by future research to identify the relative importance of indicators by variation in assigning weight.

Moreover, another limitation of this study is that the mutual effect between different dimensions and indicators was not considered. This is something that future researchers should address. The Analytic Network Process or Decision Making and Trial Evaluation Laboratory can for example be used as they are very good tools for analyzing the relationship between different dimensions and indicators

Finally, although such limitations can be numbered, the conceptualized framework is a significant contribution to rare existing literature on energy security in the global south, and can therefore, help evaluate the energy security performance for different regions or countries, especially those sharing similar characteristics to the UEMOA countries.

5. Conclusions and policy implications

This paper designed a five-dimension framework- availability and diversity, affordability and equality, efficiency and reliability, regulation and governance, and environmental sustainability - to assess the energy security (ES) within the electricity sector in the UEMOA. The five dimensions were correlated to 18 indicators, with a Fuzzy Analytical Hierarchal Process (FAHP) used to determine the weights of both dimensions and indicators. In order to quantify the energy security performances and identify the ES challenges facing the UEMOA countries in the electricity sector, the energy security framework was analyzed using Fuzzy AHP and the PROMETHEE method. The results suggest gaps in ES performances among the countries with some salient challenges to tackle for enhancing energy security within the electricity sector in the UEMOA.

Côte d'Ivoire was the most secure country in the UEMOA, followed by Senegal, and Togo in 2019, whereas Benin, Burkina Faso, and Niger still require more effort to secure their electricity sectors as they were ranked among the latest. Mali, which was more secure in the early years, showed declining ES in recent years. This makes the country the worst performer of the UEMOA in terms of change in ES for the study period, preceded by Niger and Benin, respectively. On the other hand, Senegal demonstrated to be the best performer in terms of progress in ES, followed by Togo, Cote d'Ivoire, and Burkina Faso.

In terms of trends of ES, the countries displayed various patterns. However, none of them performed well in all the indicators of the ES framework, meaning that, as in previous studies (Sovacool et al., 2011; Zhang et al., 2017), energy security was shown to be driven by not only one factor but is a multi-factorial concept. It also means that efforts are still necessary for all countries to enhance ES in the electricity sector. Therefore, the policy implications of the results are discussed country by country as shown in **Table C1**, some of which are given in short below.

First, our results suggest that most of the countries in the UEMOA have low governance and regulation ratings. Therefore, improving governance is urgently needed to enhance energy security within the electricity sector in the UEMOA. At present, all UEMOA countries are suffering from governance issues, including ineffectiveness, large scale corruption, political instability, weakened regulatory systems, and hard investment climate. Such issues translate in the electricity sector into a lack of proper planning and investment on the one hand and planning and implementation of suitable policies on the other hand. Therefore, attention is needed on investment, but also on implementing both primary and innovative policies, including, for example, the liberalization of the sector or promotion of a more competitive market, the rethinking of the investment of the private sector, the promotion of incentive programs, and more regional collaborations among the UEMOA countries. Such actions would help enhance energy security by solving primary issues like access to electricity services at affordable and stable prices.

Second, our results reveal that poor diversity in the choice of energy sources, with high penetration of fossils primary energies (71.6% in the UEMOA in 2019), is another weakness of ES in many countries of the UEMOA, including specifically Cote d'Ivoire the best ES performer, but also the likes of Benin, and Togo. Results also demonstrated that the two latter countries suffer from low self-sufficiency in satisfying the domestic demand, along with Burkina Faso and Niger. Therefore, increasing generation capacity with a higher penetration of renewable energy sources and making proper planning and investment (including R&D) in more reliable electricity generation technology/material will help reduce the countries' vulnerability to service disruptions and improve security within the electricity sector. Indeed, the UEMOA region has consistent renewable energy potential (Suberu et al., 2013). Therefore, proper planning and investment in this way, should be a primary move for these countries.

Furthermore, our results identified energy efficiency as another important weakened factor of ES within the electricity sector in the UEMOA. In this way, efforts are still needed from all the UEMOA countries, as the results showed decreasing trends for most countries' efficiency and reliability indicators. The electricity system and infrastructure in the UEMOA still consist of old and unreliable materials and technology. This situation, combined with the non-optimized positioning of the generation centers concerning the consumers, leads to high losses, representing 21% of the total electricity consumed in the Union. Moreover, a lack of policies and education about energy efficiency also leads to losses on the consumer side. Therefore, the planning and implementation of proper energy efficiency policies and measures, as well as adequately planned (simple and R&D) investments for upgrading electricity infrastructures and developing new and more reliable and efficient technologies, will play a vital role in tackling the energy efficiency issues to enhance ES within the

UEMOA. In addition, off-grid generation and individual solutions such as electrification kits can also play a vital role in reducing the grid's high losses by reducing the distances between production centers and consumers.

Finally, attention should also be paid to environmental issues, as the results demonstrated environmental concerns for the countries, which are still highly dependent on fossil fuels. Therefore, cleaner production methods and efficient consumption are essential, and prioritizing renewable sources for electricity generation appears to be a key solution. In addition, developing environmental policies and measures and promoting education on the importance of the environmental component should also be priorities for ensuring sustainable development in the UEMOA.

The five-dimension framework proposed in this paper can be seen as another contribution to the existing literature on energy security, especially for future studies on energy security assessment in the global south. Moreover, it could be extended to other developing countries that share common characteristics with the UEMOA countries.

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CRediT authorship contribution statement

Komlan H.S. Tete: Conceptualization, Investigation, Methodology, Formal analysis, Writing ‐ original draft. **Y.M. Soro:** Conceptualization, Resources, Investigation, Methodology, Validation, Formal analysis, Writing ‑ review & editing, Supervision. **S.S. Sidibé:** Methodology, Investigation, Formal analysis, Writing ‑ review & editing. **Rory V. Jones:** Methodology, Formal analysis, Writing ‑ review & editing.

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

Data availability

The data that support the findings of this study are openly available on request.

Appendix A. The Fuzzy sets theory and operations

Sets whose elements have degrees of membership are known as Fuzzy sets. In a universe of discourse X, a fuzzy number $\tilde{a}$ is a fuzzy subset of X such that for all x ϵ X, there is a number $\mu_{\tilde{a}}(x)$ ϵ [0, 1] assigned to represent the membership of x to $\tilde{a}$. Such a number is called the membership function of $\tilde{a}$. The triangular fuzzy number (TFN), which can be expressed as a triplet (a^l, a^m, a^u), is usually used in fuzzy studies. The membership function associated with such a number is defined as shown by **Eq. (A1)**. **Eqs. (A2) - (A8)** display the operational laws of two TFNs $\tilde{a} = (a^l, a^m, a^u)$ and $\tilde{b} = (b^l, b^m, b^u)$ (Sun, 2010).

$$\mu_{\tilde{a}}(x) = \begin{cases} \frac{x-a^l}{a^m-a^l}; & a^l \leq x \leq a^m \\ \frac{a^u-x}{a^u-a^m}; & a^m \leq x \leq a^u \\ 0; & \text{Otherwise} \end{cases} \tag{A1}$$

Addition of the two fuzzy numbers

$$\tilde{a} \oplus \tilde{b} = (a^l, a^m, a^u) \oplus (b^l, b^m, b^u) = (a^l + b^l, a^m + b^m, a^u + b^u) \tag{A2}$$

Subtraction of the two fuzzy numbers

$$\tilde{a} \ominus \tilde{b} = (a^l, a^m, a^u) \ominus (b^l, b^m, b^u) = (a^l - b^l, a^m - b^m, a^u - b^u) \tag{A3}$$

Multiplication of the two fuzzy numbers

$$\tilde{a} \otimes \tilde{b} = (a^l, a^m, a^u) \otimes (b^l, b^m, b^u) = (a^l b^l, a^m b^m, a^u b^u) \tag{A4}$$

Division between the two fuzzy numbers

$$\tilde{a} \oslash \tilde{b} = (a^l, a^m, a^u) \oslash (b^l, b^m, b^u) = (a^l/b^u, a^m/b^m, a^u/b^l) \tag{A5}$$

Reciprocal of one fuzzy number $\tilde{a}$

$$\tilde{a}^{-1} = (a^l, a^m, a^u)^{-1} = (1/a^u, 1/a^m, 1/a^u) \tag{A6}$$

Multiplication between the fuzzy number $\tilde{a}$ and a real number k

$$k \times \tilde{a} = k \times (a^l, a^m, a^u) = (ka^l, ka^m, ka^u) \tag{A7}$$

Where a^l, b^l, a^m, b^m, a^u, b^u are real numbers and standing respectively for the corresponding lower (l), middle (m), and upper (m) values of the two fuzzy numbers.

Appendix B. pair wise comparisons and fuzzy AHP results

In this study, twenty-three stakeholders helped make the judgment matrices using linguistic terms as it can be seen in **Tables B1–B6**. Then, the pairwise comparisons were translated into fuzzy scales for each stakeholder (using **Table 2**) and averaged fuzzy judgment matrixes were derived from them, as shown in **Tables B7-12**. Finally, the geometric mean and the fuzzy weights concerning the factors were determined using **Eqs. (3)-(5)** and presented in **Table 3**.

Appendix C. Challenges of energy security and policy implication

The Table C1 below present country by country, the challenges of energy security drawn from the results of the study, the actual policy background of the countries, and the policy implications for addressing the challenges and enhance therefore, energy security within the electricity sector in UEMOA.

Appendixes’ Tables

Table B 1. Judgment matrix (of one stakeholder) with respect to the five dimensions of energy security.

	A	**B**	**C**	**D**	**E**
A	E	E	RM	VS	S
B	E	E	VS	VS	VS
C	M	RVS	E	VS	S
D	RVS	RVS	RVS	E	RVS
E	RS	RVS	RS	VS	E

A: availability and diversity, B: affordability and equality, C: efficiency and reliability, D: regulation and governance, E: environmental sustainability.

Table B 2. Judgment matrix (of one stakeholder) with respect to Availability and diversity.

	A1	**A2**	**A3**	**A4**
A1	E	RM	VS	S
A2	M	E	S	E
A3	RVS	RS	E	RS
A4	S	E	S	E

A1: security of supply, A2: diversification, A3: dependency, A4: Availability of power plants

Table B 3. Judgment matrix (of one stakeholder) with respect to affordability and equality.

	B1	**B2**	**B3**	**B4**
B1	E	VS	E	E
B2	RVS	E	E	E
B3	E	E	E	E
B4	E	E	E	E

B1: access, B2: stability, B.3: affordability of electricity, B4: electricity Equality

Table B 4. Judgment matrix (of one stakeholder) with respect to efficiency and reliability.

	C1	C2	C3
C1	E	1/M	1/S
C2	M	E	1/S
C3	S	S	E

C1: energy efficiency, C2: grid efficiency, C3: grid Reliability

Table B 5. Judgment matrix (of one stakeholder) with respect to regulation and governance.

	D1	D2	D3
D1	E	A	E
D2	RA	E	RVS
D3	E	VS	E

D1: governance, D2: collaboration, D3: competition and markets, D4: information access

Table B 6. Judgment matrix (of one stakeholder) with respect to environmental sustainability.

	E1	E2	E3	E4
E1	E	E	M	RS
E2	E	E	RS	RM
E3	RM	S	E	RS
E4	S	M	S	E

E1: climate change, E2: emission-energy intensity, E3: emission-economy intensity, E4: sustainability

Table B 7. Averaged fuzzy comparison matrix with respect to the five dimensions.

	A	B	C	D	E
A	(1.00, 1.00, 1.00)	(1.55, 1.84, 2.17)	(1.24, 1.49, 1.78)	(1.48, 1.80, 2.12)	(1.60, 1.85, 2.11)
B	(0.46, 0.54, 0.64)	(1.00, 1.00, 1.00)	(1.26, 1.46, 1.70)	(0.99, 1.17, 1.40)	(1.46, 1.64, 1.82)
C	(0.56, 0.67, 0.81)	(0.59, 0.68, 0.80)	(1.00, 1.00, 1.00)	(1.15, 1.36, 1.60)	(1.14, 1.27, 1.40)
D	(0.47, 0.56, 0.67)	(0.72, 0.85, 1.01)	(0.63, 0.74, 0.87)	(1.00, 1.00, 1.00)	(1.05, 1.21, 1.39)
E	(0.47, 0.54, 0.63)	(0.55, 0.61, 0.68)	(0.71, 0.79, 0.88)	(0.72, 0.83, 0.95)	(1.00, 1.00, 1.00)

Table B 8. Averaged fuzzy comparison matrix with respect to Availability and diversity.

	A1	A2	A3	A4
A1	(1.00, 1.00, 1.00)	(1.31, 1.57, 1.89)	(1.40, 1.62, 1.82)	(1.46, 1.64, 1.81)
A2	(0.53, 0.64, 0.77)	(1.00, 1.00, 1.00)	(0.70, 0.81, 0.96)	(0.50, 0.57, 0.68)
A3	(0.55, 0.62, 0.71)	(1.05, 1.24, 1.43)	(1.00, 1.00, 1.00)	(0.89, 1.01, 1.17)
A4	(0.55, 0.61, 0.68)	(1.48, 1.74, 2.00)	(0.86, 0.99, 1.12)	(1.00, 1.00, 1.00)

Table B 9. Averaged fuzzy comparison matrix with respect to affordability and equality

	B1	B2	B3	B4
B1	(1.00, 1.00, 1.00)	(1.72, 1.98, 2.26)	(1.10, 1.20, 1.30)	(2.38, 2.93, 3.50)
B2	(0.44, 0.51, 0.58)	(1.00, 1.00, 1.00)	(1.02, 1.21, 1.44)	(2.09, 2.51, 2.93)
B3	(0.77, 0.83, 0.91)	(0.69, 0.83, 0.98)	(1.00, 1.00, 1.00)	(2.47, 3.04, 3.60)
B4	(0.29, 0.34, 0.42)	(0.34, 0.40, 0.48)	(0.28, 0.33, 0.40)	(1.00, 1.00, 1.00)

Table B 10. Averaged fuzzy comparison matrix with respect to efficiency and reliability

	C1	C2	C3
C1	(1.00, 1.00, 1.00)	(0.68, 0.83, 1.03)	(0.34, 0.40, 0.48)
C2	(0.97, 1.21, 1.47)	(1.00, 1.00, 1.00)	(0.74, 0.84, 0.96)
C3	(2.10, 2.53, 2.97)	(1.05, 1.19, 1.35)	(1.00, 1.00, 1.00)

Table B 11. Averaged fuzzy comparison matrix with respect to regulation and governance

	D1	D2	D3
D1	(1.00, 1.00, 1.00)	(1.70, 1.98, 2.30)	(1.46, 1.63, 1.79)
D2	(0.43, 0.50, 0.59)	(1.00, 1.00, 1.00)	(0.82, 0.96, 1.12)
D3	(0.56, 0.61, 0.69)	(0.89, 1.05, 1.23)	(1.00, 1.00, 1.00)

Table B 12. Averaged fuzzy comparison matrix with respect to environmental sustainability

	E1	E2	E3	E4
E1	(1.00, 1.00, 1.00)	(1.89, 2.23, 2.55)	(1.70, 2.03, 2.32)	(1.14, 1.28, 1.42)
E2	(0.39, 0.45, 0.53)	(1.00, 1.00, 1.00)	(0.88, 0.98, 1.10)	(0.68, 0.76, 0.85)
E3	(0.43, 0.49, 0.59)	(0.91, 1.02, 1.14)	(1.00, 1.00, 1.00)	(0.79, 0.89, 1.01)
E4	(0.70, 0.78, 0.88)	(1.18, 1.32, 1.48)	(0.99, 1.12, 1.27)	(1.00, 1.00, 1.00)

Table C 1. Policy implications driven from the study's results for energy security **enhancement in** the UEMOA

Country	Weaker points identified from the study's results to boost for ES enhancement	Policy background of the country: Actions, objectives, policies / measures introduced, predicted or in vigor about the points identified	Actual (policy) state and achievements in the country	Future policy recommendation for ES enhancement
Benin	a) Low availability of domestic power plants and poor diversity in primary energy mix for electricity generation. High dependency (low self-sufficiency) on import for domestic demand satisfaction b) High losses and lower efficiency in the electric system c) Low share of electricity use in total energy consumption d) Low governance ratings (despite increase over the study period) e) Non-negligible emissions indices due to high penetration of the fossil fuels	a) Release of the national development plan (PAG) and the national plan of renewable energies (PANER 2015), targeting in other things the increase in renewable power capacity by 425 MW by 2020: 150 MW for PV and biomass, 275 MW of hydroelectricity and increase in total power capacity by 723 MW by 2024. b) Adoption of the National Policy on Energy Management (PONAME-2009) and the release of the National Plan of Energy Efficiency (PANEE 2015) with the aims in other terms of: the reduction of the losses in the grid to 14 % by 2020 (and to 8% by 2030) and the adoption of standards on energy efficiency (5) and appliance labelling (2). c) Release of the National Plan of Energy Efficiency (PANEE 2015) and the National Electrification Master Plan with the aims in other terms of increasing of the	a) Only 129 MW of thermal (natural gas and oil) power added on the grid in 2019. No major addition of any renewable power added in the electric system before 2019. b) Adoption of only one law on the energy efficiency in the country and design of also one standard on appliance labeling. Implementation of low-scale programs energy efficiency (distribution of efficient lighting in urban zones) c) Access to electricity still at 32.7% in 2019 d) Reduction of corruption by 53% in the institutions and increase in liberalization of the electricity sector (increase in production from the IPP)	a) Increase of capacity generation with priority for diversity (renewable energies in prior), adjustment of the institutional framework to enhance the installation of IPPs and rethink of the foreign and private investment in the sector (lower the procedures for example). b) Replacement and improvement of electricity material/infrastructure and maintenance planning for use. Planning and implementation of R&D for a better future exploitation. Proper design and implementation of energy efficiency policies including incentives policies for efficient and cleaner use on the customer side.

	access to electricity to 50% by 2020 and to 75% by 2030. d) Adoption of numerous law and decrees for administration enhancement (2), participation enhancement (1), Corruption reduction (1) and Justice enhancement (1) e) Initiation of 2 sub-programs for energy transition (switching progressively from fossil to cleaner fuels) and development of a monitoring/regulation mechanism for emissions (carbons taxes).		c) Rethinking and proper planning of the strategies for increasing access to electricity by encouraging for example off-grid generation and distribution in remote areas for avoiding losses or implementing individual solutions (electrification kits). Adjustment of the investment climate for encouraging competition for electricity distribution. d) Enhancement of the institutional and regulatory frameworks. e) Increasing information on the environmental issues, design and implementation of environmental standards for production and use of energy, implementation of incentives measures for users. Adjustment of the sector’s climate to incorporate the environmental components into the policies/measures and the investment in the projects.

Burkina Faso	a) Low rates of electricity supply and increasing dependency on imports for domestic demand satisfaction b) High energy intensity c) Low access to electricity and low share of electricity use in total energy consumption d) Deteriorating governance ratings e) Lower affordability of electricity f) Non-negligible emissions indices	a) Design and release of the national plan of economic and social development (PNDES 2016) and the national plan of renewable energies (PANER 2015) targeting in other things the addition of 118 MW power capacity of renewable energy type by 2020 and increase in total power capacity to 1000 MW. b) Releasing of the National Plan of Energy Efficiency (PANEE 2015) with in other things the aim of reducing electricity intensity. c) Design and release of the national plan of economic and social development (PNDES 2016) aiming to increase to 45% the rate of access to electricity by 2020 through various strategies. d) Adoption of law and decrees for administration enhancement (2), Corruption reduction (1) and programs to enhance security.	a) Only 50 MW of thermal (oil) power added on the grid in 2019 and 31 MWc of renewable power (solar PV) added on the grid in 2017 b) Adoption of only one law on the energy efficiency in the country and the distribution of efficient lighting in urban zones, with electricity intensity still high. c) Access to electricity remains among the lowest of the Union and the global South in 2019 (28.7%). d) Corruption instead increases by 19% from 2014 to 2019 and increase of insecurity and political instability. e) Electricity services still remains among the most expensive in the union and in the south region.	a) Increase of capacity generation with priority for diversity (renewable energies especially), adjustment of the institutional framework to encourage competition (the implementation of IPPs) and make the investments procedures easier and rethink of the foreign and private investment in the sector. b) Design and implementation of policies aiming the use of cleaner technology/methods for electricity production and policies (incentive) encouraging cleaner and efficient use on the customer side. c) Rethink of the electrification programs: off-grid generation and distribution in remote areas (rural areas) for avoiding losses and individual solutions (electrification kits) and improvement of electricity

material/infrastructure. Planning and implementation of R&D for a better future exploitation. Design and implement incentives policies for auto-production and use.

d) Rethink the governing strategies in the country: Try first to review/improve the management of administrations, the institutional/juridical/regulatory frameworks and review the security situation for improving political stability and for re-attracting investors.

e) Develop and implement policies for prioritizing the use of more affordable fuels (renewable/biofuels) for production and adjustment of the climate in the electricity sector for encouraging auto-production and use on the customer side with incentives measures for use of the more affordable fuels, liberalization of the

				sector for encouraging competition and therefore quality and affordability of the services provided. f) Increasing information on the environmental issues, design and implementation of environmental standards for production and use of energy, implementation of incentives measures for users. Adjustment of the sector's climate to incorporate the environmental components into the policies/measures and the investment in the projects.
Cote d'Ivoire	a) Poor diversity in the mix of the primary energy sources use to generate electricity. b) Instability of the prices of the electricity services. c) High electricity intensity. d) High indices of emissions.	a) Release of the national plan of renewable energies (PANER 2016) and the national strategy for the enhancement of the electricity sector aiming the introduction of renewable energies including solar PV and biomass (a total of 260 MW by 2020) and increase of production from hydroelectricity (426 MW by 2020) and increase in total capacity by 3762 MW	a) Only 245 MW of hydroelectricity added on the electric system. No major addition of any other renewable energy type (solar PV or biomass) of power on the electric system. b) Electricity services tariffs remain instable since 2014. c) Launching of the distribution of the efficient lighting in urban zones, adoption of	a) Increase of capacity generation with priority for diversity (renewable energies especially). Adjustment of the investment climate to encourage the electricity production by using renewable primary sources and increase competition in the sector for increasing also diversity in supply.

	until 2030 within which renewable energy represents 35%. b) Adoption of a decree establishing the rules for determining and revising the tariffs for the sale and purchase of electrical energy as well as the rules for access to the network and energy transit. c) Release of a national plan for energy efficiency (PANEE 2016) aiming in other things, the reduction of the electricity intensity by employing actions such as improvement of the material of the electric grid for reduction of the losses to 16% by 2020, the distribution of efficient lighting, replacement of the fixtures of public lighting and the increasing of the standards, decrees and laws on energy efficiency (14). d) The environmental intervention strategy focuses on the development of renewable energy for electricity, the dissemination of improved stoves in rural and peri-urban areas.	numerous laws and decrees on the energy management (1), energy efficiency (1), appliance labeling (1), and in favor of the creation of institutions for enhancing the management in the electricity sector (1).	b) Make a better prediction of the market and the prices of the primary energies sources and make a good planning of the offers to stabilize the price of the electricity services. c) Rethink and design of proper energy efficiency policies/measures and enhancement of the institutional and regulatory frameworks to help for the implementation and success of the policies. Increase of information about energy efficiency attitudes and implementation of incentive policies on the customer side for encouraging efficient attitudes. d) Increasing information on the environmental issues, design and implementation of environmental standards for production and use of energy, implementation of incentives measures for users. Adjustment of the

				sector's climate to incorporate the environmental components into the policies/measures and the investment in the projects.
Mali	a) Decreasing diversity in production and supply and increasing dependency on imports for domestic demand satisfaction b) High energy intensity and decrease in reliability within the electricity system c) Deteriorating governance ratings and lack of competition in the electricity sector's market d) Non-negligible emissions indices due to increasing share of the fossil fuels within the energetic mix.	a) Release of the national plan of renewable energies (PANER 2015), the national strategy for the development of energy management, the national strategy for the enhancement of electricity access sector and the Optimal Investment Master Plan (PDOI) aiming in other things, the increase in power capacity with priority for diversity and especially renewable energies including solar PV, biomass and hydroelectricity (472 MW by 2020), increase of production from hydroelectricity (426 MW by 2020) and increase in total capacity by 1272 MW until 2025 within which renewable energy represents 38%. b) Release of a national plan for energy efficiency (PANEE 2015), the national strategy for the development of energy management and the Sustainable Energy for All Investment Prospectus aiming in other things, the reduction of the electricity	a) Increase in power by only 295 MW with thermal sources dominating (268 MW) and renewable addition consisting only of hydroelectricity (27MW). No major addition of any renewable power (Solar PV or biomass) in the electric system before 2020 mainly due to increase in political instability and the weakening of the institutional framework. b) Implementation of low-scale programs energy efficiency (distribution of efficient lighting in urban zones, distribution and installation of solar kits in rural zones). c) No installation or major operation/investment of any IPP within the electricity sector during the study period probably due to overall increase political	a) Increase of capacity generation with priority for diversity (renewable energies especially), and rethink of the foreign and private investment in the sector. Increase the security situation and the institutional framework and re-adjust the investment climate to encourage the electricity production by using renewable primary sources and also competition for diversity in supply. b) Design and implementation of policies aiming the use of cleaner methods for electricity production, and policies (incentive) encouraging the cleaner use on the customer side. Rethink of the electrification programs: individual solution (electrification kits),

	intensity by employing actions such as improvement of the material of the electric grid for reduction of the losses to 14% by 2020 and 10% by 2030, the distribution of efficient lighting, replacement of the fixtures of public lighting and the increasing of the standards, decrees and laws on energy efficiency, appliance labelling and purchasing (19).	instability, increase of insecurity and also corruption (45%, the highest of the Union).	off-grid generation and distribution in remote areas (rural areas) for avoiding losses and improvement of electricity material/technology. Planning and implementation of R&D for a better future exploitation. Design and implement incentives policies for auto-production and use. c) Rethink the governing strategies in the country: Try first to review/improve the management of administration, review the functioning and enhance the regulatory and institutional framework, review the security situation for improving political stability and re-attracting investors**.** f) Increasing information on the environmental issues, design and implementation of environmental standards for production and use of energy, implementation of incentives

				measures for users. Adjustment of the sector’s climate to incorporate the environmental components into the policies/measures and the investment in the projects.
Niger	a) Low ratings of security of supply and access to electricity and increasing dependency on imports for domestic demand satisfaction b) Decrease in efficiency and reliability within the electricity system c) Low governance and regulation ratings and lack of competition in the sector d) High emissions indices due to increasing penetration of the fossil fuels	a) Release of the national plan of renewable energies (PANER 2015) and the national strategy for electricity access enhancement (SNAE) aiming in other things, the increase in power capacity with priority for diversity and especially renewable energies including solar PV, hydroelectricity (205 MW by 2020), increase in total capacity by 1,015 MW by 2025 and a rate of access rate to electricity of 80% by 2035. Creation of the national agency for rural electrification (ANPER) for a focus on the rural access to electricity in 2011. b) Release of the national strategy for electricity access enhancement (SNAE) for rethinking of the electrification strategies to avoid losses and lack of reliability.	a) Addition of only 7 MWc of solar type capacity in 2018 and 153 MW of thermal type capacity and increase of access to only 13.60 % in 2019, which remains the lowest in the Union. b) No significant changes in lack of efficiency and reliability of the electric system technology or material. c) No installation or major operation/investment of any IPP within the electricity sector during the study period probably due to increase in political instability, increase of insecurity and corruption (9%).	a) Increase of capacity generation with priority for diversity (renewable energies especially), and rethink of the foreign and private investment in the sector. Adjustment of the investment climate to encourage the electricity production by using renewable primary sources. Rethink the strategies and make a proper planning for funds dedicated to increase access to electricity. b) Replacement and improvement of electricity material/infrastructure and maintenance planning for use. Planning and implementation of R&D for a better future exploitation.

	c) Release of the country electricity code for with in other things, the setting the conditions of operation of the IPPs in 2016.		Increase of information about importance of efficient use and proper design and implementation of energy efficiency policies including incentives policies for efficient and cleaner use on the customer side. c) Rethink the governing strategies in the country: Try first to review/improve the management of administrations, review the security situation for improving political stability and re-attract investors**.** Review and eventually reduce barriers to investment, for example, by simplifying investment procedures, f) Increasing information on the environmental issues, design and implementation of environmental standards for production and use of energy, implementation of incentives measures for users. Adjustment of the

				sector's climate to incorporate the environmental components into the policies/measures and the investment in the projects.
Senegal	a) Decreasing availability of the power plants due old and unreliable material. b) Instability of the prices of the electricity services and decrease in affordability of the electricity services. c) Increasing electricity intensity d) Poor emissions indices due to increasing penetration of the fossil fuels	c) Release of a national plan for energy efficiency (PANEE 2015) aiming in other things, the stabilization of the electricity intensity to 0.429 kWh/$US by employing actions such as improvement of the material of the electric grid for reduction of the losses to 3% by 2020, the distribution of efficient lighting, replacement of the fixtures of public lighting and the increasing of the standards, decrees and laws on energy efficiency (27). Creation of the national agency for energy management in 2011 (AEME) and the national agency of the renewable energy (ANER) in 2013.	c) no significant change (despite the launching of the programs of distribution of the efficient lighting fixtures) due to numerous identified barriers within which the lack of information about importance of efficiency in use, unavailability of public funds, high cost of opportunity, and the lack of a good regulatory and juridical framework.	a) Planning and implementation of R&D for a better exploitation through technology and material upgrade. Design and implementation incentives policies for auto-production and use. b) Make a better prediction of the market and the prices of the primary energies sources and make a good planning of the offers to stabilize the price of the electricity services. Increase competition within the distribution for increasing diversity, quality and affordability in service providing. c) Rethink the institutional and regulatory frameworks of the sector, increase of information about efficient

				attitudes and implementation of incentive policies on the customer side, reduce barriers to investment, for example, by simplifying investment procedures, f) Increasing information on the environmental issues, design and implementation of environmental standards for production and use of energy, implementation of incentives measures for users. Adjustment of the sector's climate to incorporate the environmental components into the policies/measures and the investment in the projects.
Togo	a) Lack of diversity in supply. b) High electricity intensity and decrease in reliability within the electric system c) Low governance ratings and lack of competition in the market of the sector	a) Release of the national plan of renewable energies (PANER 2015) aiming in other things, the increase of the power capacity by renewable energies including solar PV and hydroelectricity (65 MW) by 2020 and increase share of renewable energies in total capacity to 45.5% MW until 2030 to diversify the mix. Adoption	a) No major adds of any renewable power added in the electric system before 2020 b) No significant change (despite the launching of the programs of distribution of the efficient lighting fixtures).	a) Increase of capacity generation with priority for diversity (renewable energies in prior), and rethink of the foreign and private investment in the sector. Adjustment of the investment climate to encourage the electricity

	d) Non-negligible emissions indices due to high penetration of the fossil fuels	of a law on the promotion of the promotion of electricity production from renewable energy sources. b) Release of a national plan for energy efficiency (PANEE 2015) aiming in other things, the stabilization of the electricity intensity by employing actions such as improvement of the material of the electric grid for reduction of the losses to 17% by 2020 and 12% in 2030, the distribution of efficient lighting and solar kits, replacement of the fixtures of public lighting and the elaboration of the standards, decrees and laws on energy efficiency. Creation of the national agency for rural electrification and renewable energy in 2016 (AT2ER). c) Review of the institutional framework and adoption of a decree for encouraging the activity of the IPPs	c) No new investment or project conducted by an IPP recorded for the period of study.	production by using renewable primary sources. b) Rethink and design of proper energy efficiency policies/measures and enhancement of the institutional and regulatory frameworks to help for the implementation and success of the policies. Increase of information about efficient attitudes and implementation of incentive policies on the customer side. c) Rethink the institutional, juridical and regulatory frameworks of the country in general and especially in the electricity sector, rethink the conditions of production by the IPPs, reduce barriers to investment for example, by simplifying investment procedures, d) Increasing information on the environmental issues, design and implementation of environmental

			standards for production and use of energy, implementation of incentives measures for users. Adjustment of the sector's climate to incorporate the environmental components into the policies/measures and the investment in the projects.

References

Acquah, C.K., Sarpong, S.A., 2015. The energy security situation of Ghana; A Country Comparative Analysis of 34 other countries worldwide. J. Energy Technol. Policy 5, 46–57.

Aczel, J., Saaty, T.L., 1983. Procedures for Synthesizing Ratio Judgements. J. Math. Psychol. 27, 93–102.

AIT, 2010. Energy Security in Thailand. Glob. Netw. Energy Sustain. Dev.

Ajayi, O.O., 2013. Sustainable energy development and environmental protection: Implication for selected states in West Africa. Renew. Sustain. Energy Rev. 26, 532–539. https://doi.org/10.1016/j.rser.2013.06.009

Albadvi, A., Chaharsooghi, S.K., Esfahanipour, A., 2006. Decision making in stock trading: An application of PROMETHEE. Eur. J. Oper. Res. 177, 673–683. https://doi.org/10.1016/j.ejor.2005.11.022

Alemzero, D.A., Sun, H., Mohsin, M., Iqbal, N., Nadeem, M., Vo, X.V., 2021. Assessing energy security in Africa based on multi-dimensional approach of principal composite analysis. Environ. Sci. Pollut. Res. 28, 2158–2171. https://doi.org/10.1007/s11356-020-10554-0

Anand, G., Kodali, R., 2008. Selection of lean manufacturing systems using the PROMETHEE. J. Model. Manag. 3, 40–70. https://doi.org/10.1108/17465660810860372

Ang, B.W., Choong, W.L., Ng, T.S., 2015. Energy security: Definitions, dimensions and indexes. Renew. Sustain. Energy Rev. 42, 1077–1093. https://doi.org/10.1016/j.rser.2014.10.064

Antanasijević, D., Pocajt, V., Ristić, M., Perić-Grujić, A., 2017. A differential multi-criteria analysis for the assessment of sustainability performance of European countries: Beyond country ranking. J. Clean. Prod. 165, 213–220. https://doi.org/10.1016/j.jclepro.2017.07.131

APERC, 2007. A quest for energy security in the 21st century: resources and constraints.

ARSE-BF, 2019. Rapport annuel d'activités 2019.

ARSE-NE, 2019. Rapport annuel 2019 [WWW Document]. URL http://www.arse.gouv.ne/images/documents/Rapports activités/rapport activités ARSE.v 16 sept.2020_New1.pdf

Asif, M., Muneer, T., 2007. Energy supply, its demand and security issues for developed and emerging economies. Renew. Sustain. Energy Rev. 11, 1388–1413. https://doi.org/10.1016/j.rser.2005.12.004

Behzadian, M., Kazemzadeh, R.B., Albadvi, A., Aghdasi, M., 2010. PROMETHEE: A comprehensive literature review on methodologies and applications. Eur. J. Oper. Res. 200, 198–215. https://doi.org/10.1016/j.ejor.2009.01.021

Bellos, E., 2018. Sustainable energy development: How can the tension between energy security and energy transition be measured and managed in South Africa? J. Clean. Prod. 205, 738–753. https://doi.org/10.1016/j.jclepro.2018.08.196

Bielecki, J., 2002. Energy security: Is the wolf at the door? Q. Rev. Econ. Financ. 42, 235–250. https://doi.org/10.1016/S1062-9769(02)00137-0

Blimpo, M., McRae, S., Steinbuks, J., 2018. Why Are Connection Charges So High? An Analysis of the Electricity Sector in Sub-Saharan Africa. Why Are Connect.

Charg. So High? An Anal. Electr. Sect. Sub-Saharan Africa. https://doi.org/10.1596/1813-9450-8407

Blimpo, M.P., Cosgrove-davies, M., 2019. Electricity Access in Sub-Saharan Africa: Uptake, Reliability, and Complementary Factors for Economic Impact. Africa Development Forum series. https://doi.org/10.1596/978-1-4648-1361-0

Blimpo, M.P., Postepska, A., Xu, Y., 2020. Why is household electricity uptake low in Sub-Saharan Africa? World Dev. 133, 1–41. https://doi.org/10.1016/j.worlddev.2020.105002

BOAD, 2010. Changements climatiques et sécurité alimentaire dans la zone UEMOA : défis, impacts, enjeux actuels et futurs [WWW Document]. URL http://www.boad.org/sites/default/files/rapportfinal_boad_23juillet2010-1_0.pdf

Boamah, F., Williams, D.A., Afful, J., 2021. Justifiable energy injustices? Exploring institutionalised corruption and electricity sector “problem-solving” in Ghana and Kenya. Energy Res. Soc. Sci. 73, 101914. https://doi.org/10.1016/J.ERSS.2021.101914

Brans, J.P., Vincke, P., 1985. Note—A Preference Ranking Organisation Method. Manage. Sci. 31, 647–656. https://doi.org/10.1287/mnsc.31.6.647

Brans, J.P., Vincke, P., Mareschal, B., 1986. How to select and how to rank projects : The PROMETHEE method . European Journal of Operational Research 14 ... How to select and how to rank projects : The PROMETHEE method. Eur. J. Oper. Res. 24, 228–238.

Buckley, J.J., 1985. Fuzzy hierarchical analysis. Fuzzy Sets Syst. 17, 233–247. https://doi.org/10.1016/0165-0114(85)90090-9

Cabalu, H., 2010. Indicators of security of natural gas supply in Asia. Energy Policy 38, 218–225. https://doi.org/10.1016/j.enpol.2009.09.008

Çelen, A., 2014. Comparative analysis of normalization procedures in TOPSIS method: With an application to Turkish deposit banking market. Inform. 25, 185–208. https://doi.org/10.15388/Informatica.2014.10

Cohen, G., Joutz, F., Loungani, P., 2011. Measuring energy security: Trends in the diversification of oil and natural gas supplies. Energy Policy 39, 4860–4869. https://doi.org/10.1016/j.enpol.2011.06.034

Dorian, J.P., Franssen, H.T., Simbeck, D.R., 2006. Global challenges in energy. Energy Policy 34, 1984–1991. https://doi.org/10.1016/j.enpol.2005.03.010

ENDA, E.E.D., 2009. Energy Security in West Africa The Case of Senegal - Final draft -. Glob. Netw. Energy Sustain. Dev.

ERC, E.R.C.-U. of C.T., 2009. Energy security in South Africa. Glob. Netw. Energy Sustain. Dev.

Goldemberg, J., La Rovere, E.L., Coelho, S., Simoes, A.F., Guardabassi, P., Gorren, R., 2009. “Energy Security ” theme in Brazil. Glob. Netw. Energy Sustain. Dev.

Gregory, J., Sovacool, B.K., 2019. Rethinking the governance of energy poverty in sub-Saharan Africa: Reviewing three academic perspectives on electricity infrastructure investment. Renew. Sustain. Energy Rev. 111, 344–354. https://doi.org/10.1016/j.rser.2019.05.021

Grubb, M., Butler, L., Twomey, P., 2006. Diversity and security in UK electricity generation: The influence of low-carbon objectives. Energy Policy 34, 4050–4062. https://doi.org/10.1016/j.enpol.2005.09.004

Güngör, Z., Serhadlioğlu, G., Kesen, S.E., 2009. A fuzzy AHP approach to personnel selection problem. Appl. Soft Comput. J. 9, 641–646. https://doi.org/10.1016/j.asoc.2008.09.003

Guo, M., van Dam, K.H., Touhami, N.O., Nguyen, R., Delval, F., Jamieson, C., Shah, N., 2020. Multi-level system modelling of the resource-food-bioenergy nexus in the global south. Energy 197, 117196. https://doi.org/10.1016/j.energy.2020.117196

Hughes, L., 2012. A generic framework for the description and analysis of energy security in an energy system. Energy Policy 42, 221–231. https://doi.org/10.1016/j.enpol.2011.11.079

Hughes, L., 2009. The four 'R's of energy security. Energy Policy 37, 2459–2461. https://doi.org/10.1016/j.enpol.2009.02.038

IEA, 2021a. Access to electricity – SDG7: Data and Projections – Analysis - IEA [WWW Document]. URL https://www.iea.org/reports/sdg7-data-and-projections/access-to-electricity (accessed 9.20.21).

IEA, 2021b. Countries & Regions - IEA [WWW Document]. URL https://www.iea.org/countries (accessed 9.25.21).

IEA, 2019. World Energy Outlook 2019. World Energy Outlook Ser.

IEA, 2007. Energy Security and Climate Policy : Assessing Interactions.

IEA, 2001. Towards a Sustainable Energy Future. OECD. https://doi.org/10.1787/9789264193581-en

IFDD, UEMOA, 2020. Étiquetage des appareils électroménagers et code d'éfficacité énergétique des bâtiments neufs au sein de l'UEMOA et modération.

IndexMundi, 2021. Electricity - production - Country Comparison [WWW Document]. URL https://www.indexmundi.com/g/r.aspx?t=0&v=79&l=en (accessed 9.20.21).

Keulder, C., 2021. Les Africains jugent la corruption en hausse, craignent des représailles s'ils en parlent, Afro Barometer.

Kruyt, B., van Vuuren, D.P., de Vries, H.J.M., Groenenberg, H., 2009. Indicators for energy security. Energy Policy 37, 2166–2181. https://doi.org/10.1016/j.enpol.2009.02.006

L'Eglise, T., De Lit, P., Fouda, P., Rekiek, B., Raucent, B., Delchambre, A., 2001. A multicriteria decision-aid system for joining process selection. Proc. IEEE Int. Symp. Assem. Task Plan. 324–329. https://doi.org/10.1109/isatp.2001.929043

Le, T.H., Nguyen, C.P., 2019. Is energy security a driver for economic growth? Evidence from a global sample. Energy Policy 129, 436–451. https://doi.org/10.1016/j.enpol.2019.02.038

Lee, Q.Y., Lee, M.X., Lee, Y.C., 2021. A hybrid fuzzy decision model for evaluating mems and ic integration technologies. Micromachines 12, 1–13. https://doi.org/10.3390/mi12030276

Leite, A. da S., Léon, J.F., Macouin, M., Rousse, S., da Trindade, R.I.F., Proietti, A., Drigo, L., Antonio, P.Y.J., Akpo, A.B., Yoboué, V., Liousse, C., 2021. Pm2.5 magnetic properties in relation to urban combustion sources in southern west africa. Atmosphere (Basel). 12, 1–19. https://doi.org/10.3390/atmos12040496

Li, Y., Shi, X., Yao, L., 2016. Evaluating energy security of resource-poor economies: A modified principle component analysis approach. Energy Econ. 58, 211–221. https://doi.org/10.1016/j.eneco.2016.07.001

Macharis, C., Springael, J., De Brucker, K., Verbeke, A., 2004. PROMETHEE and AHP: The design of operational synergies in multicriteria analysis - Strengthening PROMETHEE with ideas of AHP. Eur. J. Oper. Res. 153, 307–317. https://doi.org/10.1016/S0377-2217(03)00153-X

Martchamadol, J., Kumar, S., 2012. Thailand's energy security indicators. Renew. Sustain. Energy Rev. 16, 6103–6122. https://doi.org/10.1016/J.RSER.2012.06.021

Moore, S., 2017. Evaluating the energy security of electricity interdependence: Perspectives from Morocco. Energy Res. Soc. Sci. 24, 21–29. https://doi.org/10.1016/j.erss.2016.12.008

NERC, 2019. Power Sector Report : Energy Generated and Sent Out and Consumed and Load Allocation [WWW Document]. URL https://www.nigerianstat.gov.ng/pdfuploads/Power_Generation_-_2019.pdf

Ofosu-Peasah, G., Ofosu Antwi, E., Blyth, W., 2021. Factors characterising energy security in West Africa: An integrative review of the literature. Renew. Sustain. Energy Rev. 148, 111259. https://doi.org/10.1016/J.RSER.2021.111259

Oyedepo, S.O., 2012. Energy and sustainable development in Nigeria: the way forward Sustainable energy Renewable energy Energy efficiency Energy conservation Review Background. Energy. Sustain. Soc. 1–17.

Radovanović, M., Filipović, S., Pavlović, D., 2017. Energy security measurement – A sustainable approach. Renew. Sustain. Energy Rev. 68, 1020–1032. https://doi.org/10.1016/j.rser.2016.02.010

Ren, J., Sovacool, B.K., 2014a. Quantifying, measuring, and strategizing energy security: Determining the most meaningful dimensions and metrics. Energy 76, 838–849. https://doi.org/10.1016/J.ENERGY.2014.08.083

Ren, J., Sovacool, B.K., 2014b. Enhancing China's energy security: Determining influential factors and effective strategic measures. Energy Convers. Manag. 88, 589–597. https://doi.org/10.1016/j.enconman.2014.09.001

Sarkodie, S.A., Adams, S., 2020. Electricity access and income inequality in South Africa: Evidence from Bayesian and NARDL analyses. Energy Strateg. Rev. 29. https://doi.org/10.1016/j.esr.2020.100480

SE4ALL, 2019a. Prospectus d'investissement de l'énergie durable pour tous SEforALL du Mali [WWW Document]. URL http://www.iadb.org/en/topics/energy/se4allamericas/about,15016.html

SE4ALL, 2019b. Prospectus d'investissement de l'énergie durable pour tous seforall du Niger [WWW Document]. URL https://www.se4all-africa.org/fileadmin/uploads/se4all/Documents/Country_IPs/PI_SeforALL_Niger_FINAL__1_.pdf

Sovacool, B.K., 2016. Differing cultures of energy security: An international comparison of public perceptions. Renew. Sustain. Energy Rev. 55, 811–822. https://doi.org/10.1016/j.rser.2015.10.144

Sovacool, B.K., 2013. An international assessment of energy security performance. Ecol. Econ. 88, 148–158. https://doi.org/10.1016/j.ecolecon.2013.01.019

Sovacool, B.K., 2011. Evaluating energy security in the Asia pacific: Towards a more comprehensive approach. Energy Policy 39, 7472–7479. https://doi.org/10.1016/j.enpol.2010.10.008

Sovacool, B.K., Mukherjee, I., 2011. Conceptualizing and measuring energy security: A synthesized approach. Energy 36, 5343–5355. https://doi.org/10.1016/j.energy.2011.06.043

Sovacool, B.K., Mukherjee, I., Drupady, I.M., D'Agostino, A.L., 2011. Evaluating energy security performance from 1990 to 2010 for eighteen countries. Energy 36, 5846–5853. https://doi.org/10.1016/j.energy.2011.08.040

Sovacool, B.K., Valentine, S.V., Jain Bambawale, M., Brown, M.A., de Fátima Cardoso, T., Nurbek, S., Suleimenova, G., Li, J., Xu, Y., Jain, A., Alhajji, A.F., Zubiri, A., 2012. Exploring propositions about perceptions of energy security: An international survey. Environ. Sci. Policy 16, 44–64. https://doi.org/10.1016/j.envsci.2011.10.009

Streatfeild, J.E.J., 2018. Low Electricity Supply in Sub-Saharan Africa: Causes, Implications, and Remedies. J. Int. Commer. Econ. 1.

Suberu, M.Y., Mustafa, M.W., Bashir, N., Muhamad, N.A., Mokhtar, A.S., 2013. Power sector renewable energy integration for expanding access to electricity in sub-Saharan Africa. Renew. Sustain. Energy Rev. 25, 630–642. https://doi.org/10.1016/j.rser.2013.04.033

Sun, C.C., 2010. A performance evaluation model by integrating fuzzy AHP and fuzzy TOPSIS methods. Expert Syst. Appl. 37, 7745–7754. https://doi.org/10.1016/j.eswa.2010.04.066

Talon, A., Curt, C., 2017. Selection of appropriate defuzzification methods: Application to the assessment of dam performance. Expert Syst. Appl. 70, 160–174. https://doi.org/10.1016/j.eswa.2016.09.004

Tarekegne, B., Sidortsov, R., 2021. Evaluating sub-Saharan Africa's electrification progress: Guiding principles for pro-poor strategies. Energy Res. Soc. Sci. 75, 102045. https://doi.org/10.1016/J.ERSS.2021.102045

TERI, T.E. and R.I.-N.D., 2008. Energy security. Glob. Netw. Energy Sustain. Dev.

Tractebel Engineering, GDF Suez, 2011. Update of the ECOWAS Revised Master Plan for the Generation and Transmission of Electrical Energy - Final Report Volume 2.

UEMOA, 2021. Présentation de l'UEMOA | Union Economique et Monétaire Ouest Africaine [WWW Document]. URL http://www.uemoa.int/fr/presentation-de-l-uemoa (accessed 9.22.21).

UEMOA, 2020. Atlas de l'énergie dans l'espace UEMOA.

United Nations, 2019. Livre de poche des statistiques mondiales 2019.

Vivoda, V., 2010. Evaluating energy security in the Asia-Pacific region: A novel methodological approach. Energy Policy 38, 5258–5263. https://doi.org/10.1016/j.enpol.2010.05.028

Von Hippel, D., Suzuki, T., Williams, J.H., Savage, T., Hayes, P., 2011. Energy security and sustainability in Northeast Asia. Energy Policy 39, 6719–6730. https://doi.org/10.1016/j.enpol.2009.07.001

Winzer, C., 2012. Conceptualizing energy security. Energy Policy 46, 36–48. https://doi.org/10.1016/j.enpol.2012.02.067

World Bank, 2021a. Glossary | DataBank [WWW Document]. URL https://databank.worldbank.org/metadataglossary/world-development-indicators/series/EG.ELC.ACCS.ZS (accessed 9.21.21).

World Bank, 2021b. Worldwide Governance Indicators (WGI) full dataset [WWW Document]. URL http://info.worldbank.org/governance/wgi/Home/downLoadFile?fileName=wgidataset.xlsx (accessed 10.4.21).

World Bank, 2021c. Access to electricity (% of population) | Data [WWW Document]. URL https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS (accessed 9.19.21).

Yang, C.C., Chen, B.S., 2004. Key quality performance evaluation using fuzzy AHP. J. Chinese Inst. Ind. Eng. 21, 543–550. https://doi.org/10.1080/10170660409509433

Yao, L., Chang, Y., 2014. Energy security in China: A quantitative analysis and policy implications. Energy Policy 67, 595–604. https://doi.org/10.1016/j.enpol.2013.12.047

Yergin, D., 2006. Ensuring Energy Security. Foreign Aff. 85, 69. https://doi.org/10.2307/20031912

Yergin, D., 1988. Energy Security in the 1990s. Foreign Aff. 67, 110. https://doi.org/10.2307/20043677

Zhang, L., Yu, J., Sovacool, B.K., Ren, J., 2017. Measuring energy security performance within China: Toward an inter-provincial prospective. Energy 125, 825–836. https://doi.org/10.1016/j.energy.2016.12.030