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Addressing the Challenges Facing Developing Countries in the Mining Sector: Moving Towards Sustainability

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Abstract

The sustainability of the mining sector over long term relies on a range of factors that must be carefully evaluated. To address this, Multi-Criteria Decision-Making (MCDM) techniques have been utilized for their flexibility in offering supplementary tools. In this context, we assess the condition of the mining sector in Africa by examining key fundamental challenges it faces. Based on the literature review and opinions of experts, eleven challenges in the mining sector are identified. This study applies the FullEX approach to accommodate group decision-making process. Experts' Years of Experience (YE) and educational backgrounds are utilized to determine the importance of coefficients of criteria in the group decision-making process. The findings highlight mineral depletion resulting from over-exploitation, a scarcity of skilled labor, inconsistent power supply, inadequate infrastructure, and political problems as the most significant challenges confronting the mining sector. Furthermore, a sensitivity analysis is conducted to evaluate the robustness of our approach. The insights gained from this study carry extensive implications for policymakers to devise appropriate strategies for overcoming the challenges facing the mining sector.

Keywords: Mining sector, FullEX, Multi-criteria decision making, Sustainability, Africa.

1 | Introduction

Africa is rich in mineral wealth, as the continent boasts 92% of the world's reserves of platinum, 56% of cobalt, 54% of manganese, and 36% of chromium, all of which are needed for green technologies [1]. In other words, the African continent has the most significant mineral reserves on a global scale [2]. Additionally,

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about 69% of African nations depend on mining for their primary export income [3]. This is partly due to the efforts of Bretton Woods organizations, which promoted the full exercise of their abundance by privatizing and liberalizing the continent's resources to stimulate economic modernization [4].

The 1970s were marked with several economic issues in Africa, and the abovementioned institutions launched Structural Adjustment Programs (SAP) and new mining laws and regulations. The goal was to reduce the role of the government in the national economy and support Foreign Direct Investments (FDI) in the extractive industries [4]. However, the outcomes were unpleasant. People were often displaced, while the environment was adversely affected. According to Bridge [5], the effects of mining and processing have been observable for numerous years. Yet, their implications have been a subject of ongoing debate, with no viable alternatives available at present. Due to its environmental ramifications, mining stands out as a primary concern, given its continuous expansion and rapid development [6]. These pressing matters demand attention and solutions, albeit in specific contexts.

It is common knowledge that mining in Africa faces many challenges which are highlighted in every media outlet nowadays [7]. As an illustration, Signé and Johnson [8] discussed undeveloped dimensions of the African mining sub-sector and the critical strategies to be used for the development and transformation of the entire continent. Wilson et al. [9] primarily delved into the initiatives undertaken by the Liberian government aimed at addressing various aspects of the environment and Sustainable Development Goals (SDGs). They also examined some of the environmental challenges within the mining sector. Ledwaba and Mutemeri [10] analyzed the policies and laws that are responsible for informal mining. They find out that those policies and laws were created to assist the realization of transformation, but some of these policies and laws seem not to facilitate the growth of Artisanal and Small-scale Mining (ASM). Muhirwa et al. [11] critically assessed two decades of research on large-scale extraction funding in Africa and looked at how these funds influence local development and challenged the researchers for cooperation and formulation of better development engagement strategies. Ledwaba and Nhlengetwa [12] identified prospective mining areas which were then serviced with the tailored application of development assistance.

Tuokuu et al. [13] highlighted the hurdles faced in adhering to environmental policies within Ghana's gold mining sector. These obstacles include insufficient community involvement in decision-making processes, inadequate government coordination, staffing shortages, logistical problems, and a lack of political commitment, all of which contribute to the difficulty of compliance. Existing studies have extensively addressed the challenges encountered by the African mining sector. Nevertheless, there is a discernible necessity to prioritize these challenges to identify the most critical ones. Conducting such research would provide valuable insights for policymakers and implementers to allocate resources strategically towards achieving SDGs.

1.1 | Objectives, Contributions, and Motivations of Our Study

Our study objective is as follows:

I. Pinpoint the challenges confronting the mining sector in Africa.

II. Prioritize these challenges based on their critical severity utilizing the recently developed FullEX method.

This research contributions is as follows:

I. Applying the FullEX method to identify the challenges facing mining sector in Africa,

II. Identifying the most critical challenges and providing some managerial implications to overcome them.

The motivation of using FullEX method is as follows:

Previous research on the African mining sector has underscored a notable dearth of comprehensive assessments concerning critical challenges impacting the sector. There exists a research gap in conducting an in-depth study that integrates both managerial and qualitative approaches to address this evaluation. This study endeavors to bridge this gap by employing the FullEX method. Its objective is to furnish policymakers and implementers with valuable insights to strategically allocate resources towards attaining SDGs.

Criteria weighting methods depend on decision-makers' subjective opinions [14]–[17]. They involve comparing criteria through Pairwise Comparisons (PCs). The AHP method gathers expert opinions to rank criteria on a 1–9 scale, determining their significance [18]. SWARA eliminates less significant criteria and ranks the most important ones [19]. BWM compares criteria using best and worst references, mitigating bias [20]. FUCOM compares each criterion to others using a decimal or integer scale in PCs. The FullEX method differs from other subjective approaches by considering experts' esteem, including their education degree level and experience. This initial step is crucial as experts assess and prioritize criteria based on their significance. Unlike other methods, FullEX incorporates these key parameters, enhancing decision-making. While BWM produces consistent results regardless of expert reputation, FullEX yields varying rankings, highlighting its innovative approach [21]. However, research on applying FullEX to assess critical challenges in Africa's mining sector is lacking. This study fills this gap by employing FullEX for this evaluation.

The rest of the paper is organized as follows. Section 1 is the introduction. Section 2 is the literature review. Section 3 presents the FullEX approach. Section 4 is the application of the FullEX method to the mining sector. Section 5 is the sensitivity analysis. Section 6 is the discussion and findings. Section 7 is the managerial implications, while Section 8 concludes the paper and gives future recommendations.

2|Literature Review

In this section, we explore two sub-sections which consist of approaches used in the mining sector and the Multi-Criteria Decision-Making (MCDM) related studies in the sector, respectively.

2.1|Overview of Approaches Related to Mining Sector

Studies have been carried out on the mining sector across different nations worldwide [11], [22], [23]. For instance, Tanda and Genc [24] examined how revenue leakages affect Zimbabwe's goals of making its mining sector a reliable revenue source. They pinpointed critical shortcomings in the country's mining sector, such as contraband and poor government transparency, mirror challenges in other mineral-rich African nations. Mvile and Bishoge [25] reviewed previous and ongoing research to offer insight into the connection between the mining sector and SDGs in Africa. Their findings suggest that mining doesn't align with just one SDG but impacts multiple goals simultaneously. Bester [26] explores Corporate Social Responsibility (CSR) theory to assess corporate involvement in addressing artisanal mining in South Africa. Using empirical data, they develop a unique CSR framework for mining companies to tackle the South African artisanal mining sector issues. Dikgwatlhe and Mulenga [27] shared results from a survey assessing local perspectives on the socio-economic effects of mining near their communities. Their study reveals both positive and negative effects experienced by the community due to mining operation. Bester and Groenewald [28] investigate how corporations can contribute to the development and management of artisanal mining in South Africa. Van der Watt and Marais [29] studied the collaboration between local government and mining firms in Rustenburg, South Africa.

Egunyu and Boakye-Danquah [30] found that while research on the socio-economic effects of mining in Africa has included artisanal miners and women, there is a need to involve vulnerable groups. They also stressed the importance of including indigenous people, noting that their perspectives are often overlooked. Rathobei et al. [31] analyzed endurable reports from main mineral and mining enterprises to study their stakeholder management applications. While these firms address social and environmental worries, the study recommends a more proactive approach to engage a broader range of stakeholders. Mimba et al. [32] reviewed literature to analyze the impacts of Artisanal and Small-scale Gold Mining (ASGM) in certain Cameroonian mining districts. They assessed four types of mining hazards and conducted socioeconomic and land use/cover risk evaluations.

2.2|Applications of MCDM Techniques on Ming Sector

MCDM methods are successful decision-making approaches that have been applied in various areas in the life [33]–[48]. In the mining sector , for instance, Baloyi and Meyer [49] explored 10 multi-criteria techniques capable of addressing the Mining Method Selection (MMS) issue. They aimed to integrate these techniques into a model for effective MMS implementation, utilizing essential factors and mining approaches as inputs for their developed model. Chand et al. [50] studied Supply Chain Performance (SCP) parameters for Indian mining and earthmoving equipment manufacturers. Shen et al. [51] evaluated criteria to enhance Green Supply Chain Management (GSCM) effectiveness, offering guidance for its implementation. Sitorus et al. [52] examined how MCDM methods are applied in mining and mineral processing, covering their use in decision-making and emerging trends. Zhang et al. [53] analyzed the security of China's critical minerals over time. They found that nickel, copper, and iron were particularly insecure due to limited domestic supply, showing a downward trend. Prasad et al. [54] used surveys to prioritize over 70 Global Reporting Initiative (GRI) indicators for the mining sector based on various aspects, enhancing measurement accuracy. Govindan et al. [55] explored the factors influencing CSR implementation in the mining sector, examining various stakeholder perspectives. Ortiz-Barrios et al. [56] employed advanced MCDM techniques to select the best supplier of forklift filters in mining. Poormirzaee et al. [57] introduced an innovative integrated framework for evaluating and ranking smart mining strategies.

Kusi-Sarpong et al. [58] presented a thorough framework for implementing Green Supply Chain Practices (GSCP) within the mining sector. Wang et al. [59] conducted an assessment of lithium extraction projects worldwide. Xu and Dong [60] put forward a novel framework for analyzing China's contemporary coal-to-chemical sector. Sivakumar et al. [61] presented a model scheme to assess outsourcing vendor performance and select the best one for the production of the mining sector. Wang et al. [62] studied China's mining investment in Africa, establishing indicators to assess these investment strategies in the African mining sector. Hosseini et al. [63] examined how Industry 4.0 technologies can be applied to determine the most effective strategy for the Nigerian mining sector. Banda [64] proposed a model to prioritize challenges in Zambia's artisanal and small-scale manganese mining. The application of MCDM approaches to related studies to the mining is indicated in *Table 1*.

Table 1. Application of MCDM methods to ming sector related studies.

Source	Location	Focus	GDM	SA	Methodology
Baloyi and Meyer [49]	İran	Mining approach choice model establishment	Yes	No	TOPSIS, TODIM, VIKOR, GRA, PROMETHEE, OCRA, ARAS, COPRAS, SAW
Chand et al. [50]	India	SCP metrics evaluation for mining equipment manufacturing enterprises	Yes	Yes	Delphi, BWM, DEMATEL
Shen et al. [51]	İndia	Durable development framework of mining sector	Yes	Yes	AHP
Sitorus et al. [52]	-	Review of existing methodologies	No	No	Articles
Zhang et al. [53]	China	Assessment of significant mineral security	Yes	No	Fuzzy AHP,
Prasad et al. [54]	-	Sustainability parameters rank in the mining sector	Yes	No	TOPSIS, MOORA, SAW, Delphi
Govindan et al. [55]	İndia	Assessment of the drives of CSR in the mining sector	Yes	Yes	F-DEMATEL
Ortiz-Barrios et al. [56]	-	Sustainable supplier choice of forklift filter	Yes	Yes	F-AHP, F-DEMATEL
Poormirzaee et al. [57]	İran	Prioritization of smart mining strategies	Yes	Yes	Z-number, F-VIKOR

Table 1. Continued.

Source	Location	Focus	GDM	SA	Methodology
Kusi-Sarpong et al. [58]	-	GSCP assessment	Yes	No	FRTOPSIS
Wang et al. [59]	Global	Lithium mining project assessment	Yes	No	AHP, DEA
Xu and Dong [60]	China	Coal to chemical sector diagnosis	Yes	No	SWOT, DEMATEL, ANP
Sivakumar et al. [61]	-	Green vendor assessment and choice	Yes	No	AHP, Taguchi loss function
Wang et al. [62]	China, Sub-saharan Africa	Assessing Chinese investment strategies in africa	Yes	No	VIKOR
Hosseini et al. [63]	Nigeria	Mining 4.0 strategies ranking	Yes	No	FCM, F-CoCoSo
Banda [64]	Zambia	Assessment challenges in the artisanak mining sector	Yes	No	DEMATEL
Our study	Africa	Assessing the challenges facing mining sector and find out the most critical ones	Yes	Yes	FullEX

Note: AHP-Analytic Hierarchy Process; ANP- Analytic Network Process; ARAS- Additive Ratio ASsessment; BWM- Best Worst Method; CA-Comparative Analysis; COPRAS- Complex Proportional Assessment; CoCoSo- Combined Compromise Solution; DEA- Data envelopment analysis; DEMATEL- Decision Making Trial and Evaluation Laboratory; FCM- Fuzzy Cognitive Map; GDM- Group Decision Making; GRA-Grey Relational Analysis; MOORA- Multi-Objective Optimization on the basis of Ratio Analysis; OCRA- Operational Competitiveness Rating; PROMETHEE- Preference Ranking Organization Method for Enrichment Evaluation; SAW- Simple Additive Weighting; SWOT- Strengths, Weaknesses, Opportunities, Threats; TODIM- An Acronym in Portuguese of Interactive and Multicriteria Decision Making; TOPSIS-Technique for Order Preference by Similarity to Ideal Solution; VIKOR- Vlsekriterijumska Optimizacija I KOmpromisno Resenje.

As can be seen from *Table 1*, our study applied the FullEX approach for the first time in the literature review to assess and evaluate the challenges facing the mining sector in Africa. The applied approach differentiates itself from previous MCDM based on the consideration of two critical aspects that are important for accuracy in the decision-making: Years of Experience (YE) and educational level of the experts.

3 | FullEX Approach

The FullEX method, developed by Bošković et al. [21], offers a unique way to assess decision-making criteria using expert opinions, considering their education and experience. It involves two stages as can be seen in the flowchart of our methodology in *Fig. 1*.

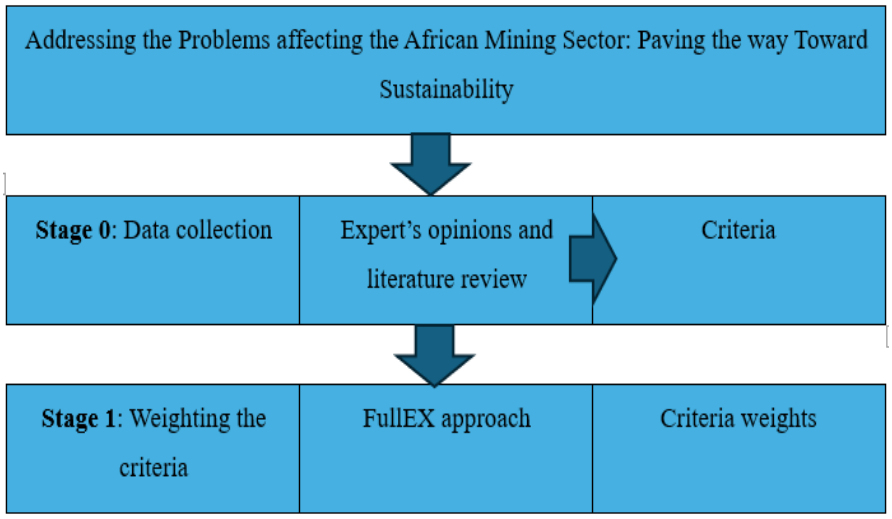

Fig. 1. Flowchart of the methodology.

Step 1. The establishment of input data matrix (*Table A1* in appendix). Fuller's method evaluates criteria importance through paired comparisons, with experts selecting the more significant criterion in each pair. They indicate their preference for one criterion over another.

Step 2. Computation of expert's recognition. The triangular form arises from gradual criterion comparison, excluding the previously compared criterion in each step. Expert reputations are calculated based on competence level (L_i), considering the two distinct parameters.

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

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

Step 3. Normalization of the input-data matrix. Once the input data matrix is ready, the normalization process begins using the technique described in *Eq. (3)*, (*Table A2* in the appendix).

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

Step 4. Obtention of the expert-weighted normalized input-data matrix. In this phase, the normalized input data is multiplied by the experts' significance, as in Step 2 using *Eq. (4)* (*Table A3* in the appendix).

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

Step 5. Identify an optimal value for each criterion. This step aims to ascertain the optimal value ($V_{j\,max}$) for each criterion within columns. It is computed using *Eq. (5)* (*Table A4* in the appendix).

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

Step 6. Obtention of the optimal decision-making matrix. This step involves dividing each element in the expert-weighted normalized matrix by its equivalent optimal value ($V_{j\,max}$), using *Eq. (6)* (*Table A5* in the appendix).

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

Step 7. Aggregate the values column-wise in the optimal decision-making matrix.

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

Step 8. Application of the final rank. In this phase, the importance of criteria (F_j) is determined as follows:

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

Step 9. Computation of the consistency index. To ensure reliability in subjective methods like FullEX, while AHP relies on established inconsistency rates, FullEX adopts a different approach [21]. It involves a second round of interviews where experts assign percentage importance scores to each criterion, ensuring a cumulative sum of 100%. Comparing these results with initial FullEX weights determines the consistency index (CI) using *Eq. (9)*.

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

A CI below 0.1 indicates satisfactory consistency, signifying reliable findings. Conversely, if the CI exceeds this threshold, experts should reassess the criteria assessment process.

4 | Application

A study was conducted to evaluate the effectiveness of the FullEX technique in analyzing challenges within the African mining sector. The main aim was to evaluate and prioritize these challenges. Initially, the study formed an expert panel consisting of five individuals with extensive experience in mining, as detailed in *Table 2*. Experts were invited to provide their judgments on the severity of challenges facing the mining sector in Africa. Eleven challenges were identified through an extensive literature review and validated by expert opinions, confirming that these challenges are prevalent in African countries with a mining sector. These challenges are shown in *Table 3*. As indicated in the FullEX approach two parameters were very important: experience and educational level (1) Ph.D., 2) Master, and 3) Bachelor).

Table 2. Background information of experts.

Experts (Es)	Professional Role	Gender	YE	Education Degree
E_1	Practionner	Male	22	3
E_2	Associate professor	Female	8	1
E_3	Manager	Male	7	2
E_4	Manager	Female	12	2
E_5	Full professor	Male	6	1

Table 3. Mining sector related challenges in Africa.

Criteria	References
Decline or exhaustion of mineral deposits due to over-exploitation (C1)	[65]–[68]
Poor number of skilled labour (C2)	
Lack of important mineral deposits in some countries (C3)	
Poor capital (C4)	
Poor infrastructure system (C5)	
Competition with others sectors for water supply (C6)	
Severe problem of constant power supply (C7)	
Poor conditions of workers in the mining area (C8)	
Political problems (C9)	
Problems of local market (C10)	
Problems of food supply in some countries (C11)	

Step 1. Experts use Fuller's triangle principle to evaluate two criteria and designate the superior one based on their judgment. This establishes the input data matrix, a crucial initial step for assessing criteria importance further. After the experts completed their assessment, the input data matrix was constructed and presented in *Table 4*.

Table 4. Input-data matrix.

Experts/Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
E_1	3	4	7	4	3	9	1	5	9	5	5
E_2	6	9	4	1	1	8	5	10	7	3	1
E_3	3	7	6	7	5	6	5	5	9	1	1
E_4	6	2	9	0	3	7	6	1	10	4	7
E_5	5	6	4	6	4	5	6	4	9	5	1
Sum (E1 to E5)	23	28	30	18	16	35	23	25	44	18	15

Step 2. Once the initial input data matrix is formulated, the expert assessment follows.

Steps 3 and 4. The input data is normalized using the expert weighted matrix through *Eq. (6)* and *Eq. (7)*, with results displayed in *Tables 5* and *6*.

Table 5. Normalized input-data matrix.

Experts/Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
E_1	0.130	0.143	0.233	0.222	0.187	0.257	0.043	0.200	0.204	0.277	0.333
E_2	0.261	0.321	0.133	0.055	0.062	0.228	0.217	0.400	0.159	0.166	0.066
E_3	0.130	0.250	0.200	0.388	0.312	0.171	0.217	0.200	0.204	0.055	0.066
E_4	0.261	0.071	0.300	0.000	0.187	0.200	0.260	0.400	0.227	0.222	0.466
E_5	0.217	0.214	0.133	0.333	0.250	0.142	0.260	0.160	0.204	0.277	0.066

Steps 5 and 6. The optimal decision-making matrix (*Table 7*) is derived by dividing each element of the expert-weighted normalized input data matrix by its corresponding optimal value (V_{jmax}).

Table 6. Expert-weighted normalized input-data matrix.

Experts/Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
E_1	0.051	0.056	0.091	0.087	0.073	0.100	0.017	0.078	0.079	0.109	0.130
E_2	0.037	0.045	0.019	0.008	0.008	0.032	0.031	0.056	0.022	0.023	0.009
E_3	0.018	0.035	0.028	0.055	0.043	0.024	0.031	0.028	0.029	0.008	0.009
E_4	0.057	0.016	0.066	0.000	0.041	0.044	0.057	0.008	0.049	0.049	0.102
E_5	0.024	0.023	0.015	0.037	0.027	0.016	0.029	0.018	0.022	0.030	0.007
V_{jmax}	0.057	0.056	0.091	0.087	0.073	0.100	0.057	0.078	0.079	0.109	0.130

Table 7. Optimal decision-making matrix.

Experts/Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
E_1	0.892	1.000	1.000	1.000	1.000	1.000	0.298	1.000	1.000	1.000	1.000
E_2	0.642	0.809	0.205	0.090	0.120	0.320	0.536	0.719	0.280	0.216	0.072
E_3	0.321	0.629	0.308	0.629	0.599	0.240	0.536	0.360	0.360	0.072	0.072
E_4	1.000	0.280	0.720	0.000	0.560	0.436	1.000	0.112	0.622	0.448	0.784
E_5	0.416	0.420	0.160	0.420	0.373	0.155	0.500	0.224	0.280	0.280	0.056

Steps 7 and 8. The optimal decision-making matrix combines all values to compute the final criteria weights (F_j) using *Eq. (8)*, shown in *Fig. 2*.

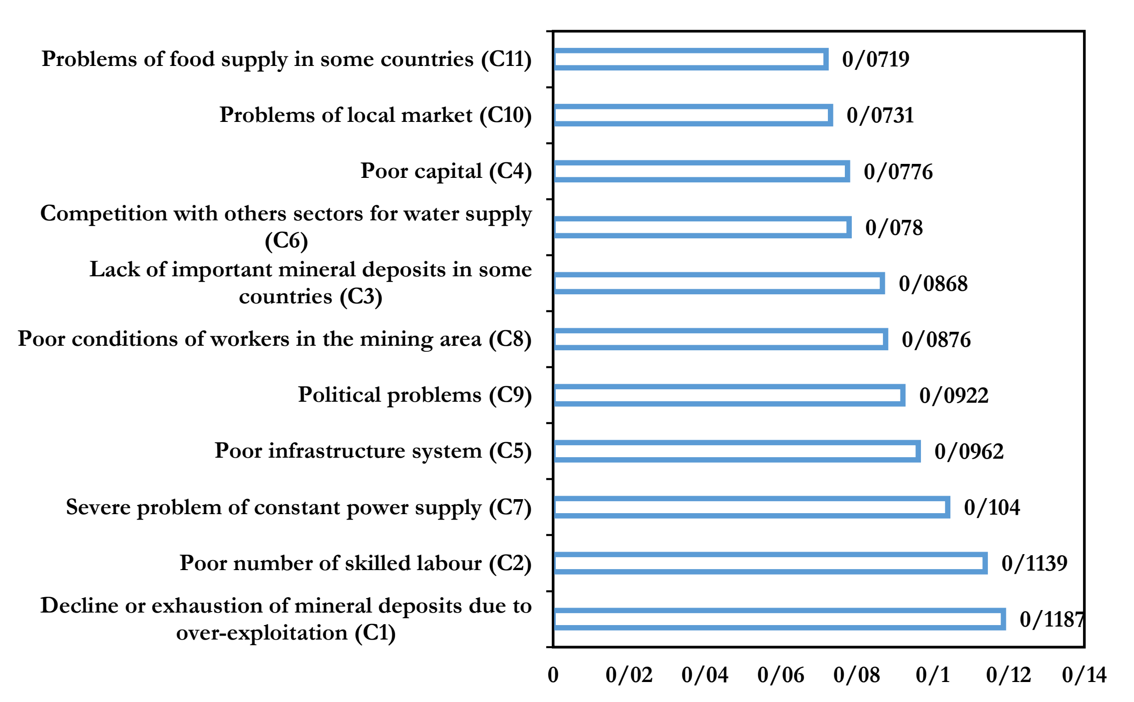

Fig. 2. Final rank of challenges related to the mining sector.

According to the FullEX approach results in *Fig. 2*, the top five critical challenges impacting the sustainability of the mining sector in Africa are: over-exploitation leading to decline or exhaustion of mineral deposits C1 (0.1187), poor number of skilled labor C2 (0.1139), severe problem of constant power supply C7 (0.1040), poor infrastructure system C5 (0.0962), and political problems-C9 (0.0922) based on the final values of the criteria. The rankings of other challenges are as follows: C8 (0.0876) > C3 (0.0868) > C6 (0.0780) > C4 (0.0776) > C10 (0.0731) > C11 (0.0719).

Step 9. To ensure the credibility of the results, another series of interviews with experts was carried out as last step to the FullEX technique to collect data on the percentage distribution (0-100%) of criteria importance. As depicted in *Table 8*, the findings reveal a consistency rate of less than 0.1 (CI = 0.088), indicating a satisfactory level of reliability.

Table 8. CI calculation.

	L_j	E_1	E_2	E_3	E_4	E_5	Average P_j	$\lvert F_j * 100 - P_j \rvert$	CI
C1	0.119	17	14	12	14	12	13.8	1.93	0.019
C2	0.114	15	13	12	13	11	12.8	1.41	0.014
C3	0.086	8	9	10	8	7	8.4	0.28	0.002
C4	0.077	7	8	6	8	7	7.2	0.56	0.005
C5	0.096	7	8	8	10	9	8.4	1.22	0.012
C6	0.078	6	7	8	10	9	8	0.20	0.002
C7	0.104	10	11	12	11	9	10.6	0.20	0.002
C8	0.087	8	7	7	7	8	7.4	1.36	0.013
C9	0.092	8	9	9	7	8	8.2	1.02	0.010
C10	0.073	7	7	9	7	10	8	0.69	0.006
C11	0.072	7	7	7	5	10	7.2	0.01	0.001
									0.088

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

5 | Sensitivity Analysis

The sensitivity analysis, crucial for assessing the robustness of the applied approach [69], consists of two phases aimed at evaluating the stability of the FullEX model. While the first stage consists of ranking the challenges faced by the mining sector via the expert's reputation variation, the second stage is related to the omission of the most experienced expert.

5.1 | Ranking of Criteria while Varying the Reputation of Experts

In this part, the model compares the criteria weights based on the variations in experts' reputations in three options: the first option (original) is both YE and educational degree (ED), the second option is only YE, and the third option is only educational degree. Results are presented in *Fig. 3*.

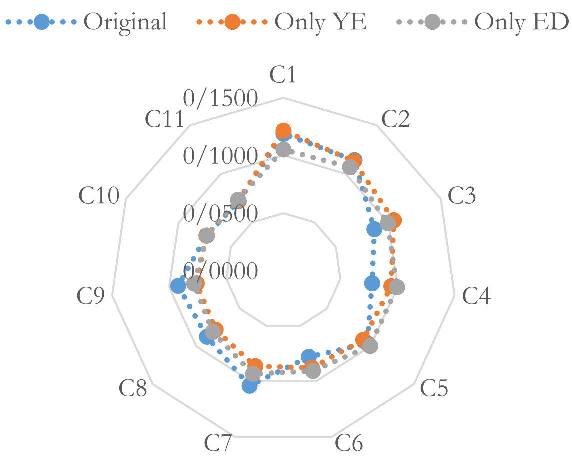

Fig. 3. First sensitivity analysis outcomes.

Fig. 3 highlights that utilizing both variables for experts' reputation calculation enhances model stability (shown by the blue line), whereas relying on just one variable can significantly impact the final criteria ranking. This underscores the importance of considering both variables, supporting the need for the application of FullEX approach, which is a recently developed criterion weighting technique.

5.2 | Omitting the most Experienced Expert during the Procedure

In the next step, the stability of the FullEX method is assessed by excluding the most experienced expert (E1) which has more YE (22) and high degree level (Ph. D-3) and one randomly selected expert (E5) with least experience (6 years) and educational level (Bachelor-1) for comparison. *Fig. 4* shows the results of this test.

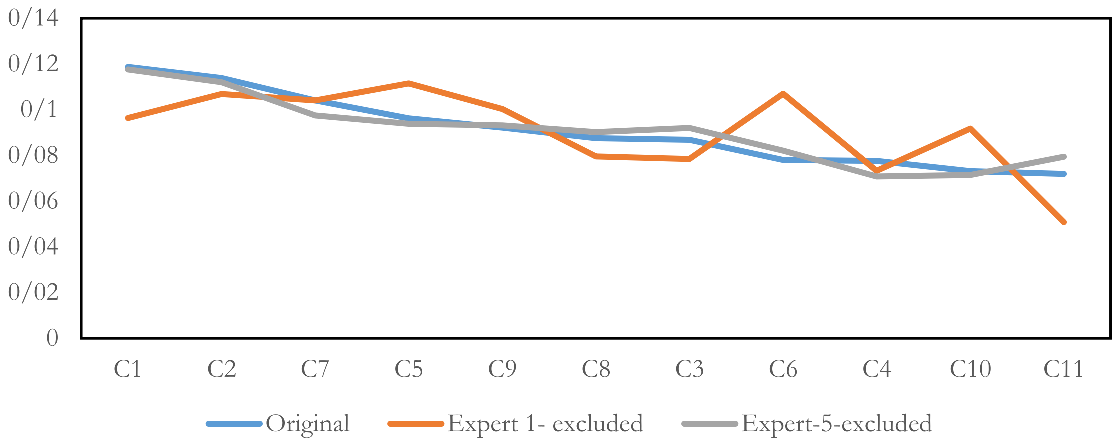

Fig. 4. Second sensitivity analysis outcome.

Analysis of *Fig. 4* reveals a distinct change in criteria ranking when excluding the most experienced expert (E1) from the decision-making process. Conversely, the criteria ranking remained largely unchanged when excluding a randomly selected expert (E5), whose importance did not rank among the highest. These findings emphasize the significant influence of an expert's reputation on the decision-making process.

6 | Discussion and Findings

Drawing on previous research and expert perspectives, it is evident that the mining sector in Africa grapples with several challenges that impede its long-term viability. To pinpoint the most pressing challenges, a FullEX methodology was employed to gauge their severity.

Our research findings emphasize the critical issue of mineral depletion through over-exploitation in Africa's mining sector. This is consistent with the study of Pedersen et al. [66], who highlight mining's significant economic contribution to African countries. They noted that dwindling mineral reserves can lead to revenue decline and job loss, impacting both economic growth and social stability. Furthermore, the decline in mining activity could hinder infrastructure development and exacerbate environmental degradation, posing long-term challenges for local communities. To tackle this issue, sustainable mining practices, responsible resource management, economic diversification, exploration support, governance enhancement, community engagement should be prioritized.

The shortage of skilled labor ranks as the sector's second most critical challenge, echoing Rubbers [68] findings on the crucial need for technical expertise in mining operations. Despite growing reliance on technology, the scarcity of skilled workers hampers the effective adoption of advanced technologies, impacting competitiveness and productivity. Safety concerns escalated due to this scarcity, leading to more accidents and damaging the sector's reputation. Additionally, African mining firms face global competitiveness challenges and struggle to attract investments and access markets due to the lack of skilled labor. Addressing this challenge requires investments in education, training, and tailored workforce development programs to align with sector needs.

A third major challenge for the African mining sector is the unreliability of power supply, as pointed out by Anfom et al. [65]. For instance, in 2014, the Democratic Republic of Congo (DRC) faced severe electricity shortages, stalling the development of new mines. This problem persists, prompting the country to seek energy imports from South Africa in 2017 to support its mining operations. Consistent power is crucial for efficient machinery operation in mining, but frequent outages disrupt activities, pushing companies to costly alternatives like diesel generators, which inflate expenses and diminish profitability. Addressing this problem necessitates modernizing power plants and expanding energy sources.

The inadequate infrastructure system ranks as the fourth most pressing issue confronting the African mining sector. This aligns with findings by Reed and Miranda [67], highlighting how deficient infrastructure, along with restricted access to ports and utilities like electricity, pose challenges for mining companies in conveying their products to market, leading to increased costs and decreased efficiency. Hence, enhancing logistics and transportation infrastructure is crucial to lowering costs, enhancing efficiency, and facilitating easier access to markets for mining companies.

Political problems rank as the fifth most prominent obstacle for the African mining sector, echoing the insights of Mvile and Bishoge [25]. Political instability and recurrent policy variations have introduced ambiguity for mining enterprises, affecting regulatory frameworks, taxation, and licensing procedures, thus discouraging investment, and obstructing long-term planning. Additionally, corruption remains pervasive in most African countries, influencing the mining sector through illegal practices, which inflate costs and undermine transparency and the rule of law. Moreover, some governments adopted resource nationalist policies, heightening state control over mineral resources and leading to tensions and disputes with mining enterprises over resource ownership. Political instability, including civil unrest and conflicts, further disrupts mining processes, creating risks to both company assets and workers and exacerbating investment reluctance. Addressing political challenges in Africa's mining sector requires transparency, community engagement, stability, regional cooperation, and anti-corruption measures. Collaboration among stakeholders is essential for success.

7 | Managerial implications

The conclusions drawn from this study provide valuable insights for policymakers in the mining sector. The research identifies five significant challenges faced by the African mining sector, including mineral depletion due to over-exploitation, a shortage of skilled labor, unreliable power supply, inadequate infrastructure, and political issues. These findings are particularly pertinent for policymakers aiming to foster a sustainable mining sector in Africa. The study offers practical recommendations, emphasizing the importance of embracing sustainable mining practices, responsible resource management, economic diversification, and support for exploration efforts. Additionally, it advocates for investments in education, training, and tailored workforce development initiatives to meet the evolving needs of the sector. Upgrading power infrastructure and diversifying energy sources are highlighted as critical steps toward sustainable growth in the mining sector. Furthermore, improving logistics and transportation networks is essential for reducing costs, enhancing efficiency, and enabling better market access for mining companies. Governments are encouraged to establish transparent regulatory frameworks, address corruption, and engage with local communities to ensure sustainable development in the mining sector. Implementing these measures can effectively address the challenges confronting the African mining sector and pave the way for its long-term sustainability.

8 | Conclusions, and future recommendations

This study presents the application of the FullEX technique to analyze challenges within the mining sector, offering valuable insights for policymakers. Notably, it evaluates these challenges considering experts' YE and educational backgrounds, laying a crucial foundation for decision-making. Focusing on an African case study, this research demonstrates the effectiveness of the technique in identifying critical challenges. The study underscores mineral depletion from over-exploitation, a shortage of skilled labor, unreliable power supply, insufficient infrastructure, and political problems as the most pressing concerns. Our research study, though impactful, has some limitations. Firstly, it was conducted at a continental level, overlooking Africa's diverse countries and regions. Future research could compare different regions or conduct country-level analyses for a comprehensive understanding. Secondly, the FullEX technique has limitations: outcomes may vary based on experts' expertise, and it is confined to crisp values. To address these, future studies should incorporate uncertainty and widen the scope of investigation. Future studies should consider rank the alternatives or strategies to overcome these challenges.

Author Contribution

Conceptualization: Mouhamed Bayane Bouraima; Methodology: Tafuteni Nicholaus Chusi, Mouhamed Bayane Bouraima, Stefan Jovčić; Software: Mouhamed Bayane Bouraima, Stefan Jovčić; Validation: Tafuteni Nicholaus Chusi, Mouhamed Bayane Bouraima, Stefan Jovčić; Formal analysis: Mouhamed Bayane Bouraima, Stefan Jovčić; Investigation: Morteza Yazdani, Violeta Doval Hernández; Resources: Tafuteni Nicholaus Chusi; Data maintenance: Mouhamed Bayane Bouraima, Stefan Jovčić; Writing-creating the initial design: Tafuteni Nicholaus Chusi , Mouhamed Bayane Bouraima; Writing-reviewing and editing: Tafuteni Nicholaus Chusi, Mouhamed Bayane Bouraima, Stefan Jovčić; Visualization: Morteza Yazdani; Monitoring: Morteza Yazdani, Violeta Doval Hernández; Project management: Tafuteni Nicholaus Chusi, Mouhamed Bayane Bouraima; Funding procurement: Tafuteni Nicholaus Chusi. All authors have read and agreed to the published version of the manuscript.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflict of interest.

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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 $E_1, E_2, \ldots, E_q$ are experts and q is the number of experts, $C_1, C_2, \ldots, C_p$ 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
E_1	r_{11}	r_{12}	…	r_{1j}	…	r_{1p}
E_1	r_{21}	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}
V_{jmax}	V_{1max}	V_{2max}	…	V_{jmax}	…	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}