

Tracking sustainable energy indicators in Africa: New evidence from technique for order of preference by similarity to ideal solution

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ABSTRACT

African countries are actively working to enhance energy sustainability and minimize adverse impacts in the pursuit of Sustainable Development Goal 7, which is assessed through range of multidimensional indicators. To contribute to research that can be replicated, this study employed the Technique for Order of Preference by Similarity to Ideal Solution method, implemented using Python, to analyze optimal policy solutions in Africa within the sustainable development framework. The study focused on the five highest energy-consuming countries to determine which one has the most effective policy solutions. The results indicate that Nigeria has the most successful policy strategies, particularly in electricity access, clean cooking services, energy intensity, renewable energy integration, and investment in energy infrastructure technologies. Morocco follows closely, demonstrating balanced approach with moderate scores across the indicators, while Algeria, Egypt and South Africa face multiple challenges, including limited electricity access and renewable energy deployment. The findings suggest that reducing reliance on fossil fuels and other non-renewable energy sources is crucial for minimizing negative solutions in African countries, as these are significant contributors to climate change. In conclusion, the study recommends institutional collaborations, implementation of technological solutions, including integration of smart grid technologies, to enhance energy sustainability among African countries.

1. Introduction

By 2030, world leaders have set ambitious targets to address critical indicators related to energy sustainability [1] within the framework of the Sustainable Development Goals (SDGs). Through SDG 7 [2,3], policymakers aim to achieve the following objectives: 1) Ensure universal access to affordable, reliable, and clean electricity and cooking services (ECCA). 2) Increase the share of renewable energy in the global energy mix, promoting renewable energy integration (REI). 3) double the global rate of improvement in energy intensity (EI). 4) Enhance international cooperation to facilitate access to clean energy research, technology, and investment in energy infrastructure and technologies (IEIT). These SDG7 indicators reflect the global collective commitment to promoting a sustainable environment and fostering development through access to clean, affordable, and reliable energy services [4]. Towards achieving

these SDGs indicators, many developed and developing countries are facing multi-conflicting objectives. For instance, while increasing access to electricity is essential for improving living standards and economic development, it may conflict with environmental sustainability goals if the electricity is primarily generated from fossil fuels with high greenhouse gas emissions. Also, whereas increasing the share of renewable energy contributes to mitigating climate change and reducing environmental impacts, it may conflict with goals related to energy security and reliability, provided the renewable energy sources are intermittent or less reliable than traditional fossil fuels [5]. These examples illustrate the complexity of trade-offs and challenges inherent in achieving energy sustainability under SDG7 [6]. The presence of multi-conflicting indicators underscores the need for strategic research consideration of technical and economic implications in transitioning towards sustainable energy systems. As a result, addressing these conflicting indicators

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necessitates targeted policy interventions. Nonetheless, there is currently limited literature proposing optimal energy solutions to navigate the complexities of global energy transition and access amidst these conflicting indicators as the world progresses toward meeting the SDGs by 2030 [7]. Therefore, harmonizing these multi-conflicting SDG7 indicators requires multi-decision criteria approaches, policy coherence, and stakeholder engagement to ensure that progress toward SDG7 is sustainable [8].

The world has barely made minimal progress in these indicators, as in Fig. 1.

As of 2022, Africa has set various targets for renewable energy integration, electricity access, investment in renewable technologies, and energy intensity under the SDG7 towards 2030. These targets align with broader global initiatives in SDGs and the Paris Agreement on climate change. This includes targets for expanding renewable energy capacity, such as solar, wind, hydroelectric, and geothermal power. For example, some African countries aim to achieve a certain percentage of electricity generation from renewable sources by 2030, often ranging from 20 % to 50 % [9]. Similarly, several initiatives have been aimed at improving access to electricity in Africa, with the goal of ensuring universal access to affordable, reliable, and modern energy services by 2030. This involves extending electricity grids, deploying off-grid solutions such as solar home systems and mini-grids, and promoting energy intensity measures. What is more, energy intensity under the SDG7 indicators focuses on reducing energy consumption per unit of output or increasing energy productivity across various sectors, including industry, transportation, buildings, and agriculture [10]. By 2030, many African countries aim to achieve significant improvements in energy intensity through measures such as upgrading infrastructure, implementing energy technologies, and promoting energy conservation practices. Towards achieving SDG7 targets reflects Africa's commitment to transitioning to more sustainable, low-carbon energy future while addressing energy poverty and promoting development. It is, therefore, imperative to monitor the progress regularly and adjust policy strategies as needed to ensure that Africa remains on track to meet its energy goals by 2030 and beyond.

The current literature on sustainable energy goals in Africa presents several critical research gaps that need to be addressed in contributing to the continent's energy transition effectively [11]. These gaps reflect the complexity of Africa's energy setting and the unique challenges faced by different regions and countries. One of the most significant research gaps concerns the socio-technical dynamics of energy systems across Africa. The continent's energy background is diverse, with substantial differences not only between countries but also within regions. This diversity makes it clear that a one-size-fits-all approach to energy transition is not feasible. However, the existing literature lacks a comprehensive understanding of how these diverse socio-technical systems can be integrated or adapted to local contexts. Research is needed to develop models that are tailored to the specific socio-economic, cultural, and technical characteristics of each region [11]. Another major gap is the lack of empirical studies on energy justice and inclusive governance. Energy policies often have unequal impacts on different socio-economic groups, with marginalized communities frequently bearing the impact of adverse effects. Despite this, there is a scarcity of in-depth research exploring how these communities can be included in energy transition decisions. Understanding the intersection between energy transitions, energy access, and social equity is crucial, yet current studies provide limited insights. More empirical research is needed to explore how energy policies affect various groups and to develop governance frameworks that ensure fairness and inclusivity in the energy transition process [11]. Financial barriers to clean energy investment represent another critical area where research is lacking. Achieving sustainable energy goals in Africa requires substantial investment, yet there is a significant funding shortfall. The literature highlights the need for focused research on identifying effective financial mechanisms that may attract private sector investment and mitigate the risks associated with

renewable energy projects. Addressing this gap is crucial for mobilizing the necessary financial resources to support Africa's energy transition [12]. The effectiveness of policy and governance frameworks is also a vital area requiring further research. Many African countries face fragmented regulatory environments that hinder progress in sustainable energy development.¹ Studies are wherefore needed to explore how cohesive and inclusive policy frameworks can be developed to support the integration of renewable energy sources. Existing studies often overlook the challenges posed by local governance structures and the complexities of policy implementation. Furthermore, there is an inadequate understanding of how to design policies that promote a just transition consistent with the SDGs. Addressing this research gap would lead to the development of more robust and effective policy frameworks capable of driving Africa's energy transition [13]. Technological innovation is another underexplored area, despite its potential to significantly enhance the efficiency and reach of renewable energy systems. The literature lacks a comprehensive analysis of how digital technologies can be effectively leveraged in the African context under SDG9. Research is needed to investigate how new models of energy production and distribution would be created using digital innovations, focusing on sustainability and inclusivity [14]. Finally, there is a notable gap in identifying countries with optimal policy solutions for achieving energy sustainability in alignment with SDG7. The literature points out the challenges posed by conflicting indicators, which complicate the identification of effective policy strategies. There is a need for research that systematically examines the best-performing African countries to identify successful policy frameworks [15].

In contributing to the literature, this study designed the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) model and developed Python codes for examining optimal policy solutions under the SDGs framework in Africa. In doing this, the study sampled the top 5 (South Africa, Egypt, Algeria, Nigeria, and Morocco)² energy-consuming countries in Africa to track their progress under the SDG7 [16] with current data of 2022 obtained from WDI. Therefore, this study aims to augment the existing literature on energy sustainability in Africa, with particular emphasis on identifying optimal energy policy solutions in meeting SDGs, particularly 7 with other relevant goals, i.e., SDG13. Identifying countries with optimal policy solutions in energy sustainability is paramount for Africa's socio-economic development, environmental preservation, and global competitiveness. With reliable and affordable energy sources, industries, businesses, and households in Africa may thrive, driving economic growth and creating employment opportunities [5]. Additionally, sustainable energy practices may contribute to poverty alleviation by improving living standards, enhancing access to education and healthcare, and fostering income-generating activities.

Subsequently, this study aims to investigate optimal policy solutions for SDG7 indicators within the African perspective, focusing on the top five energy-consuming countries [17]. Specifically, the authors objectively seek to determine which African country has the ideal policy solution for achieving energy sustainability under SDG7, aligning with Nationally Determined Contributions (NDCs). Also, how can policy-makers balance multi-conflicting priorities in advancing energy sustainability? Moreover, what are the best weighting priorities for achieving energy sustainability in Africa? To successfully examine these objectives, the authors contribute to the literature by proposing the TOPSIS technique, which is a multi-criteria decision-making (MCDM) method used to evaluate and rank a set of alternatives based on their proximity to an ideal solution under the SDG7 in Africa. The application

¹ The Renewable Energy Transition in Africa: <https://www.irena.org/publications/2021/March/The-Renewable-Energy-Transition-in-Africa>.

² IEA data statistics suggest these are the top 5 energy consuming countries in Africa as of 2021. That is, the authors ranked the countries and these 5 were sampled for the study.

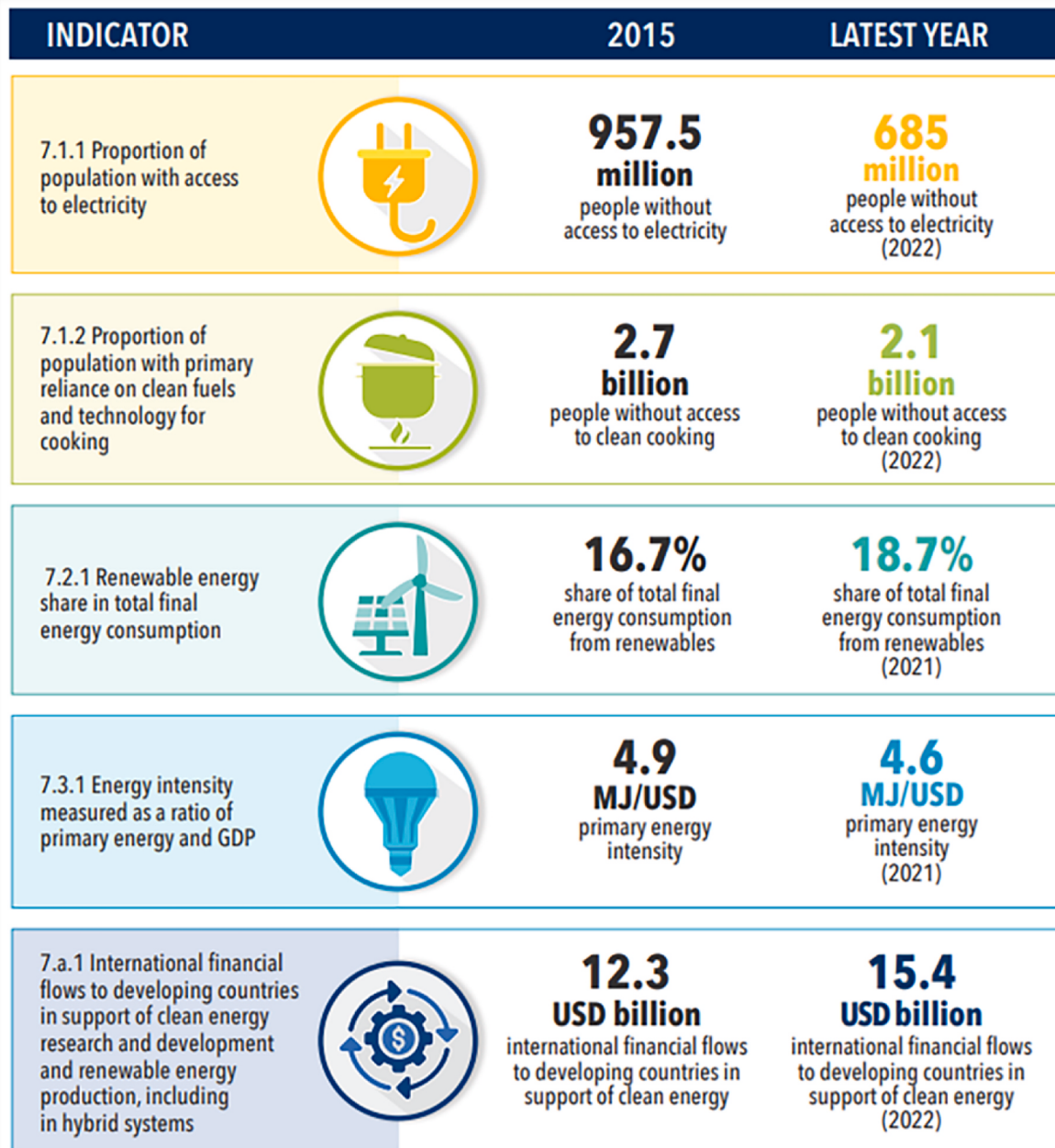


Fig. 1. SDG7 Indicators progress.

of the TOPSIS model serves as an innovative way to support the implementation of SDG7 indicators through partnership and collaboration. Therefore, the novelty of using TOPSIS may allow policymakers to collaboratively rank energy solutions while considering the continent's specific socio-economic and environmental factors, providing targeted strategies for each country. Also, this study may enable researchers and policymakers in Africa to select energy options that strike balance between economic viability, environmental protection, and social welfare, thereby aligning decisions with long-term sustainability goals under the SDGs [16]. Finally, the application of TOPSIS strategies may be adapted to include local criteria such as energy poverty, renewable energy potential, and geographic factors. That is, by customizing the decision-making model to local conditions, it offers a novel way of incorporating Africa's diverse energy settings, making it more relevant than generic models.

2. Background information on countries of comparison

2.1. Geographical comparison

The geographical topographies of South Africa, Egypt, Algeria, Nigeria, and Morocco play a crucial role in shaping renewable energy generation and energy access in each of these countries [18]. South Africa, the continent's most industrialized nation, has high energy access with about 88.85 % (WDI, 2022)³ of its population connected to the grid, and has significant potential for renewable energy in regions like the Northern and Eastern Cape. Egypt, with nearly universal energy access, benefits from its strategic location between Africa and the Middle East, using its expansive deserts and Red Sea coast to develop major solar and wind projects, like the Benban Solar Park, aiming to achieve

³ <https://databank.worldbank.org/source/world-development-indicators>.

42 % renewables by 2035 [19]. Algeria, the largest country in Africa by land area, relies heavily on its rich natural gas resources, which has delayed its transition to renewable energy. However, the government is currently focusing on utilizing the vast Saharan desert to expand solar energy capacity by 2030 [19]. Nigeria, Africa’s most populous nation, faces significant energy access challenges, with about 60 % of its population connected to the grid. Despite these challenges, Nigeria’s northern regions, has abundant sunshine, are well-suited for solar energy development, especially for off-grid communities (David et al., 2024). Finally, Morocco, with limited fossil fuel resources, has great potential for renewable energy in Africa. The country’s geographical diversity, including the Atlas Mountains and extensive desert areas, supports a variety of renewable energy projects. Morocco has great geographical dynamics and has invested heavily in solar, wind, and hydroelectric power, aiming to generate 52 % of its electricity from renewables by 2030, with the Noor Ouarzazate Solar Complex highlighting the country’s commitment to sustainable energy. Morocco’s nearly universal energy access and strategic investments are positioning it as a renewable energy hub in Africa [19].

2.2. Demographic comparison

In the context of achieving SDG7 on affordable and clean energy, the demographic landscapes of these countries present unique challenges and opportunities that significantly impact their ability to meet this target. Nigeria, with its rapidly growing population of approximately 223 million, faces immense pressure on its energy infrastructure. The surging demand for electricity, particularly in rapidly expanding urban centers, exacerbates the strain on existing energy resources and complicates efforts to transition to clean energy (David et al., 2024). Egypt, home to around 111 million people concentrated along the Nile, experiences similar challenges, with intense urban sprawl leading to increased energy consumption and environmental stress, making the shift to sustainable energy sources more urgent [20]. South Africa, with a population of about 62 million, encounters its own set of hurdles in achieving SDG7. Despite a more evenly distributed population, the country struggles with the legacy of apartheid, which has left deep-rooted inequalities in access to energy. This uneven access hinders progress toward ensuring affordable and clean energy for all. Algeria, with a population of roughly 46 million, and Morocco, with approximately 38 million people, are both experiencing rapid urbanization. This urban growth leads to increased energy demand contributing to rural depopulation and creating disparities in energy access. While Morocco’s demographic situation appears more manageable, challenges in rural energy development persist, highlighting the need for targeted strategies to achieve SDG7 [21] in both urban and rural areas.

2.3. Economic comparison

In this economic comparison, the authors used gross domestic product (GDP) as the key metric, drawing on data from the WDI dataset 2022. Nigeria, with a nominal GDP exceeding \$500 billion, emerges as the largest economy among the five countries, primarily driven by the oil sector. Despite efforts to diversify into agriculture, telecommunications, and services, Nigeria’s full potential is hampered by challenges such as political instability and socio-economic issues ([20]; David et al., 2024). South Africa, with a GDP of approximately \$400 billion, stands as the most industrialized and diversified economy in Africa, benefiting from robust sectors like mining and manufacturing. However, its developmental growth is constrained by high unemployment and inequality. Egypt, with a GDP similar to that of South Africa, has a diversified economy with significant contributions from agriculture, manufacturing, and tourism. While recent economic reforms have spurred growth, the country still faces persistent challenges, such as population growth and poverty. Algeria, with a GDP of about \$170 billion, is heavily reliant on oil and natural gas exports. Its slow pace in

diversifying the economy leaves it vulnerable to global oil price fluctuations despite some recent efforts at reform. Morocco, with the smallest GDP of around \$140 billion, is recognized for its economic stability and steady growth. The Moroccan economy is well-diversified, supported by proactive reforms in infrastructure and renewable energy [9] as well as strong ties to the European Union, which have bolstered its development.

2.4. Energy intensity comparison

Energy consumption across the countries of comparison highlights both their resource dependencies and sustainability challenges. South Africa’s heavy reliance on coal makes it one of the highest carbon emitters, posing significant challenges in meeting climate goals [22]. In contrast, Morocco has made significant strides in renewable energy, with ambitious targets for solar and wind power, although its heavy reliance on energy imports leaves it vulnerable to external shocks [9]. Egypt, while expanding its renewable energy capacity, still relies heavily on natural gas and oil, raising sustainability concerns. Algeria, nearly entirely dependent on natural gas, is both an energy exporter and highly vulnerable to fluctuations in global energy markets. Nigeria presents a paradox: despite being oil-rich, its electricity infrastructure is underdeveloped, leading to widespread energy poverty (David et al., 2024) and reliance on generators-a stark contrast to Morocco’s proactive renewable energy strategy (WDI, 2022) & as shown in Table 1.

2.5. Policy and regulatory framework comparison

The policy and regulatory frameworks in South Africa, Morocco, Egypt, Algeria, and Nigeria significantly impact their energy and economic outcomes, though their effectiveness varies [23]. South Africa aims to reduce carbon emissions and boost renewable energy, but its reliance on coal and Eskom’s financial instability undermine progress. Morocco’s coherent and forward-looking policies, supported by strong government commitment and international partnerships, drive its renewable energy ambitions. Egypt’s focus on diversification and efficiency is slowed by the need to balance social stability with economic reforms. Algeria prioritizes energy security and export revenues, yet its slow renewable energy development raises sustainability concerns. Nigeria, despite its goal to expand energy access and renewables, struggles with implementation issues (David et al., 2024). Morocco leads in proactive renewable energy efforts but is vulnerable due to energy import reliance [21].

In contributing to the literature, the authors align the study with SDG7 indicators by integrating all relevant factors within the MCDM framework. The study specifically utilizes the TOPSIS method, incorporating the ECCA criterion to account for population size measured by the proportion of the population with access to clean energy. The EI criterion considers both GDP and energy consumption, expressed as energy use per unit of GDP. The REI criterion takes into account land availability and geographic conditions for renewable energy generation. Additionally, the regulatory policy framework of each country significantly influences the determination of IEIT. This approach standardizes the evaluation across countries, eliminating differences and enabling effective comparison within the TOPSIS analysis. Thus, the use of equal

Table 1
Basic statistics.

Country	ECCA%	REI %	EI \$	IEIT \$
South Africa	88.85	9.76	6.95	8.26 E+08
Nigeria	59.50	1.80	4.97	1.16 E+08
Egypt	99.95	8.25	3.00	1.65 E+08
Algeria	99.74	0.32	5.32	30300000
Morocco	99.10	14.31	3.36	1.68 E+08

Data source: WDI, 2022

stakeholder weights in each criterion is guided by the policy priorities of the countries, such as improving ECCA, REI, and IEIT, while reducing EI, all in consideration of demographic and geographic conditions, GDP, energy use, and the regulatory policy framework.

3. Methodology design and data modeling

3.1. Methodology design

The assessment of energy sustainability in the five selected African countries is grounded in a multidimensional approach [24], which considers key SDG7 indicators such as ECCA, REI, improvements in EI, and IEIT [16]. To effectively apply TOPSIS, the study adopts the Sustainable Development Theory, integrating various energy-related factors to ensure a balanced and comprehensive multi-criteria analysis [20]. The authors innovatively utilize the TOPSIS method to address the study's objectives and research questions regarding energy sustainability in Africa [25]. By employing the TOPSIS technique, we explore the SDG7 indicators as relevant criteria, following a structured procedure [26]. First, the criteria pertinent to each aspect of energy sustainability in the top five energy-consuming African countries were identified, as shown in Table 1. The corresponding data were then normalized to ensure consistency across different measurement units using equation (2), with the results presented in Table 2. This normalization process guarantees that each criterion contributes proportionally to the overall evaluation, preventing any single criterion from exerting excessive influence. Following this, the study assigned equal weights of 0.25 to each criterion, reflecting their relative significance in the African context and aligning with the broader SDG7 goals [12]. After normalizing and weighting the data, the ideal and anti-ideal solutions for each criterion were determined based on the mathematical framework outlined in equations (1)–(6). To empirically analyze energy sustainability in the top five energy-consuming African countries relative to the four criteria, the study applies the TOPSIS model steps [20] as detailed in the equations below.

Step 1: Construction of decision matrix

Form the decision matrix A for, m alternatives and n criteria.

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix} \quad [1]$$

Also, a_{ij} is the original score of alternative i-th for criterion j-th criterion [20]. Thus, 5 countries in this with 4 criteria (ECCA, REI, EI, and IEIT), see Table 1.

Step 2: Normalization of the decision matrix

$$x_{ij} = \frac{a_{ij}}{\sqrt{\sum_{j=1}^n (a_{ij})^2}} \quad [2]$$

In normalizing the decision matrix A, equation (2) is applied where x_{ij} is the normalized values corresponding to a_{ij} [3].

Step 3: Weighted normalization decision matrix

$$y_{ij} = x_{ij} * w_j \quad [3]$$

Where y_{ij} is the weighted normalized decision matrix and w_j is the weight of j-th criterion [20].

Step 4: Ideal and negative ideal solutions

The authors denote the Ideal solution A^+ and the negative ideal solution be A^- [3,20].

For A^+ equation,

$$A_j^+ = \max(y_{ij}) \text{ for } j = 1, 2, 3, 4 \quad [4a]$$

For A^- equation,

$$A_j^- = \min(y_{ij}) \text{ for } j = 1, 2, 3, 4 \quad [4b]$$

Step 5: Distance calculation

To calculate the Euclidean distance of each alternative from the ideal and negative ideal solutions [20] the following equations are used for the positive ideal solution S_i^+ and S_i^- .

$$\text{For a positive ideal solution, } S_i^+ = \sqrt{\sum_{j=1}^n (y_{ij} - A_j^+)^2} \quad [5a]$$

$$\text{For a negative ideal solution, } S_i^- = \sqrt{\sum_{j=1}^n (y_{ij} - A_j^-)^2} \quad [5b]$$

Step 6: Similarity score calculation

In determining the similarity score (closeness) of each alternative to the ideal solution, equation (6) is used [18].

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad [6]$$

Where C_i is the similarity score of alternative i, and S_i^+ and S_i^- are the distance from alternative i to the positive and negative ideal solutions, respectively [27]. Lastly, the authors determine the alternative ranking as the step 7 based on their similarity scores, where higher similarity scores indicate better performance on the four criteria, and the results are presented in Table 4. In contributing to research and ensuring replicability, the authors developed Python code based on equations (1)–(6), of which this study is the first on SDG7 [3] comparing African top energy-consuming countries. The algorithms for equations (1)–(6) are computed and presented in Appendix A. Also, the empirical the empirical results codes are presented in Appendix B for future researchers. This study is among the few that apply computational algorithms using Python. To further enhance research validity, the authors used a fuzzy logic method implemented through Python as a robustness check [24,28]. The code for this method is presented in Appendix C, and the results are shown in Fig. 2. In applying the fuzzy logic technique, the authors applied the dataset in Table 2a, by first converting values into low, medium, and high categories [28] as shown in Appendix C and consistent with the literature [24]. Additionally, implementing both TOPSIS and fuzzy logic techniques using Python is relevant and advantageous due to Python's efficiency in data handling, accuracy, and flexibility, which contribute to robust results.

3.2. Data modeling

The authors obtained 2022 data from WDI on the following variables ECCA, REI, EI, and IEIT in the top five energy-consuming African countries. The data for ECCA and REI are measured in percentages (%), and EI and IEIT are measured in United States dollars, see Table 1. Furthermore, as stated in subsection 3.1, in determining the weighted scale for each criterion, the authors employed the technique of equal weighting priority, assigning a value of 0.25 to each criterion (ECCA, REI, EI, and IEIT), thus precluding any potential biases. The rationale behind this weighting approach is embedded in the utilization of secondary data in this study and the lack of established weighting priorities by the United Nations, a principal stakeholder, towards achieving the SDG7 indicators [18]. Consequently, the authors adopted equal weighting, given the absence of specified priority scores by UN experts overseeing SDG7 initiatives. Therefore, the study decision preserves

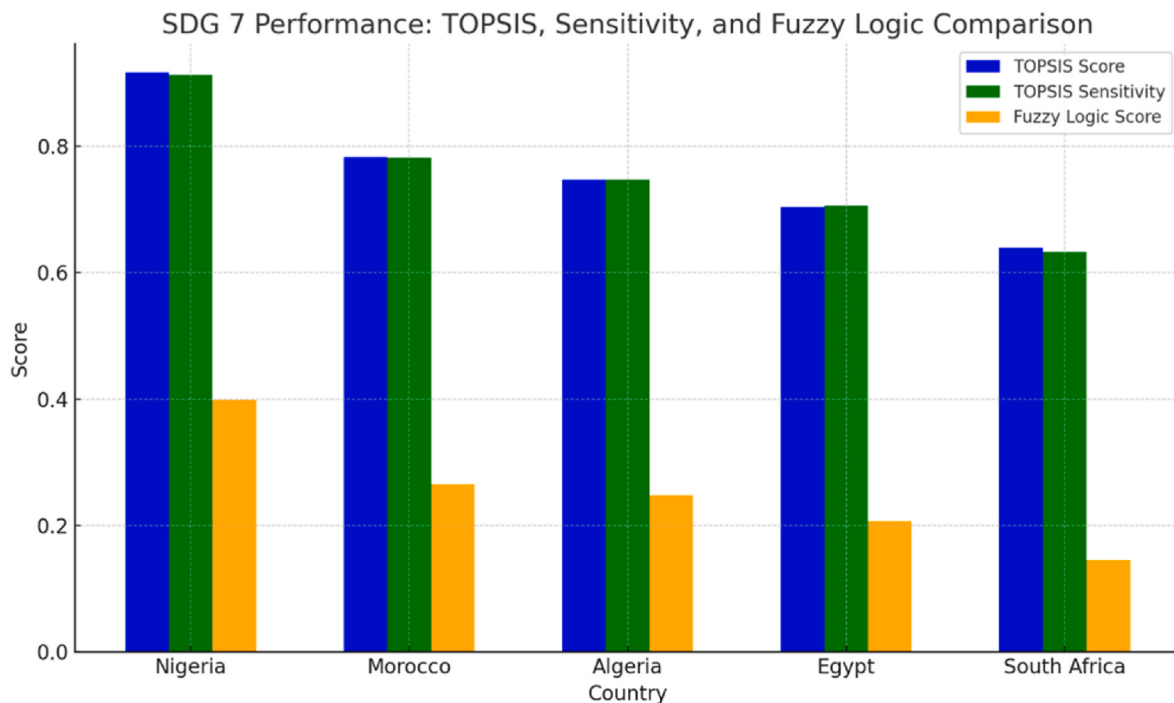


Fig. 2. SDG7 indicators performance in top five African countries.

Table 2a
Normalized data.

Country	ECCA	REI	EI	IEIT
South Africa	0.038	0.080	0.395	0.067
Nigeria	0.312	0.292	0.500	0.492
Egypt	0.355	0.286	0.258	0.094
Algeria	0.354	0.008	0.443	0.022
Morocco	0.349	0.333	0.282	0.094

impartiality and enhances transparency in the assessment process. The application of equal-weighted priority within the TOPSIS technique in this study fosters originality, equity, risk mitigation, and consensus building, rendering it a pragmatic approach in multifaceted decision-making scenarios [29]. This approach acknowledges the inherent complexities and uncertainties within the decision-making process while striving for a balanced assessment of the SDGs framework.

Across, the basic statistics reveal varying degrees of performance in energy-related criteria. Egypt emerges as an important leader in terms of access to electricity and clean cooking services, boasting the highest score of 99.95 %. This suggests a relatively high level of infrastructure development and provision of essential energy services within the country in Africa. In contrast, Nigeria lags behind with the lowest ECCA score of 59.50 %, indicating a significant gap in access to electricity and clean cooking services compared to its counterparts [30]. When examining renewable energy integration, Morocco stands out with the highest score of 14.31 %, signaling robust efforts in incorporating renewable energy sources into its energy mix [31]. This highlights Morocco's commitment to energy sustainability and reducing reliance on non-renewable energy sources [5]. Additionally, South Africa and Egypt also demonstrate noteworthy levels of renewable energy integration, however to varying degrees. Furthermore, the statistics shed light on areas for improvement in energy intensity. Egypt and Morocco exhibit relatively low scores in energy intensity, with values of \$3.0 and \$3.36, respectively. In terms of investment in energy infrastructure and technologies, South Africa emerges as the best with a policy option of \$8.26 E+08 investment. This underscores the country's commitment to developing robust energy infrastructure and deploying advanced

technologies to meet its energy needs. Similarly, Egypt and Morocco also demonstrate substantial investments in energy-related infrastructure and technologies, with values of %1.65 E+08 and %1.68 E+08, respectively. The analysis highlights both strengths and areas for improvement across the analyzed countries towards the year 2030 in Africa [32].

4. Results discussion and analysis

4.1. TOPSIS model results

By applying Equation (2) to the original data presented in Table 1, we obtained the results presented in Table 2a. The normalized data has been adjusted to a common scale without distorting differences for comparison in the ranges of values. The normalization involves converting the different data measurements into a comparable format by scaling values between 0 and 1 [20]. This process ensures that no single criterion or indicator disproportionately influences the overall analysis, permitting a fair comparison across the SDG7 indicators.

Using Equation (3) with the data from Table 2a, we derived the weighted normalized decision matrix shown in Table 2b. The analysis of the weighted normalized data in Table 2b reveals insights into the relative performance of countries across four key criteria. South Africa emerges as the most balanced performer across all categories. Its strengths are particularly evident in its leadership in doubling the global efforts in EI and IEIT. These SDG indicators reflect South Africa's strong commitment to energy efficiency and innovation in clean energy technologies. However, while South Africa performs moderately well in

Table 2b
Weighted normalized decision matrix.

Country	ECCA	REI	EI	IEIT
South Africa	0.093	0.087	0.150	0.148
Nigeria	0.012	0.024	0.119	0.020
Egypt	0.106	0.086	0.077	0.028
Algeria	0.106	0.002	0.133	0.007
Morocco	0.104	0.100	0.085	0.028

ECCA and in increasing REI, these indicators are not its strongest, suggesting room for further enhancement. Also, Nigeria’s performance shows evidence of a mix of strengths and weaknesses. Nigeria’s primary strength is reflected in its relatively high score for improving EI and IEIT, demonstrating significant advancements in energy efficiency and sustainability. Notwithstanding, Nigeria scores low on the ECCA and in promoting REI, as indicated by the weighted normalized decision matrix [30]. These weaknesses suggest challenges in expanding energy access, integrating renewable energy, and fostering international collaboration in clean energy initiatives. Similarly, Egypt demonstrates strengths primarily in ensuring ECCA, positioning it as a key player in expanding energy access across the continent. It also has a moderate level of success in promoting REI. Nonetheless, Egypt’s weaknesses are apparent in its lower scores in improving EI and enhancing IEIT. These weaknesses could limit its long-term progress in energy efficiency and its ability to lead in clean energy technology and infrastructure under the SGD7. Furthermore, Algeria shares strengths with Egypt in ensuring ECCA, highlighting its resilient efforts in expanding energy access. It also demonstrates significant strength in improving EI, suggesting a robust approach to energy efficiency. Conversely, Algeria’s weaknesses are pronounced in REI, where it shows minimal progress, and in IEIT, where it scores the lowest. These weaknesses might restrict its ability to integrate renewable energy into its energy mix and participate actively in global clean energy advancements. Finally, Morocco’s strengths are primarily reflected in its high scores for promoting REI and ensuring ECCA. These dynamics make Morocco a significant contributor to both energy access and renewable energy integration [5]. Yet, its weaknesses are seen in its moderate improvement in EI and lower performance in enhancing IEIT. These dimensions indicate that while Morocco is making progress in renewable energy, it may face challenges in achieving energy efficiency and leveraging international cooperation for clean energy advancements under the SGD7 towards the year 2030 [10]. Further and comprehensive analysis of each country’s strengths and weaknesses in various dimensions of energy sustainability are presented in Table 3, highlighting areas towards improvement and potential policy interventions.

Table 3 presents the ideal and negative ideal solutions for each criterion, with an equal-weighted scale for the four criteria of energy sustainability in Africa. The ideal solutions represent the best performance in each criterion, while the negative ideal solutions represent the worst possible performance. For example, the ideal solution for ECCA is 0.089, with a negative ideal solution of 0.010. This indicates that the continent is still far from achieving universal access to electricity and clean cooking services. The relatively low ideal solution score suggests significant challenges and deficiencies that must be addressed to enhance access, affordability, and quality of services in this area.

Additionally, the negative ideal solution value indicates that some communities on the continent continue to rely on traditional and inefficient energy sources, such as kerosene lamps or biomass. This highlights the persistence of energy poverty, where certain segments of the population lack access to reliable and affordable electricity and clean cooking services [33]. The implication for Africa is that while some progress has been made in providing access to electricity and clean cooking services, particularly in urban areas, significant improvements are still needed, especially in remote or underserved regions. Efforts to address these challenges should focus on expanding infrastructure, promoting renewable energy solutions, enhancing affordability, and

targeting interventions in areas with the greatest need [33]. The ideal solution for renewable energy adoption has a score of 0.083, while the negative ideal solution is 0.002. This indicates that the optimal integration of renewable energy sources into the energy mix is still far from being achieved among African countries. The negative ideal solution of 0.002 suggests that the current energy mix relies heavily on non-renewable sources such as fossil fuels (coal, oil, natural gas), with minimal contributions from renewable sources. This underscores the ongoing reliance on traditional energy sources and the pressing need to diversify towards cleaner alternatives. Largely, this implies that there is significant potential for further development and adoption of renewable technologies in Africa [33]. By investing in renewable energy infrastructure, promoting supportive policies for renewable energy deployment, and incentivizing clean energy investments, African countries can enhance energy sustainability and reduce dependence on fossil fuels. This transition to renewable energy sources not only mitigates environmental impact but also contributes to energy security, economic development, and welfare in the region [14].

Furthermore, the ideal solutions for EI and IEIT exhibit similar scores of 0.125 and 0.123, respectively, with negative ideal solutions of 0.065 and 0.006. These findings suggest that African countries have shown relative proficiency in these areas compared to ECCA and REI. However, despite efforts to enhance energy efficiency and invest in renewable energy infrastructure and technology, these policies have not yet reached the levels necessary to achieve optimal energy sustainability under SDG 7. Additionally, the presence of negative ideal solutions, indicates that certain countries in Africa are still operating at suboptimal levels in terms of energy intensity and investment in energy infrastructure and technology [34]. This underscores the urgent need for increased investment in energy infrastructure, technologies, and efficiency to support sustainable development within the SDG7 framework. It also highlights the necessity for collective action and concerted efforts by governments, businesses, and civil society to address energy-related issues and pave the way towards a more sustainable future in Africa [35].

Table 4 presents the similarity scores and rankings for each country based on specific criteria, indicating how closely each country’s performance aligns with the ideal solution. A score of 0.917 denotes near-perfect alignment with the ideal solution, with lower scores indicating greater deviation. The findings indicate that Nigeria achieved the highest similarity score, signifying that its performance closely aligns with the ideal solution for the energy sustainability criteria assessed. This suggests that Nigeria has made significant progress in implementing policies and initiatives that promote access to clean and affordable energy, as outlined in SDG7 ([3]; Hossin et al.,203; David et al., 2024). Nigeria’s top ranking in achieving SDG7, which aims to provide affordable, reliable, and sustainable energy for all, is due to several key initiatives implemented. The country has implemented the National Renewable Energy and Energy Efficiency Policy (NREEEP) to promote renewable energy and improve efficiency. Major projects like the Nigeria Electrification Project (NEP) and the Solar Power Naija Program have expanded energy access, particularly in rural areas [30]. Additionally, Nigeria’s Feed-in Tariff (FiT) has encouraged private investment in renewable energy, while partnerships with international organizations and the Green Bond Program have provided essential support and funding for sustainable energy projects ([35]; David et al.,

Table 3
Criteria weight, ideal and negative ideal solutions.

Criteria	Weight	Ideal solution	Negative ideal solution
ECCA	0.25	0.089	0.010
REI	0.25	0.083	0.002
EI	0.25	0.125	0.065
IEIT	0.25	0.123	0.006

Table 4
Similarity score for each alternative to the ideal solution.

Country	Similarity score	Ranking
South Africa	0.640	5
Nigeria	0.917	1
Egypt	0.704	4
Algeria	0.747	3
Morocco	0.783	2

2024). Also, Morocco is the second-highest similarity score and ranking, reflecting commendable progress in advancing energy sustainability goals. This suggests the country's proactive approach to renewable energy development, including investments in solar and wind power, has contributed to its strong performance under SDG7. Additionally, Algeria obtained the third rank with its similarity score, indicating substantial efforts towards achieving energy sustainability objectives. The country's abundant natural resources, including oil and gas reserves, provide opportunities for transitioning towards cleaner and more sustainable energy sources.

Similarly, Egypt achieved moderate similarity score and ranked fourth, suggesting ongoing efforts to address energy sustainability challenges. The country currently faces various energy-related issues, including high energy consumption and dependency on fossil fuels, despite having widespread electricity access [33]. These issues require targeted interventions, policy measures, and investments to accelerate progress towards SDG7 targets. The findings indicate that South Africa attained the lowest similarity score and ranked fifth among the countries analyzed, highlighting significant room for improvement in energy sustainability performance. Despite being the most industrialized economy in Africa, South Africa struggles with energy access issues, energy poverty, and a heavy reliance on coal-fired power generation, accounting for over 30 % of its energy mix. These factors pose challenges to achieving SDG7 indicators by 2030 ([3]; David et al., 2024). South Africa's ranking underscores the urgency of implementing comprehensive energy reforms and transitioning towards cleaner and more sustainable energy pathways. The similarity scores and rankings provide insights into the relative performance of the top five energy-consuming countries, enabling policymakers and stakeholders to identify areas of strength and areas needing improvement. This analysis highlights the need for continuous monitoring and evaluation of performance metrics to inform policy decisions and interventions aimed at enhancing energy sustainability and development in Africa. Currently, Nigeria has achieved improved scores across all indicators, indicating a balanced policy approach towards energy sustainability. In contrast, South Africa faces multiple challenges among the SDG7 indicators ([36]; David et al., 2024) and, therefore, requires urgent policy measures in energy sustainability.

4.2. TOPSIS model sensitivity analysis

Sensitivity analysis is a crucial component in the TOPSIS model as it offers valuable insights into the robustness, validity, and reliability of the study. This technique plays a vital role in enhancing decision-making processes by providing insights into decision stability, weighting schemes, and critical criteria. Through sensitivity analysis, the study identifies which criteria have the most significant influence on the final decision outcomes [3]. By varying the weights assigned to each criterion, it becomes clear which criteria drive changes in rankings and thus requires careful consideration and potential improvement. The authors systematically explored the sensitivity of the results presented in [sub-section 4.1](#) by varying the weights assigned to each criterion (ECCA, REI, EI, and IEIT). Initially, the study used equal weights of 0.25 for each criterion. Furthermore, to conduct the sensitivity analysis effectively, the authors adjusted equal weights to 0.30, 0.40, 0.20, and 0.10, respectively, for each criterion. These adjustments are based on scientific considerations rooted in the current challenges and priorities within Africa's energy sector. Given the significant challenges of electricity and clean cooking access in many African countries, a weight of 0.30 was allocated to underscore the paramount importance of addressing these issues. Reliable electricity and clean cooking solutions are fundamental for improving livelihoods, health outcomes, and overall development in the region. Recognizing the critical role of renewable energy integration in Africa's energy transition, a weight of 0.40 was assigned. Transitioning to renewable sources of energy is essential for achieving energy sustainability, reducing carbon emissions [36], and enhancing energy

security. Addressing challenges associated with energy intensity or efficiency, including the rebound effect, is vital for optimizing energy use and minimizing waste. Therefore, the study assigned a weight of 0.20 score to this energy dimension. Promoting energy-efficient practices and technologies is crucial for mitigating environmental impacts and enhancing energy sustainability in Africa. Investment in energy infrastructure and technologies plays a critical role in modernizing energy systems, expanding access, and supporting economic growth. To address this need while balancing investments across multiple priorities, the authors allocated a weight of 0.10. This weight emphasizes the importance of strategic investments in infrastructure and technological innovation to support Africa's energy transition. Following the assignment of weights based on the challenges and potential in the African context, the authors applied these values in the TOPSIS model equations (1)–(6) using the developed Python programming codes. The resulting analysis, including sensitivity analysis, is presented in [Tables 5 and 6](#).

The sensitivity analysis presented in [Tables 5 and 6](#) demonstrates how the rankings of countries vary with different sets of weights. Specifically, [Tables 4 and 6](#) exhibit similar findings despite using varied weighted scales outlined in [Table 5](#). Even when different weights are applied to reflect the current energy conditions in Africa, the results remain consistent with the original findings obtained using equal weights of 0.25. Nigeria consistently maintains the highest similarity score across all sets of criteria, indicating its robust performance relative to other countries. Similarly, Morocco consistently follows Nigeria with relatively high similarity scores. This consistency underlines the reliability of the results and highlights the strong performance of these countries in their energy sustainability efforts. The sensitivity analysis helps the authors understand how changes in weights influence the ranking of alternatives and provides insights into the stability of the decision-making process. By observing how rankings shift under different weight scenarios, stakeholders may gain a deeper understanding of the factors influencing the findings, enabling them to make informed decisions regarding energy policies in Africa.

4.3. Robustness test under fuzzy logic

[Fig. 2](#), presents the robustness test using fuzzy logic together with the combined original TOPSIS, TOPSIS sensitivity test results. The application of fuzzy logic in this analysis confirms the rankings and results derived from the TOPSIS method. Both approaches produce consistent rankings for the countries under evaluation. Nigeria ranks first in both methods, indicating it has the highest performance score, while South Africa ranks last, showing the lowest performance. The middle-ranked countries-Morocco maintained second rank, while Algeria is now ranked fourth and Egypt third, which demonstrates that the overall assessment is stable across different approaches [3]. In addition to the rankings, the category assignments (High, Medium, and Low) based on performance scores further support the consistency between the two methods. Nigeria, with a performance score of 0.399, is categorized as "High" by both fuzzy logic and TOPSIS, highlighting its strong performance [20]. On the other hand, South Africa, with a score of 0.145, falls into the "Low" category, confirming its position as the lowest-performing country. The other countries-Morocco, Egypt, and Algeria are all classified as "Medium," which aligns with their intermediate scores and rankings. Consequently, the performance scores derived from fuzzy logic closely match the expectations from the TOPSIS

Table 5
TOPSIS sensitivity analysis on ideal and negative ideal solutions.

Criteria	Weight	Ideal solution	Negative ideal solution
ECCA	0.30	0.106	0.012
REI	0.40	0.100	0.002
EI	0.20	0.150	0.077
IEIT	0.10	0.148	0.007

Table 6
TOPSIS sensitivity analysis similarity scores and ranking.

Country	Similarity score	Ranking
South Africa	0.633	5
Nigeria	0.914	1
Egypt	0.706	4
Algeria	0.747	3
Morocco	0.782	2

approach, even though the underlying methodologies are different. The application of fuzzy logic provides a robust technique to handle uncertainty and complex relationships between the variables, while TOPSIS focuses on comparing alternatives to an ideal solution (Ture et al., 2020). Effectively, the consistent results across both methods indicate that fuzzy logic offers a reliable alternative to traditional decision-making techniques like TOPSIS and, therefore, reinforces the validity of the rankings and classifications, particularly in complex scenarios where multiple factors influence the SDG7 performance in different countries in Africa [19]. Both methods converged that Nigeria performs best and South Africa performs worst, providing a strong basis for decision-making in African countries toward meeting their energy policies [19].

5. Discussion and policy implications

5.1. Discussions

The analysis of similarity scores and rankings provides valuable insights into the relative performance of African countries in achieving energy sustainability under SDG7 indicators. The criteria assessed: ECCA, REI, EI, and IEIT-represent critical dimensions of this sustainability. The ideal and negative ideal solutions serve as benchmarks for evaluating each country’s performance, allowing for comparisons and the identification of areas for improvement. Within the African context, the variation in similarity scores highlights the differing levels of progress toward energy sustainability, with some countries achieving notable successes while others face ongoing challenges. Notably, Nigeria currently leads the continent in energy sustainability, as reflected in its high similarity score, demonstrating strong alignment with SDG7 indicators [3]. This underscores Nigeria’s commitment to promoting access to clean and affordable energy, a key pillar of sustainable development [18]. While several countries have made significant progress, there is a pressing need to accelerate efforts across the continent. This involves enhancing energy access, promoting renewable energy adoption, improving energy efficiency, and addressing socio-economic disparities to ensure inclusive and sustainable development. Technological solutions, such as Carbon Capture, Utilization, and Storage (CCUS), can play a crucial role in these efforts by reducing emissions from fossil fuel use while allowing for the continued use of existing energy infrastructure. Additionally, the integration of smart grid technologies may improve energy efficiency and reliability, particularly in regions with limited access to stable power supplies. Prioritizing these efforts, alongside fostering collaboration among stakeholders, can help Africa move towards a more resilient, equitable, and environmentally sustainable energy future. The rankings of African countries in achieving energy sustainability provide a strategic framework for prioritizing interventions and effectively allocating resources. Minimizing negative ideal solutions involves reducing reliance on fossil fuels and other non-renewable energy sources, which are major contributors to emissions and climate change, and implementing technologies like CCUS to mitigate their environmental impact [18]. This approach aligns with SDG13’s objectives to mitigate climate change impacts and promote sustainable energy practices [37]. Moreover, enhancing ideal solutions in energy sustainability involves increasing the adoption of renewable energy sources, such as solar and wind

technologies, and exploring innovative energy storage solutions to ensure a reliable supply [31]. Transitioning to clean and renewable energy not only reduces carbon emissions but also builds resilience against the adverse effects of climate change, including extreme weather events and rising sea levels [37]. By integrating advanced technologies like CCUS, smart grids, and energy storage and fostering collaborative efforts among governments, businesses, and civil society, African countries may significantly improve their energy sustainability and contribute to global climate goals.

5.2. Policy implications

Policymakers and stakeholders may leverage these findings to develop evidence-based policies and strategies aimed at enhancing energy sustainability in Africa. To effectively meet energy sustainability targets, it is crucial for policymakers to consider the following policy priority weights for energy sustainability criteria: ECCA (0.25–0.30), REI (0.25–0.40), EI (0.20–0.25), and IEIT (0.10–0.25) toward 2030. These weight ranges are derived from empirical analysis of SDG7 indicators and sensitivity analysis, ensuring an optimized approach to energy sustainability across multiple dimensions [10]. Aligning policy options with these weight ranges allows policymakers to foster balanced energy solutions. By distributing weights within the specified ranges, they can address key priorities such as energy access, renewable energy integration, efficiency, and infrastructure development in a comprehensive manner. This balanced approach is critical for advancing energy sustainability in the region. Moreover, optimal weight allocation enhances the effectiveness of energy policies and interventions. By strategically assigning weights, policymakers would maximize the impact of their efforts in achieving SDG7 targets, ultimately improving overall energy sustainability across the continent. This targeted approach ensures that policies are not only well-designed but also impactful. Strategic resource allocation is another significant benefit of aligning with these weight ranges. Policymakers can more effectively leverage limited resources by prioritizing investments based on the relative importance of each criterion. This strategic approach enables them to address the most pressing energy challenges in Africa, ensuring that resources are directed where they are needed most. In addition, clear and consistent weight ranges provide a solid foundation for implementing policy and regulatory reforms. These guidelines may help in enacting supportive policies and creating regulatory frameworks that incentivize private sector investment, promote market competition, and facilitate project financing. This, in turn, may spur innovation and drive sustainable energy development in the region. Furthermore, collaborative initiatives and knowledge-sharing platforms play a crucial role in this process. By facilitating the exchange of best practices and lessons learned among countries, these platforms foster a collective approach to addressing energy challenges in Africa. When implemented in a coordinated and integrated manner, these policy strategies can significantly advance African countries toward achieving SDG7 targets, ensuring universal access to affordable, reliable, sustainable, and modern energy for all [3].

6. Conclusion and study limitations

6.1. Conclusion

In conclusion, the assessment of criteria and countries offers a comprehensive overview of energy sustainability in Africa, highlighting both successes and areas in need of improvement. The findings suggest that advancing energy sustainability requires increased adoption of renewable energy sources such as solar, wind, and hydroelectric power. Also, integrating advanced technologies like CCUS, smart grids, and energy storage and fostering collaborative efforts. By focusing on these efforts, African countries are effectively addressing the challenges of climate change, as outlined in SDG13. The study identifies Nigeria as the current leader in energy sustainability within Africa, showing strong

alignment with SDG7 indicators. In contrast, South Africa ranks lowest among the top five energy-consuming countries, reflecting varying degrees of misalignment with these sustainability goals. This suggests that Nigeria has successfully implemented optimal policy solutions for achieving energy sustainability, followed by Morocco. Conversely, South Africa exhibits several negative ideal solutions, indicating significant areas requiring attention and improvement. The application of the TOPSIS method in evaluating SDG7 indicators proves its effectiveness as a robust analytical tool for assessing sustainable energy development at both national and global levels. By systematically analyzing countries' performance across key criteria-such as electricity access, renewable energy integration, energy intensity, and investment in energy infrastructure and technologies -TOPSIS provides valuable insights into the progress and challenges related to energy sustainability. Its ability to calculate similarity scores and rankings offers a comprehensive framework for assessing how well countries align with SDG7 objectives and for identifying areas needing improvement. This technique enables researchers, policymakers, and stakeholders to make informed decisions and prioritize interventions that will accelerate progress toward achieving energy sustainability goals.

6.2. Study limitations and future research opportunity

While TOPSIS is a powerful tool under MCDM, it has limitations, particularly when using secondary data. Firstly, the findings are limited to the countries under study. These limitations, however, do not undermine the applicability of the results or the policy implications. The effectiveness of TOPSIS is heavily dependent on the quality of the input data, meaning that any inconsistencies or errors in the secondary data can impact the reliability of the analysis. Moreover, this study utilized an equal weights technique in TOPSIS, which is just one of many approaches available in MCDM techniques. By addressing data quality concerns and leveraging the insights gained from this study, African countries can continue to make significant progress towards energy sustainability, fostering a resilient, equitable, and sustainable energy future. Consequently, one major opportunity for future direction grounds expanding the scope of the analysis beyond the top five energy-consuming countries in this study by allowing for a broader understanding of energy sustainability across Africa using a more comprehensive and real-time dataset. Additionally, using alternative weighting techniques in future analyses, such as expert opinion-based or dynamic weights, could offer insights into the various factors affecting energy sustainability. Also, future research could focus on analyzing how countries can transition from fossil fuel dependence to clean energy using TOPSIS. Incorporating renewable energy potential, carbon

emissions, and technological readiness into the model could help evaluate which countries are best positioned to achieve a sustainable energy transition. Finally, future studies could adopt the TOPSIS model to integrate country-specific factors, such as energy poverty levels, renewable energy potential, and geographic conditions. By considering local energy demands, climate conditions, and available resources, TOPSIS and fuzzy logic techniques may provide more customized policy recommendations for individual countries under SDG 7 in Africa.

CRediT authorship contribution statement

Md Altab Hossin: Writing – original draft, Validation, Supervision, Investigation, Conceptualization. **Hermas Abudu:** Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Johnson Katsepor:** Writing – review & editing, Software, Resources, Formal analysis, Data curation. **Mu Lei:** Writing – review & editing, Supervision, Resources, Project administration, Formal analysis. **Elvis Banoemuleng Botah:** Writing – review & editing, Writing – original draft, Resources, Formal analysis, Data curation.

Informed consent statement

Not applicable.

Data availability statement

Data is available upon request from the corresponding author.

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Declaration of competing interest

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

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This manuscript uses appropriate citations for the extant literature to avoid all kinds of copyright issues. All working papers, prior drafts, and/or final version of this manuscript were not posted on any website as well as not under review in any other journals.

Appendix A. TOPSIS computational model algorithm input

Input: Decision matrix A [m][n], Weight vector w [n]

1. Normalize the Decision Matrix R:
 - for j from 1 to n:
 - sumSquares = sum (D [k][j]² for k from 1 to m)
 - for i from 1 to m:
 - $X[i][j] = D[i][j] / \sqrt{\text{sumSquares}}$
2. Calculate the Weighted Normalized Decision Matrix Y:
 - for j from 1 to n:
 - for i from 1 to m:
 - $y[i][j] = w[j] * x[i][j]$
3. Determine the PIS (A+) and NIS (A-):
 - for j from 1 to n:
 - if criterion j is benefit:
 - $A_{\text{plus}}[j] = \max(y[i][j] \text{ for } i \text{ from } 1 \text{ to } m)$
 - $A_{\text{minus}}[j] = \min(y[i][j] \text{ for } i \text{ from } 1 \text{ to } m)$
 - else if criterion j is cost:
 - $A_{\text{plus}}[j] = \min(y[i][j] \text{ for } i \text{ from } 1 \text{ to } m)$

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    A_minus[j] = max(y[i][j] for i from 1 to m)
4. Calculate the Separation Measures S+ and S-:
    for i from 1 to m:
        S_plus[i] = sqrt(sum((y[i][j] - A_plus[j])2 for j from 1 to n))
        S_minus[i] = sqrt(sum((y[i][j] - A_minus[j])2 for j from 1 to n))
5. Calculate the Relative Closeness to the Ideal Solution C:
    for i from 1 to m:
        C[i] = S_minus[i]/(S_plus[i] + S_minus[i])
6. Rank the alternatives based on C

```

Appendix B. Python Code for empirical input

```

Initial import numpy as np
import pandas as pd

#Step 1: Create the decision matrix
data = {
    'Country': ['South Africa', 'Nigeria', 'Egypt', 'Algeria', 'Morocco'],
    'ECCA': [0.038, 0.312, 0.355, 0.354, 0.349],
    'REI': [0.080, 0.292, 0.286, 0.008, 0.333],
    'EI': [0.395, 0.500, 0.258, 0.443, 0.282],
    'IEIT': [0.067, 0.492, 0.094, 0.022, 0.094]
}
df = pd.DataFrame(data)

# Step 2: Normalize the decision matrix
normalized_matrix = df.iloc[:, 1:].values/np.sqrt((df.iloc[:, 1:]**2).sum(axis=0))

# Step 3: Using equal weights
weights = np.array([0.25, 0.25, 0.25, 0.25])

# Step 4: Weighted normalized decision matrix
weighted_matrix = normalized_matrix * weights

# Step 5: Determine the ideal and negative-ideal solutions
ideal_solution = np.max(weighted_matrix, axis=0)
negative_ideal_solution = np.min(weighted_matrix, axis=0)

# Step 6: Calculate the separation measures
separation_ideal = np.sqrt(((weighted_matrix - ideal_solution)**2).sum(axis=1))
separation_negative_ideal = np.sqrt(((weighted_matrix - negative_ideal_solution)**2).sum(axis=1))

#Step 7: Calculate the relative closeness to the ideal solution
relative_closeness = separation_negative_ideal/(separation_ideal + separation_negative_ideal)

# Step 8: Rank the countries
df['Relative Closeness'] = relative_closeness
df['Rank'] = df['Relative Closeness'].rank(ascending=False)

# Display the results
import ace_tools as tools; tools.display_dataframe_to_user(name="TOPSIS Rankings", dataframe=df)
df.sort_values(by='Rank', inplace=True)
print(df)

```

Appendix C. Python Code for Fuzzy Logic Model as Robustness Test

```

import numpy as np
import skfuzzy as fuzz
from skfuzzy import control as ctrl
import pandas as pd

# Define the fuzzy variables for ECCA, REI, EI, IEIT
ecca = ctrl.Antecedent(np.arange(0, 0.41, 0.01), 'ecca')
rei = ctrl.Antecedent(np.arange(0, 0.36, 0.01), 'rei')
ei = ctrl.Antecedent(np.arange(0, 0.51, 0.01), 'ei')
ieit = ctrl.Antecedent(np.arange(0, 0.51, 0.01), 'ieit')

#Output variable to estimate overall performance
performance = ctrl.Consequent(np.arange(0, 1.1, 0.1), 'performance')

#Define membership functions for ECCA
ecca['low'] = fuzz.trimf(ecca.universe, [0, 0, 0.1])
ecca['medium'] = fuzz.trimf(ecca.universe, [0.1, 0.2, 0.3])
ecca['high'] = fuzz.trimf(ecca.universe, [0.3, 0.4, 0.4])

#Define membership functions for REI
rei['low'] = fuzz.trimf(rei.universe, [0, 0, 0.1])
rei['medium'] = fuzz.trimf(rei.universe, [0.1, 0.2, 0.25])
rei['high'] = fuzz.trimf(rei.universe, [0.25, 0.35, 0.35])

# Define membership functions for EI
ei['low'] = fuzz.trimf(ei.universe, [0, 0, 0.2])

```

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```

ei ['medium'] = fuzz.trimf (ei.universe, [0.2, 0.3, 0.4])
ei ['high'] = fuzz.trimf (ei.universe, [0.4, 0.5, 0.5])
#Define membership functions for IEIT
ieit ['low'] = fuzz.trimf (ieit.universe, [0, 0, 0.1])
ieit ['medium'] = fuzz.trimf (ieit.universe, [0.1, 0.2, 0.3])
ieit ['high'] = fuzz.trimf (ieit.universe, [0.3, 0.4, 0.5])
#Define membership functions for the output (performance)
performance ['low'] = fuzz.trimf (performance.universe, [0, 0, 0.5])
performance ['medium'] = fuzz.trimf (performance.universe, [0.3, 0.5, 0.7])
performance ['high'] = fuzz.trimf (performance.universe, [0.6, 0.8, 1])
# Define fuzzy rules
rule1 = ctrl.Rule (ecca ['high'] & rei ['high'], performance ['high'])
rule2 = ctrl.Rule (ecca ['low'] & ei ['high'], performance ['low'])
rule3 = ctrl.Rule (ecca ['medium'] & rei ['medium'] & ei ['medium'], performance ['medium'])
rule4 = ctrl.Rule (ieit ['high'] & ei ['high'], performance ['low'])
rule5 = ctrl.Rule (ecca ['high'] & ei ['low'], performance ['medium'])
# Create control system
performance_ctrl = ctrl.ControlSystem ([rule1, rule2, rule3, rule4, rule5])
performance_simulation = ctrl.ControlSystemSimulation (performance_ctrl)
# Input data for each country
countries = {
    'South Africa': [0.038, 0.080, 0.395, 0.067],
    'Nigeria': [0.312, 0.292, 0.500, 0.492],
    'Egypt': [0.355, 0.286, 0.258, 0.094],
    'Algeria': [0.354, 0.008, 0.443, 0.022],
    'Morocco': [0.349, 0.333, 0.282, 0.094]
}
# Run simulation for each country and store results
results = {}
for country, values in countries.items :
    performance_simulation.input ['ecca'] = values [0]
    performance_simulation.input ['rei'] = values [1]
    performance_simulation.input ['ei'] = values [2]
    performance_simulation.input ['ieit'] = values [3]
    performance_simulation.compute
    results [country] = performance_simulation.output ['performance']
# Display results in a table format
result_table = pd.DataFrame (list (results.items), columns = ['Country', 'Estimated Performance'])
print (result_table)

```

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