Computer and Decision Making

An International Journal

www.comdem.org
eISSN: xxxx-xxxx

Evaluating the Barriers to the Transition to Net-Zero Emissions in Developing Countries: A Multi-Criteria Decision-Making Approach

Tafuteni Nicholaus Chusi[1], Mouhamed Bayane Bouraima[2*], Su Qian[2], Ibrahim Badi[3], Elizabeth Abosede Oloketuyi [4], Yanjun Qiu [5]

[1] Center for Industrial and Business Organization, Dongbei University of Finance and Economics, Dalian, 116025 Liaoning Province, China
[2] Sichuan College of Architectural Technology, Deyang Campus: No.4, West Jialingjiang Road, Deyang, Sichuan 618000, China
[3] Libyan Academy, Mechanical Engineering Department, Libya
[4] Organization of African Academic Doctors (OAAD), Off Kamiti Road, P.O Box 25305-00100, Nairobi, Kenya
[5] School of Civil Engineering, Southwest Jiaotong University, Chengdu, Sichuan 610031, P.R. China

ARTICLE INFO

Article history:
Received 22 June 2024
Received in revised form 3 August 2024
Accepted 4 August 2024
Available online 4 August 2024

Keywords:

Net-zero emissions, FullEX; Multi-criteria decision making; Developing countries.

ABSTRACT

Many countries have engaged in net-zero emissions achievement by 2050 in line with United Nations Sustainable Development Goals (SDGs) and The Paris Agreement, aiming to foster sustainable social and economic practices while reducing emissions. Some countries have devised sector-specific plans to achieve net-zero emissions, aiming to balance energy consumption and production with current energy sources to meet SDGs. However, these plans will encounter challenges, particularly in reducing reliance on non-renewable fuels and reducing existing emissions. This study, employing the FullEX approach, identifies and analyses five barriers to the transition to net-zero emissions in Africa. The findings revealed financial constraints and ineffective policy and regulatory frameworks as the most critical barriers to address. Sensitivity analysis was applied to show the robustness of our approach.

1. Introduction

Climate change represents one of the most urgent challenges facing humanity [1], with a scientific consensus attributing it to the emission of greenhouse gases (GHGs) into the atmosphere [2]. Since 1900, these emissions have caused a significant increase in GHG concentrations, leading to severe and irremediable changes in the climate system, such as more recurrent and major weather events [3]. If current emission trends continue unabated, global temperatures could rise by more than 3.5°C, resulting in catastrophic impacts [2]. Given the potential destruction associated with this level of temperature rise, there is an urgent need to decarbonize global economies. However, even this target poses significant risks. To attain carbon neutrality and prevent the catastrophes of climate change, the world must intensify its efforts [4].

To achieve the Paris Agreement's goal of limiting global warming to below 2°C, global emissions must be balanced with sinks and sources through a transition to low emissions. The intergovernmental panel on climate change (IPCC) sixth report states that to limit warming to 1.5°C, global emissions must peak by 2030 and reach net-zero by 2050 [5]. To limit warming to 1.5°C, global CO2 emissions need to be net-zero by the 2050s, with other greenhouse gases following by the 2070s [5]. This emphasizes the need for global organizations to develop and implement plans for net-zero emissions by mid-century.

Africa's limited 7% historical contribution to global emissions contrasts with its critical role in the shift to net-zero emissions [5]. Sub-Saharan Africa, excluding South Africa, contributes just 4% of these emissions [6]. Despite its minor historical role, Africa suffers excessively from global warming, with a 10-15% decline in gross domestic product (GDP) per capita growth due to past warming. This vulnerability to climate change risks indicates the need for urgent action [7]. In a high-warming setting, West and East African countries could see GDP per capita reductions of more than 10% by 2050 in contrast to the baseline [7]. Africa's future relies on global efforts to achieve net-zero emissions and its own response to climate change risks. In Africa, the net-zero debate highlights the importance of fair transitions. Some governments worry it could worsen inequalities [8], while others argue short-term fossil fuel investments are necessary for energy needs [9]. A fair transition in Africa should prioritize development goals and poverty reduction [10]. Although net-zero commitments are limited, every African country has provided updated nationally determined contributions (NDCs) detailing their emission reduction targets.

Several studies have focused on Africa's transition to net-zero emissions. For instance, Musah et al., [11] assessed environmental quality in Sub-Saharan Africa, using Ghana as a case study. They found that the net-zero emissions goal of the Paris Agreement is accomplishable through increased funds in green transformations and global financial flows to boost Ghana's sustainability. Chevallier [12] identified African priorities for the United Nations Climate Change Conference in Glasgow (COP26), recommending that climate pledges align with achieving net-zero emissions by 2050. Nwokolo et al., [13] urged quick frameworks establishment using technological paths to meet Paris Agreement goals. Olujobi [14] evaluated the Act's impact on net-zero emissions and energy security, noting fragile implementation and absence of political determination as barriers. The study recommended public awareness campaigns, improved financial resources for regulators, and adherence to the Paris Agreement and SDG 13 for a sustainable energy future. However, none of these studies have ranked the barriers to net-zero emissions in developing countries by severity. To address this, there is a necessity of a clear managerial perspective for the identification and assessment of these critical barriers [15-18]. Multi-criteria decision-making (MCDM) techniques are ideal for this [19-22].

The objectives of our study are to: (1) Evaluate the barriers that developing countries, especially in Africa, encounter in transitioning to net-zero emissions, and (2) Rank these barriers based on their critical severity. This research offers the following contributions: (a) For the first time in the literature, the barriers that African countries encounter in transitioning to net-zero emissions have been evaluated using an MCDM perspective, specifically through the recently developed FullEX approach, and (b) it provides some implications to address the most critical barriers identified in the ranking. The motivation of using FullEX method is as follows. Previous research on Africa's transition to net-zero emissions has highlighted a significant lack of comprehensive assessments of the key barriers. There is a notable gap in studies integrating managerial and qualitative approaches. This study addresses this gap using the FullEX method, aiming to provide policymakers with insights for strategically allocating resources to achieve net-zero emissions. Criteria weighting methods like AHP, SWARA, BWM, and FUCOM rely on subjective opinions and involve pairwise comparisons (PCs). AHP ranks criteria on a 1–9 scale based on expert opinions [23], SWARA eliminates less significant criteria [24, 25], BWM compares criteria using best and worst references [26], and FUCOM uses a decimal or integer scale for comparisons [27, 28]. The FullEX method differs by considering experts' education and experience, allowing them to prioritize criteria based on their significance. This approach enhances decision-making, producing varying rankings compared to BWM's consistent results. Despite its advantages, FullEX has not been applied to assess and rank the barriers to transition to net-zero emissions in Africa. This study fills that gap by using FullEX for this evaluation.

The rest of the paper is organized as follows: Section 2: Literature review, 3 Methodology, 4 Application, 5 Sensitivity analysis, 6 Findings and discussion, 7 Managerial implications and 8 Conclusion and recommendations.

2. Literature Review

Two sub-sections have been defined herein.

2.1 Overview of Approaches related to Studies on the Transition to Net-Zero Emissions Targets

Several studies have explored net-zero emissions in various contexts. For instance, Panos et al., [29] used a techno-economic energy systems framework to highlight barriers in the Swiss energy transition and proposed solutions. Dafnomilis et al., [30] used the IMAGE model to study the impact of various scenarios on GHGs emissions predictions. Zhang et al., [31] found that energy transition and green financing impacts on COP26 targets vary, with GDP per capita raising emissions in market-based systems and reducing them in bank-based systems. Millot et al., [32] suggested comparing France's and Sweden's energy transitions, which have successfully diminished CO2 emissions and fossil fuel dependence. Their aim is to identify the key factors driving these changes to inform strategies for achieving carbon neutrality. Wimbadi and Djalante [33] examined essential concepts in climate change mitigation, emphasizing CO2 reduction and the pursuit of net-zero emissions. Bistline [34] reviewed nation-level studies on net-zero emissions frameworks. Azevedo et al., [35] offer perspectives on net-zero emissions systems, guiding policymakers and decision-makers on their essential characteristics.

2.2 MCDM related Studies on the Transition to Net-Zero Emissions Targets

MCDM methods are effective approaches that have been utilized in various aspects of life [36-41]. Kumar et al., [42] identified major low carbon procedures issues, prioritized them, and explained their cause-effect relationships. Kuo et al., [43] identified, ranked, and mapped the relationships between EV adoption barriers in the automotive industry. Pamucar et al., [44] presented a framework for implementing zero-carbon projects, using London's transport strategy as a case study. Karunathilake et al., [45] proposed a framework to assess and choose the most suitable renewable energy (RE) technologies for achieving net-zero energy communities, considering various decision criteria. Krishankumar et al., [46] assessed strategies for achieving zero carbon emissions in sustainable transportation within smart cities. Ohene et al., [47] identified barriers to net-zero carbon building (NZCB) adoption, prioritized them, and suggested strategies for overcoming these barriers. Cui et al., [48] found the best integrated RE system for UK homes to reach net-zero emissions. Table 1 provides the related studies.

Table 1. Application of MCDM to transition to net-zero emission targets

Authors	Focus	Method	Location
Kumar et al., [42]	Low-carbon operations adoption barriers evaluation	BWM, DEMATEL	India
Kuo et al., [43]	Electric vehicle adoption barrier assessment	ANP, DEMATEL	-
Pamucar et al., [44]	Zero-carbon project assessment	BWM, TODIM, D-number	London
Karunathilake et al., [45]	Choice of RE for net-zero energy community	F-MCDM	-
Krishankumar et al., [46]	Zero-carbon measures assessment	Q-Rung, CRITIC, MARCOS	India
Ohene et al., [47]	Net-zero carbon building assessment	BWM	-
Cui et al., [48]	Optimal hybrid RE system assessment	F-AHP	UK
Our study	**Assessment of barriers to the transition to net-zero emissions**	**FullEX**	**Africa**

Note: **ANP**- Analytic Network Process; **BWM**- Best-Worst Method; **CRITIC**-CRiteria Importance Through Inter-Criteria Correlation, **DEMATEL**- Decision Making Trial and Evaluation Laboratory; **MARCOS**- Measurement of alternatives and ranking according to COmpromise solution; **TODIM**- an acronym in Portuguese for Interactive and Multicriteria Decision Making.

As evident from sections 2.1 and 2.2, no study has yet examined the barriers to transitioning to net-zero emissions in Africa. Furthermore, the FullEX method has not been applied to assess these barriers to date.

3. FullEX Approach

The FullEX method provides a distinctive approach to evaluating decision-making criteria based on expert opinions. Our methodology, illustrated in Fig.1, outlines the process in two stages.

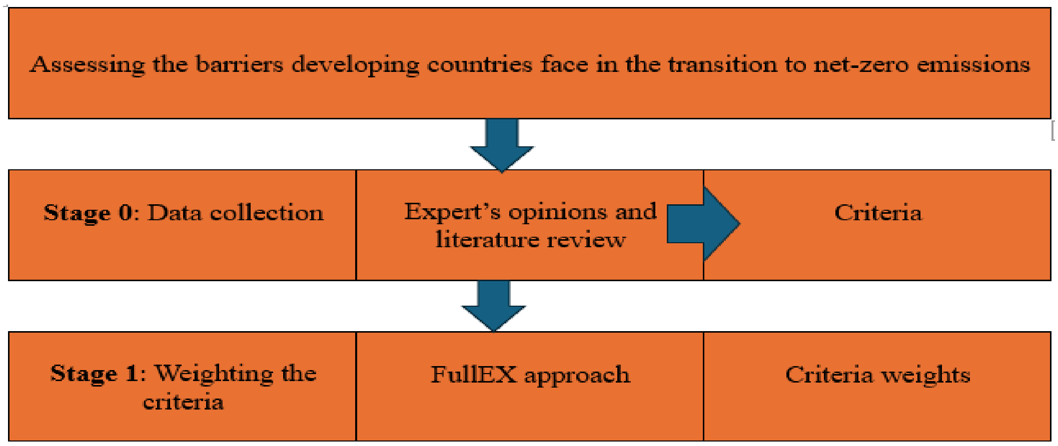

Fig.1. Flowchart of the methodology.

Step 1. The input data matrix (Table A1 in the appendix) is established for Fuller's method, which assesses the importance of criteria through paired comparisons. Experts indicate their preference for one criterion over another to determine criterion significance.

Step 2. It is computed using a triangular comparison method, wherein criteria are evaluated sequentially, excluding previously compared ones in each step. Expert reputations are then calculated based on their competence level (L_i), considering two distinct parameters

$$L_i = \frac{YE_i + ED_i}{2}, i = 1, 2, \ldots, q, \tag{1}$$

Here, YE_i represents years of experience, while ED_i indicates the level of education.

$$W^{Ei} = \frac{L_i}{\sum_{i=1}^{q} E_i}, i = 1, 2, \ldots, q. \tag{2}$$

Step 3. Once the input data matrix is prepared, the normalization process starts using the method detailed in Eq. (3), as outlined in Table A2 in the appendix

$$v_{ij} = \frac{x_{ij}}{\sum_{i=1}^{q} x_{ij}}, i = 1, 2, \ldots, q, j = 1, 2, \ldots, p. \tag{3}$$

Step 4. In this stage, the normalized input data is scaled by the experts' weights using Eq. (4) (Table A3 in the appendix)

$$r_{ij} = v_{ij} \cdot W^{Ei}, i = 1, 2, \ldots, q, j = 1, 2, \ldots, p. \tag{4}$$

Step 5. This step aims to find the optimal value ($V_{j\,max}$) for each criterion in the columns, calculated using Eq. (5) (Table A4 in the appendix).

$$V_{j\,max} = \max_{i=1,2,\ldots,q} r_{ij}, j = 1, 2, \ldots, p. \tag{5}$$

Step 6. In this step, each element in the expert-weighted normalized matrix is divided by its corresponding optimal value ($V_{j\,max}$), as defined in **Eq. (6)** (Table A5 in the appendix).

$$y_{ij} = \frac{r_{ij}}{V_{j\,max}}, i = 1, 2, \ldots, q, j = 1, 2, \ldots, p. \tag{6}$$

Step 7. Combination of the values vertically in the optimal decision-making matrix.

$$K_j = \sum_{i=1}^{q} y_{ij}, i = 1, 2, \ldots q, j = 1, 2, \ldots, p. \tag{7}$$

Step 8. During this phase, the criteria importance (F_j) is determined as follows:

$$F_j = \frac{K_j}{\sum_{j=1}^{p} K_j}, i = 1, 2, \ldots q, j = 1, 2, \ldots, p. \tag{8}$$

Step 9. In ensuring reliability, FullEX diverges from AHP [49] by conducting another interview where experts assign percentage importance scores to each criterion, summing up to 100%. The consistency index (CI) is then computed by comparing these scores with the initial FullEX weights using Eq. (9).

$$\mathrm{CI} = \frac{\sum_{j=1}^{n} |F_j * 100 - P_j|}{100} \tag{9}$$

A CI below 0.1 indicates reliable findings with satisfactory consistency. Conversely, if the CI surpasses this threshold, experts should reconsider their criteria assessment process.

4. Application

A study was carried out to assess the FullEX technique's effectiveness in identifying barriers to transition to net-zero emissions in Africa. The main goal was to evaluate and prioritize these barriers, starting with an expert panel of three experienced individuals which have expertise in renewable energy and climate change mitigation, as detailed in **Table 2**. Experts identified five key barriers, as shown in **Table 3**. The FullEX approach emphasized two important parameters: experience and educational level (1-Ph.D., 2-M. Sc, 3-B. Sc).

Table 2 Background information of experts

Experts (Es)	***Professional role***	***Gender***	***Years of experience***	***Education degree***
E_1	Practionner	Male	18	3
E_2	Academician	Female	10	2
E_3	Manager	Male	7	1

Table 3 Transition to net-zero emissions related barriers in Africa

Criteria	References
Financial constraints (B1)	[50-52]
Limited access to clean energy (B2)	
Insufficient infrastructure and basic utilities (B3)	
Ineffective policy and regulatory framework (B4)	
Limited Technology transfer and poor capacity building (B5)	

Step 1. The input data matrix is formulated and shown in Table 4.

Table 4 Input-data matrix

Experts/Criteria	***C1***	***C2***	***C3***	***C4***	***C5***
E_1	3	4	2	1	0
E_2	4	2	3	1	0
E_3	3	2	0	1	4
Sum	10	8	5	3	4

Step 2. After formulating the initial input data matrix, the expert assessment begins.

Step 3 and step 4. The matrix weights via expert is used to normalize the input data, with the outcomes detailed in Tables 5 and 6 via **Eq. (6)** and **Eq. (7)**.

Table 5 Normalized input-data matrix

Experts/Criteria	***C1***	***C2***	***C3***	***C4***	***C5***
E_1	0.300	0.500	0.400	0.333	0.000
E_2	0.400	0.250	0.600	0.333	0.000
E_3	0.300	0.250	0.000	0.333	1.000

Step 5 and step 6. Table 7 showcases the optimal decision-making matrix.

Table 6 Expert-weighted normalized input-data matrix

Experts/Criteria	***C1***	***C2***	***C3***	***C4***	***C5***
E_1	0.153	0.256	0.204	0.170	0.000
E_2	0.117	0.073	0.175	0.097	0.000
E_3	0.058	0.048	0.000	0.065	0.195
V_{jmax}	0.153	0.256	0.2049	0.170	0.195

Table 7 Average decision-making matrix

Experts/Criteria	***C1***	***C2***	***C3***	***C4***	***C5***
E_1	1.000	1.000	1.000	1.000	0.000
E_2	0.761	0.285	0.852	0.571	0.000
E_3	0.380	0.190	0.000	0.380	1.000

Step 7 and step 8. The optimal decision-making matrix integrates all values to calculate the final criteria weights (F_j) using Eq. (8), illustrated in Fig. 2**.**

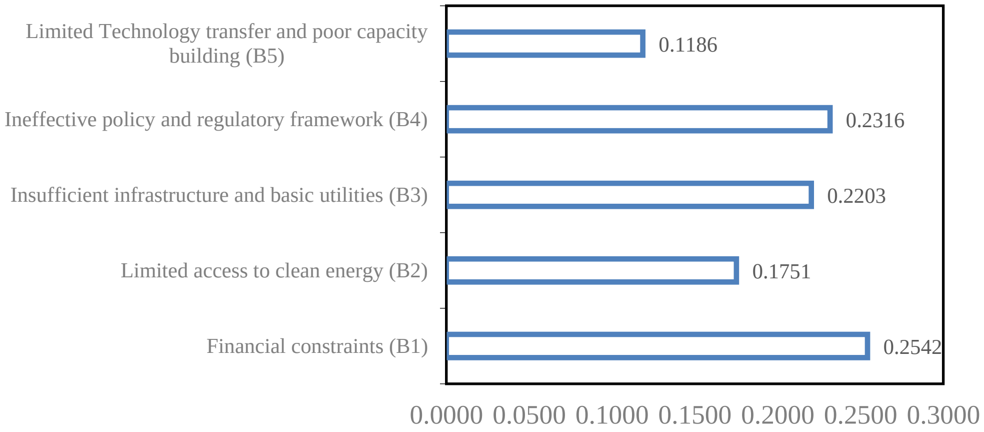

Fig.2. Final rank of barriers to transition to net-zero-emissions in Africa.

Based on the findings from the FullEX approach in Fig. 2, financial constraints (B1) at 0.2542 and ineffective policy and regulatory framework (B4) at 0.2316 emerge as the most critical barriers. The rankings for other barriers are as follows: B3 at 0.2203 is higher than B2 at 0.1751, with B5 at 0.1186 being the lowest ranked barrier.

Step 9. As a final step in the FullEX technique to ensure result credibility, data were gathered on the percentage distribution (0-100%) of criteria importance. In Table 8, the findings indicate a consistency rate of less than 0.1 (**CI = 0.053**), affirming a satisfactory level of reliability.

Table 8 CI calculation

	L_j	E_1	E_2	E_3	**Average** P_j	$\left\|F_j * 100 - P_j\right\|$	**CI**
B1	0.254	25	20	27	24	1.42	0.014
B2	0.175	15	20	25	20	2.48	0.024
B3	0.220	25	20	20	21.66	0.36	0.003
B4	0.231	25	20	25	23.33	0.16	0.001
B5	0.118	10	20	3	11	0.86	0.008
							0.053

Note: The values from second to sixth columns are given in percentage (%).

5. Sensitivity analysis

Sensitivity analysis, crucial for assessing model robustness [53, 54], has two phases: ranking barriers to net-zero emissions in Africa based on expert reputation variation, and omitting the most experienced expert.

5.1 Rank of criteria while varying the reputation of experts

This section compares criteria weights based on variations in experts' reputations across three options: the first option (original) considers both years of experience (YE) and educational degree (ED), the second option considers only years of experience, and the third option considers only educational degree. The results in Fig. 3 indicated that using both variables for expert reputation calculations enhances model stability (blue line), while relying on just one variable significantly affects the values of criteria. This underscores the importance of using the FullEX approach.

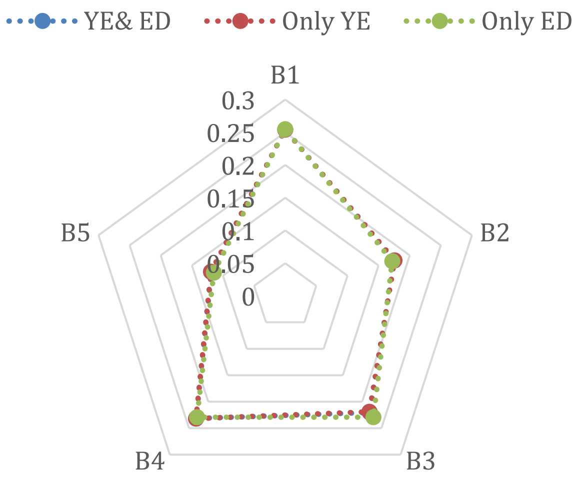

Fig.3. First sensitivity analysis outcomes.

5.2 Omitting the most experienced expert during the procedure

Next, the FullEX method's stability is tested by removing (E_1-Experienced expert) and (E_2-Average expert), respectively. **Fig. 4** shows significant changes in criteria ranking when E_1 is excluded, while E_2's exclusion has no effect. This highlights the impact of an expert's reputation on decision-making.

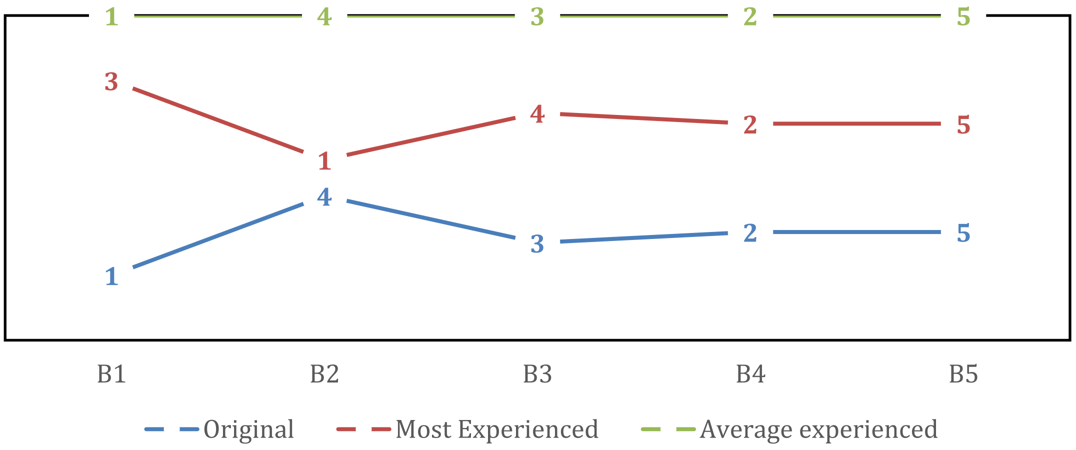

Fig.4. Second sensitivity analysis outcome.

6. Findings and discussion

Africa's face barriers to transition to net-zero emissions. To identify the very critical ones, the FullEX methodology was utilized. Our research findings emphasize the critical issue of financial constraints in this transition. Chapungu et al., [55] noted that financing the transition to net-zero emissions is an issue for African countries, which often struggle to attract investment for RE due to limited financial resources. Competing priorities like infrastructure, poverty reduction, and healthcare further limit available funds. The significant upfront costs of renewable technologies and the lack of supportive financing mechanisms hamper progress. Renewable technologies typically require high initial investments, which can be a major hurdle for African countries with constrained financial resources. To address financial constraints in Africa, enhancing tax collection, curbing illicit financial flows, and improving governance can create fiscal space for clean energy investments. Public-private partnerships can unlock funding by utilizing private sector expertise and resources aligned with public policy goals. The second key barrier in reaching net-zero emissions is the absence of effective policies and regulatory schemes, as noted by Uspenskaia et al., [56]. Many African countries do not have extensive policies or incentives for clean energy investments. Functional regulations are necessary to support RE acquisition and transition to net-zero emission.

7. Managerial implications

The conclusions drawn from this study provide valuable insights for policymakers in the transition to net-zero emissions. The research identifies two significant challenges faced in this transition, including financial constraints and ineffective policy and regulatory frameworks. These findings are especially relevant for policymakers striving to address the obstacles to achieving net-zero emissions in Africa. The study provides practical recommendations, highlighting the necessity of boosting tax collection, curtailing illicit financial flows, and enhancing governance to create fiscal space for clean energy investments. Additionally, involving public-private partnerships is crucial, as they can unlock funding by leveraging private sector expertise and resources in line with public policy objectives. Moreover, effective regulations are essential to support the acquisition of renewable energy and the transition to net-zero emissions. Implementing these measures can effectively tackle the challenges Africa faces in transitioning to net-zero emissions.

8 Conclusion and future recommendations

This study utilizes the FullEX technique to examine the barriers to net-zero emissions achievement in Africa, offering crucial insights for policymakers. By considering experts’ years of experience and educational backgrounds, it establishes a solid foundation for informed decision-making. The African case study demonstrates the technique’s effectiveness in identifying key barriers, with financial constraints and ineffective policies and regulatory frameworks emerging as the most significant issues.

While our research is impactful, it has some limitations. First, it was conducted at a continental level, neglecting the diverse contexts of Africa’s various countries and regions. Future research should consider regional comparisons or country-specific analyses for a more comprehensive understanding. Second, the FullEX technique has its limitations: results may vary based on experts’ background, and it is restricted to precise values. Future studies should address these limitations by incorporating uncertainty and expanding the scope of investigation. Lastly, future research should consider proposing strategies to overcome these barriers after ranking them.

Appendix

Table A1 Input data matrix

Experts/Criteria	C_1	C_1	…	C_j	…	C_p
E_1	x_{11}	x_{12}	…	x_{1j}	…	x_{1p}
E_1	x_{21}	x_{22}	…	x_{2j}	…	x_{2p}
…	…	…	…	…	…	…
E_i	x_{i1}	x_{i2}	…	x_{ij}	…	x_{ip}
…	…	…	…	…	…	…
E_q	x_{q1}	x_{q2}	…	x_{qj}	…	x_{qp}

where E_1, E_2, …, E_q are experts and q is the number of experts, C_1, C_2, …, C_p are criteria and p is the number of criteria, and x_{ij} are the experts' criteria importance assessments based on Fuller's triangle.

Table A2 Input-data matrix normalization

Experts/Criteria	C_1	C_1	…	C_j	…	C_p
E_1	v_{11}	v_{12}	…	v_{1j}	…	v_{1p}
E_1	v_{21}	v_{22}	…	v_{2j}	…	v_{2p}
…	…	…	…	…	…	…
E_i	v_{i1}	v_{i2}	…	v_{ij}	…	v_{ip}
…	…	…	…	…	…	…
E_q	v_{q1}	v_{q2}	…	v_{qj}	…	v_{qp}

Table A3 Expert-weighted normalized input-data matrix

Experts/Criteria	C_1	C_1	…	C_j	…	C_p
E_1	r_{11}	r_{12}	…	r_{1j}	…	r_{1p}
E_1	r_{12}	r_{22}	…	r_{2j}	…	r_{2p}
…	…	…	…	…	…	…
E_i	r_{i1}	r_{i2}	…	r_{ij}	…	r_{ip}
…	…	…	…	…	…	…
E_q	r_{q1}	r_{q2}	…	r_{qj}	…	r_{qp}

Table A4 Optimal value for each criterion in the matrix of expert-weighted normalized input data ($V_{j\ max}$)

Experts/Criteria	C_1	C_1	…	C_j	…	C_p
$\boldsymbol{E_1}$	$\boldsymbol{r_{11}}$	$\boldsymbol{r_{12}}$	…	$\boldsymbol{r_{1j}}$	…	$\boldsymbol{r_{1p}}$
$\boldsymbol{E_1}$	$\boldsymbol{r_{21}}$	$\boldsymbol{r_{22}}$	…	$\boldsymbol{r_{2j}}$	…	$\boldsymbol{r_{2p}}$
…	…	…	…	…	…	…
$\boldsymbol{E_i}$	$\boldsymbol{r_{i1}}$	$\boldsymbol{r_{i2}}$	…	$\boldsymbol{r_{ij}}$	…	$\boldsymbol{r_{ip}}$
…	…	…	…	…	…	…
$\boldsymbol{E_q}$	$\boldsymbol{r_{q1}}$	$\boldsymbol{r_{q2}}$	…	$\boldsymbol{r_{qj}}$	…	$\boldsymbol{r_{qp}}$
$\boldsymbol{V_{jmax}}$	$\boldsymbol{V_{1max}}$	$\boldsymbol{V_{2max}}$	…	$\boldsymbol{V_{jmax}}$	…	$\boldsymbol{V_{pmax}}$

Table A5 Optimal decision-making matrix

Experts/Criteria	C_1	C_1	…	C_j	…	C_p
E_1	y_{11}	y_{12}	…	y_{1j}	…	y_{1p}
E_1	y_{21}	y_{22}	…	y_{2j}	…	y_{2p}

…	…	…	…	…	…	…
E_i	y_{i1}	y_{i2}	…	y_{ij}	…	y_{ip}
…	…	…	…	…	…	…
E_q	y_{q1}	y_{q2}	…	y_{qj}	…	y_{qp}

Author Contributions

Conceptualization, M.B.B. and T.N.F.; methodology, M.B.B. and S.Q.; software, M.B.B. and S.Q.; validation, M.B.B. and I.B.; formal analysis, I.B., E.A.O and Y.Q.; investigation, E.A.O. and Y.Q.; data curation, I.B., E.A.O. and Y.Q.; writing—original draft preparation, M.B.B., I.B. and E.A.O.; writing—review and editing, I.B., E.A.O. and Y.Q.; visualization, E.A.O. and Y.Q.; supervision, E.A.O. and Y.Q.; project administration, S.Q. and Y.Q.

Conflicts of 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.

References

[1] Viola, E., & Basso, L. (2016). Wandering decarbonization: the BRIC countries as conservative climate powers. Revista Brasileira de Política Internacional, 59, e001. https://doi.org/10.1590/0034-7329201600101

[2] Chapungu, L., Nhamo, L., & Gatti, R. C. (2020). Estimating biomass of savanna grasslands as a proxy of carbon stock using multispectral remote sensing. Remote sensing applications: Society and environment, 17, 100275.

[3] Oladunni, O. J., Mpofu, K., & Olanrewaju, O. A. (2022). Greenhouse gas emissions and its driving forces in the transport sector of South Africa. Energy Reports, 8, 2052-2061. https://doi.org/10.1016/j.egyr.2022.01.123

[4] Obobisa, E. S. (2022). Achieving 1.5 C and net-zero emissions target: The role of renewable energy and financial development. Renewable Energy, 188, 967-985. https://doi.org/10.1016/j.renene.2022.02.056

[5] Shukla, A., Skea, J., Reisinger, A., Slade, R., Fradera, R., Pathak, M., Al Khourdajie, A., Belkacemi, M., Van Diemen, R., & Hasija, A. (2022). Summary for policymakers.

[6] AfDB. (2021). Leveraging Private Sector Engagement for the Africa we Want. Retrieved from https://au.int/en/pressreleases/20211108/leveraging-private-sector-engagement-africa-we-want

[7] Baarsch, F., Granadillos, J. R., Hare, W., Knaus, M., Krapp, M., Schaeffer, M., & Lotze-Campen, H. (2020). The impact of climate change on incomes and convergence in Africa. World Development, 126, 104699. https://doi.org/10.1016/j.worlddev.2019.104699

[8] LMCD. (2021). LMCD Ministerial Statement. Retrieved from https://static.pib.gov.in/WriteReadData/specificdocs/documents/2021/oct/doc2021101821.pdf

[9] Communique, K. (2021). Ensuring a just and equitable energy transition in Africa: Seven transformative actions for SDG7. Retrieved from

[10] Lang, J., Hyslop, C., Yeo, Z. Y., Black, R., Chalkley, P., Hale, T., & Hans, F. (2022). Net Zero Tracker. Energy and Climate Intelligence Unit, Data-Driven EnviroLab, NewClimate Institute, Oxford Net Zero."

[11] Musah, M., Onifade, S. T., Ankrah, I., Gyamfi, B. A., & Amoako, G. K. (2024). Achieving net-zero emission target in Africa: Are sustainable energy innovations and financialization crucial for environmental sustainability of sub-Saharan African state? Applied Energy, 364, 123120.
[12] Chevallier, R. (2021). The Urgent Race to Net Zero: Exploring African Priorities for COP 26. South African Institute of International Affairs (SAIIA), 5, 137-151.
[13] Nwokolo, S. C., Singh, R., Khan, S., Kumar, A., & Luthra, S. (2023). Technological Pathways to Net-Zero Goals in Africa. In Africa's Path to Net-Zero: Exploring Scenarios for a Sustainable Energy Transition (pp. 93-210). Springer. https://doi.org/10.1007/978-3-031-44514-9
[14] Olujobi, O. J. (2024). Nigeria's Climate Change Act 2021: A pathway to net-zero carbon emission, energy security and sustainability. Environmental Science and Pollution Research, 1-15. https://doi.org/10.1007/s11356-024-33347-1
[15] Görçün, Ö. F., Aytekin, A., Korucuk, S., & Tirkolaee, E. B. (2023). Evaluating and selecting sustainable logistics service providers for medical waste disposal treatment in the healthcare industry. Journal of Cleaner Production, 408, 137194. https://doi.org/10.1016/j.jclepro.2023.137194
[16] Edalatpanah, S. A., Hassani, F. S., Smarandache, F., Sorourkhah, A., Pamucar, D., & Cui, B. (2024). A hybrid time series forecasting method based on neutrosophic logic with applications in financial issues. Engineering Applications of Artificial Intelligence, 129, 107531. https://doi.org/10.1016/j.engappai.2023.107531
[17] Bouraima, M. B., Stević, Ž., Tanackov, I., & Qiu, Y. (2021). Assessing the performance of Sub-Saharan African (SSA) railways based on an integrated Entropy-MARCOS approach. Operational Research in Engineering Sciences: Theory and Applications, 4(2), 13-35. https://doi.org/10.31181/oresta20402013b
[18] Badi, I., & Abdulshahid, A. (2023). Unlocking economic opportunities: Libya as a maritime gateway for landlocked African countries. African Transport Studies, 1, 100004. https://doi.org/10.1016/j.aftran.2024.100004
[19] Elomiya, A., Křupka, J., Jovčić, S., Simic, V., Švadlenka, L., & Pamucar, D. (2024). A hybrid suitability mapping model integrating GIS, machine learning, and multi-criteria decision analytics for optimizing service quality of electric vehicle charging stations. Sustainable Cities and Society, 106, 105397. https://doi.org/10.1016/j.scs.2024.105397
[20] Jana, C., Garg, H., Pal, M., Sarkar, B., & Wei, G. (2024). MABAC framework for logarithmic bipolar fuzzy multiple attribute group decision-making for supplier selection. Complex & Intelligent Systems, 10(1), 273-288. https://doi.org/10.1007/s40747-023-01108-1
[21] Bouraima, M. B., Qiu, Y., Yusupov, B., & Ndjegwes, C. M. (2020). A study on the development strategy of the railway transportation system in the West African Economic and Monetary Union (WAEMU) based on the SWOT/AHP technique. Scientific African, 8, e00388. https://doi.org/10.1016/j.sciaf.2020.e00388
[22] Ayyildiz, E., Erdogan, M., & Gul, M. (2024). A comprehensive risk assessment framework for occupational health and safety in pharmaceutical warehouses using Pythagorean fuzzy Bayesian networks. Engineering Applications of Artificial Intelligence, 135, 108763. https://doi.org/10.1016/j.engappai.2024.108763
[23] Moslem, S. (2024). A Novel Parsimonious Spherical Fuzzy Analytic Hierarchy Process for Sustainable Urban Transport Solutions. Engineering Applications of Artificial Intelligence, 128, 107447. https://doi.org/10.1016/j.engappai.2023.107447
[24] Bouraima, M. B., Qiu, Y., Stević, Ž., & Simić, V. (2022). Assessment of alternative railway systems for sustainable transportation using an integrated IRN SWARA and IRN CoCoSo model. Socio-Economic Planning Sciences, 101475. https://doi.org/https://doi.org/10.1016/j.seps.2022.101475
[25] Qiu, Y. J., Bouraima, M. B., Badi, I., Stević, Ž., & Simic, V. (2024). A decision-making model for prioritizing low-carbon policies in climate change mitigation. Chall. Sustain., 12(1), 1-17. https://doi.org/10.56578/cis120101
[26] Moslem, S. (2023). A Novel Parsimonious Best Worst Method for Evaluating Travel Mode Choice. IEEE Access, 11, 16768-16773. https://doi.org/10.1109/ACCESS.2023.3242120
[27] Badi, I., & Abdulshahed, A. (2019). Ranking the Libyan airlines by using full consistency method (FUCOM) and analytical hierarchy process (AHP). Operational Research in Engineering Sciences: Theory and Applications, 2(1), 1-14. https://doi.org/10.31181/oresta1901001b

[28] Pamučar, D., Stević, Ž., & Sremac, S. (2018). A new model for determining weight coefficients of criteria in mcdm models: Full consistency method (fucom). Symmetry, 10(9), 393. https://doi.org/10.3390/sym10090393

[29] Panos, E., Kannan, R., Hirschberg, S., & Kober, T. (2023). An assessment of energy system transformation pathways to achieve net-zero carbon dioxide emissions in Switzerland. Communications Earth & Environment, 4(1), 157. https://doi.org/10.1038/s43247-023-00865-8

[30] Dafnomilis, I., den Elzen, M., & van Vuuren, D. P. (2023). Achieving net ‐ zero emissions targets: An analysis of long ‐ term scenarios using an integrated assessment model. Annals of the New York Academy of Sciences, 1522(1), 98-108. https://doi.org/10.1111/nyas.14970

[31] Zhang, D., Guo, Y., & Taghizadeh-Hesary, F. (2023). Green finance and energy transition to achieve net-zero emission target. Energy Economics, 126, 106936. https://doi.org/10.1016/j.eneco.2023.106936

[32] Millot, A., Krook-Riekkola, A., & Maïzi, N. (2020). Guiding the future energy transition to net-zero emissions: Lessons from exploring the differences between France and Sweden. Energy Policy, 139, 111358. https://doi.org/10.1016/j.enpol.2020.111358

[33] Wimbadi, R. W., & Djalante, R. (2020). From decarbonization to low carbon development and transition: A systematic literature review of the conceptualization of moving toward net-zero carbon dioxide emission (1995-2019). Journal of Cleaner Production, 256, 120307. https://doi.org/10.1016/j.jclepro.2020.120307

[34] Bistline, J. E. (2021). Roadmaps to net-zero emissions systems: emerging insights and modeling challenges. Joule, 5(10), 2551-2563. https://doi.org/10.1016/j.joule.2021.09.012

[35] Azevedo, I., Bataille, C., Bistline, J., Clarke, L., & Davis, S. (2021). Net-zero emissions energy systems: What we know and do not know. Energy and Climate Change, 2, 100049. https://doi.org/10.1016/j.egycc.2021.100049

[36] Radovanović, M., Petrovski, A., Cirkin, E., Behlić, A., Jokić, Ž., Chemezov, D., Hashimov, E. G., Bouraima, M. B., & Jana, C. (2024). Application of the new hybrid model LMAW-G-EDAS multi-criteria decision-making when choosing an assault rifle for the needs of the army. Journal of Decision Analytics and Intelligent Computing, 4(1), 16-31. https://doi.org/10.31181/jdaic10021012024r

[37] Ayyildiz, E., & Erdogan, M. (2024). Addressing the challenges of using autonomous robots for last-mile delivery. Computers & Industrial Engineering, 190, 110096. https://doi.org/10.1016/j.cie.2024.110096

[38] Badi, I., Stević, Ž., & Bouraima, M. B. (2023). Overcoming Obstacles to Renewable Energy Development in Libya: An MCDM Approach towards Effective Strategy Formulation. Decision Making Advances, 1(1), 17-24. https://doi.org/10.31181/v120234

[39] Badi, I., & Bouraima, M. B. (2023). Development of MCDM-based Frameworks for Proactively Managing the Most Critical Risk Factors for Transport Accidents: A Case Study in Libya. Spectrum of Engineering and Management Sciences, 1(1), 38-47. https://doi.org/10.31181/sems1120231b

[40] Kiptum, C. K., Bouraima, M. B., Badi, I., Zonon, B. I. P., Ndiema, K. M., & Qiu, Y. (2023). Assessment of the Challenges to Urban Sustainable Development Using an Interval-Valued Fermatean Fuzzy Approach. Systemic Analytics, 1(1), 11-26. https://doi.org/10.31181/sa1120233

[41] Bouraima, M. B., Ayyildiz, E., Özçelik, G., Tengecha, N. A., & Stević, Ž. (2024). Alternative prioritization for mitigating urban transportation challenges using a Fermatean fuzzy-based intelligent decision support model. Neural Computing and Applications https://doi.org/https://doi.org/10.1007/s00521-024-09463-x

[42] Kumar, A., Luthra, S., Mangla, S. K., Garza-Reyes, J. A., & Kazancoglu, Y. (2023). Analysing the adoption barriers of low-carbon operations: A step forward for achieving net-zero emissions. Resources Policy, 80, 103256. https://doi.org/10.1016/j.resourpol.2022.103256

[43] Kuo, T.-C., Shen, Y.-S., Sriwattana, N., & Yeh, R.-H. (2022). Toward net-zero: The barrier analysis of electric vehicle adoption and transition using anp and dematel. Processes, 10(11), 2334. https://doi.org/10.3390/pr10112334

[44] Pamucar, D., Deveci, M., Canıtez, F., Paksoy, T., & Lukovac, V. (2021). A novel methodology for prioritizing zero-carbon measures for sustainable transport. Sustainable Production and Consumption, 27, 1093-1112. https://doi.org/10.1016/j.spc.2021.02.016

[45] Karunathilake, H., Hewage, K., Mérida, W., & Sadiq, R. (2019). Renewable energy selection for net-zero energy communities: Life cycle based decision making under uncertainty. Renewable Energy, 130, 558-573. https://doi.org/10.1016/j.renene.2018.06.086

[46] Krishankumar, R., Mishra, A. R., Rani, P., Ecer, F., & Ravichandran, K. (2023). Assessment of zero-carbon measures for sustainable transportation in smart cities: a CRITIC-MARCOS framework based on Q-rung fuzzy preferences. IEEE Internet of Things Journal. https://doi.org/10.1109/JIOT.2023.3293513

[47] Ohene, E., Chan, A. P., & Darko, A. (2022). Prioritizing barriers and developing mitigation strategies toward net-zero carbon building sector. Building and Environment, 223, 109437. https://doi.org/10.1016/j.buildenv.2022.10943

[48] Cui, Z., Latif, E., & Stevenson, V. (2023). Decision-making framework to identify the optimal hybrid renewable energy system for switching UK representative domestic buildings towards the net-zero target. In Resilient and Responsible Smart Cities: The Path to Future Resiliency (pp. 229-241). Springer.

[49] Bošković, S., Švadlenka, L., Jovčić, S., Dobrodolac, M., Simic, V., & Bacanin, N. (2023). A New FullEX Decision-Making Technique for Criteria Importance Assessment: An Application to the Sustainable Last-Mile Delivery Courier Selection. IEEE Access, 11, 137426-137436. https://doi.org/10.1109/ACCESS.2023.3339580

[50] Stern, N., & Valero, A. (2021). Innovation, growth and the transition to net-zero emissions. Research Policy, 50(9), 104293. https://doi.org/10.1016/j.respol.2021.104293

[51] Nnabuife, S. G., Oko, E., Kuang, B., Bello, A., Onwualu, A. P., Oyagha, S., & Whidborne, J. (2023). The prospects of hydrogen in achieving net zero emissions by 2050: A critical review. Sustainable Chemistry for Climate Action, 100024. https://doi.org/10.1016/j.scca.2023.100024

[52] Das, A., Saini, V., Parikh, K., Parikh, J., Ghosh, P., & Tot, M. (2023). Pathways to net zero emissions for the Indian power sector. Energy Strategy Reviews, 45, 101042. https://doi.org/10.1016/j.esr.2022.101042

[53] Więckowski, J., & Sałabun, W. (2024). A new sensitivity analysis method for decision-making with multiple parameters modification. Information Sciences, 120902. https://doi.org/10.1016/j.ins.2024.120902

[54] Więckowski, J., & Sałabun, W. (2023). Sensitivity analysis approaches in multi-criteria decision analysis: A systematic review. Applied Soft Computing, 110915. https://doi.org/10.1016/j.asoc.2023.110915

[55] Chapungu, L., Nhamo, G., Chikodzi, D., & Maoela, M. A. (2022). BRICS and the Race to Net-Zero Emissions by 2050: Is COVID-19 a Barrier or an Opportunity? Journal of Open Innovation: Technology, Market, and Complexity, 8(4), 172.

[56] Uspenskaia, D., Specht, K., Kondziella, H., & Bruckner, T. (2021). Challenges and barriers for net‐zero/positive energy buildings and districts-empirical evidence from the smart city project SPARCS. Buildings, 11(2), 78. https://doi.org/10.3390/buildings11020078