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An Integrated Fuzzy SIWEC-RAWEC Approach for Assessing the Challenges and Solutions for Sustainable Development in Developing Countries

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ABSTRACT

Over the past thirty years, the global community has acknowledged the importance of transitioning from traditional development models to sustainable development (SD). This shift was driven by the realization that previous development approaches were unsustainable. While African governments have implemented several policies towards SD, there appears to be deep skepticism about whether it can achieve SD. This paper aims to identify challenges to SD in Africa and explore strategies to overcome these challenges. Data for this paper were collected through consultations with experts in the field. The key novelty of this study lies in the application of an integrated fuzzy simple weight calculation (F-SIWEC) and fuzzy ranking alternatives with weights of criterion (F-RAWEC). F-SIWEC determines the relative importance of criteria, and F-RAWEC is employed to rank the strategies. The findings of the study indicated that entrenched and widespread poverty and persistent international inequalities and external dependency are the most critical challenges to SD, while scaling up national social protection programs with conditional cash support remains the most appropriate strategy to overcome these challenges.

1. Introduction

Africa continues to face significant obstacles in achieving the sustained economic growth required to meaningfully reduce poverty [1]. Although gross domestic product (GDP) has grown at an average rate of about 3.4% over the past decade, this pace remains inadequate for meeting the continent's 2030 poverty-reduction goals. Economic performance is further constrained by heavy reliance on primary commodities, limited industrial diversification, and persistent institutional weaknesses [2]. While agricultural products make up a large share of exports, their contribution to GDP is relatively small, underscoring the need for broader economic diversification [3]. Despite progress in policy

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reforms, deep-rooted structural and institutional barriers still impede more inclusive and sustainable growth across the region [4].

In Africa, unemployment, poverty, and conflict continue to rise despite ongoing international aid efforts [5]. Rapid population growth is outpacing the expansion of infrastructure and social services, while the economy faces persistent challenges, including inadequate transport systems, low industrial output, and an underdeveloped agricultural sector. Poor urban planning and increasing rural-to-urban migration have resulted in overcrowded cities, prompting many citizens to migrate or seek asylum in more developed countries. Analysts are increasingly concerned about the continent's ability to manage its natural resource potential and the financial support it receives from international organizations. Rising external and domestic debt have further raised doubts about Africa's long-term economic prospects. At the same time, accelerating urbanization is making it more difficult to achieve sustainable development (SD) and effective urban governance. These challenges have produced significant environmental, cultural, and socio-economic impacts across many African countries [6]. Despite the continent's abundance of natural resources, poor management, particularly in rural areas, has fueled conflicts. Strengthening governance is therefore crucial for addressing urban development issues, managing resources responsibly, and supporting sustainable growth.

Numerous studies address the SD aspect in Africa. For example, Adebayo *et al.,* [7] adopted a common approach to explore how the quality of governance affects the SD under three socio-economic and environmental dimensions. Their study indicated how the quality of governance can enhance this development. Habimana Simbi *et al.,* [8] proposed a statistical model to explore the durable cooperation among economic growth, carbon dioxide (CO2), and various socio-economic parameters. Their results indicated how there is an increase of GDP with emissions of CO2. Azam Khan [9] analyzed two decades data to examine the impact of economic discomfort in SD for over 30 African countries. Their findings revealed how lack of jobs and inflation have a negative influence. Although previous studies have explored SD from economic, social, or environmental aspects, they did not completely assess the critical challenges to SD as well as appropriate strategies to overcome the challenges. Moreover, most of these studies have adopted empirical or statistical approaches. In recent years, many scholars have used the multi-criteria decision-making (MCDM) approaches because of their ability to deal with uncertainty [10, 11]. Zadeh [12] introduced a fuzzy set (FS) theory that has been later extended to surpass ambiguity in making decisions. In the intuitionistic fuzzy set (IFSs), Khan *et al.,* [13] presented both hesitation and non-membership but were restricted by a precise supplement restriction. In Neutrosophic sets (NSs), Yalçın *et al.,* [14] generalized IFSs by separately modeling truth, indeterminacy, and falsity degrees, providing higher flexibility in addressing incomplete and inconsistent information. Additionally, in the Hesitant fuzzy sets (HFSs), Bihari *et al.,* [15] apprehend situations where decision-makers hesitate among various possible memberships values, making them especially appropriate for group decision-making contexts. This evolution of fuzzy theory demonstrates a progressive effort to better align mathematical models with the complexity of real-world engineering decision problems.

In this study, the challenges to SD in Africa are assessed and effective strategies to overcome them are proposed. An integrated framework is adopted and comprises of the simple weight calculation (SIWEC) and ranking alternatives with weights of criterion (RAWEC) methods within a fuzzy environment. The integrated use of fuzzy SIWEC and fuzzy RAWEC represents an innovative methodological approach, as it explicitly captures uncertainty and expert subjectivity. This integrated approach, applied for the first time in this context, aims to enable a SD in the continent. Moreover, compared with traditional single-method or non-fuzzy decision-making techniques, the proposed framework enhances the clarity and robustness of strategy prioritization, leading to more reliable and transparent policy -relevant insights.

The remaining of the study is comprised of six sections: Section presents the literature review; Section 3 explains the problem definition; Section 4 presents the methodology; Section deals with the application, and Section 6 presents the conclusions and recommendations.

2. Literature review

2.1 Overview of approaches related to sustainable development

Extensive research on various indicators of SD has been conducted worldwide. For instance, De Guimarães *et al.,* [16] investigated how smart governance factors impact quality of life in smart cities. Their study identified key strategic drivers that can assist city leaders in crafting public policies and municipal actions involving the population to achieve the SDGs. Wei *et al.,* [17] examined the connections and conflicts between SDGs by using the SDG index and multidimensional poverty index. They also explored how poverty affects different groups and the factors driving these relationships. González García *et al.,* [18] explored SDG 4, emphasizing the importance of inclusive, quality education and lifelong learning as a core goal of the 2030 Agenda. Leal Filho *et al.,* [19] evaluated gender issues across all 16 SDGs, beyond SDG 5, and recommended prioritizing gender in SDG implementation. They emphasized the need for greater awareness and focus on best practices. Obaideen *et al.,* [20] demonstrated that wastewater management supports 11 out of 17 SDGs by improving water availability, global health, income for smallholders, waste-to-energy conversion, and reducing environmental impact. George *et al.,* [21] showed that digital technologies help tackle climate change and drive SD by enabling innovative solutions for complex societal issues. Saliu *et al.,* [22] emphasized the need for sustainable use of Africa's biodiversity to secure long-term ecosystem benefits for future generations. They noted that this requires effective institutional mechanisms, robust and enforced conservation policies, and ongoing data collection on biodiversity status. Akudugu and Ogwu [23] performed a bibliometric analysis of academic contributions to SD, finding that over 160,076 works were published between 1999 and 2022, predominantly consisting of research articles.

2.2 Applications and extensions of SIWEC approach

Since the introduction of SIWEC approach by Puška *et al.,* [24], various studies have used in different extensions. Badi *et al.,* [25] adopted it in a fuzzy environment to assess potential alternatives for strategic railway infrastructure planning in Libya. Their results indicated the strategy related to the development of coastal corridor as the most appropriate one. Katrancı *et al.,* [26] applied it for the choice of durable disposal technology and revealed how composting is considered the most appropriate technology. Şimşek *et al.,* [27] proposed an approach to pinpoint the most influential parameters to the procurement performance in the investment of solar energy projects. Their findings indicated how important strategy definition is during this process. Štilić *et al.,* [28] evaluated the ability to valorize tourist in botanical gardens and found that how these gardens playing an important role in varying tourist offerings. Yalçın *et al.,* [29] adopted a new integrated framework for choosing a transport policy in Northern Russia. Cao *et al.,* [30] assisted countries in the selection of transport policies on the Northern Sea route. Çizmecioğlu *et al.,* [31] adopted an integrated framework to evaluate the most appropriate investment strategies for enhancing the technologies related to digital twins. Puška *et al.,* [32] adopted a fuzzy rough technique for the choice of electric vehicles for small farming. Eti *et al.,* [33] assessed the main strategies for the adoption of renewable energy in localized supply chain networks. The application areas and methodological extensions of SIWEC approach in previous studies is indicated in Table 1.

Table 1
Application areas and methodological extensions of the SIWEC method

Authors	Objective	Methodology	Location
Puška *et al.,*[24]	Choice of sales channels for agricultural products	SIWEC, F-SIWEC	Bosnia and Herzegovina
Badi *et al.,* [25]	Strategic railway planning development	F-SIWEC, RAWEC	Libya
Katrancı *et al.,* [26]	Choice of sustainable waste disposal	F-SIWEC, F-RAWEC	Turkey
Şimşek et al., [27]	Assessment of purchasing procedure in solar energy project investment	SIWEC	-
Štilić *et al.,* [28]	Valorizing tourism in botanical gardens	F-SIWEC, TOPSIS	Croatia
Yalçın et *al.,* [29]	Choice of transportation policy	IF-SIWEC-ARLON	Northern Russia
Cao *et al.,* [30]	Implementing new techniques to green digital twins	SF-SIWEC-SAW	-
Çizmecioğlu et al., [31]	Strategic choice of competitive intelligence platforms	p, q-QOFN, SIWEC-MABAC	-
Puška *et al.,* [32]	Choice of electric cars	FR-SIWEC-RAWEC	-
Eti *et al.,* [33]	Strategy building for the adoption of renewable energy in localized supply chain networks	FF-SIWEC-EDAS	-

Note: ARLON- Alternative Ranking using two-step LOgarithmic Normalization; EDAS- Evaluation Based on Distance from Average Solution ; FF-Fermatean Fuzzy; FR-Fuzzy Rough; MABAC- Multi-Attributive Border Approximation area Comparison ; p, q-QOFN- p , q-quasirung orthopair fuzzy number; RAWEC- Ranking of Alternatives with Weights of Criterion; SAW - Simple Additive Weighting; TOPSIS- Technique for Order of Preference by Similarity to Ideal Solution.

2.3 Applications and extensions of RAWEC approach

Since the introduction of RAWEC technique by Puška *et al.,* [34], it has been applied in various fields. For instance, Nedeljković *et al.,* [35] adopted an integrated approach to determine the channel for selling cabbage for customers. Their study showed that good results are obtained with online sales. Puška *et al.,* [36] examined the implementation of renewable energy alternatives in the agriculture sector. Their findings revealed that solar energy is the most prioritized. Petrović *et al.,* [37] adopted a multi-criteria approach for sustainability assessment of distinct transportations modes in Europe. Demir and Ulusoy [38] implement a hybrid approach to explore which of the communications technologies are the most sustainable. Dündar and Karadağ [39] determined which of the 45 African countries is appropriate for a top cosmetic enterprise operating in Turkey. Mukhametzyanov and Pamucar [40] compared various MCDM approaches to find the most appropriate. Tešić *et al.,* [41] extends the RAWEC method under Fermatean fuzzy approach. Badi *et al.,* [42] presented an integrated technique to evaluate pharmacies through some service measures. The application domains and methodological extensions of the RAWEC approach in literature is indicated in Table 2.

Table 2
Application domains and methodological extensions of RAWEC method

Authors	Objective	Methodology	Location
Nedeljković *et al.,* [35]	Choice related to agricultural products sales	F-MEREC-RAWEC	Bosnia and Herzegovina
Puška *et al.,* [36]	Enhancing agricultural sustainability	DIWEC, F-RAWEC	Bosnia and Herzegovina
Petrović *et al.,* [37]	Sustainable transport mode evaluation	RAWEC	European Union
Demir and Ulusoy [38]	Sustainable communication technology assessment	F-WENSLO-RAWEC	-
Dündar and Karadağ [39]	Facility location choice for cosmetic enterprise	F-LBWA, I-RAWEC	Africa

Table 2
Application domains and methodological extensions of RAWEC method

Authors	Objective	Methodology	Location
Mukhametzyanov and Pamucar [40]	Comparative analysis of MCDM approaches	WSM, RS, MABAC, TOPSIS, MAIRCA, RAWEC	-
Tešić *et al.,* [41]	Improvement of MCDM approach for alternative ranking	FF-RAWEC	-
Badi *et al.,* [42]	Performance assessment of pharmacy service measures	DES, RAWEC	Libya

Note: DIWEC- Direct Weight Calculation; F-Fermatean; LBWA- Level Based Weight Assessment; MAIRCA- Multi Atributive Ideal-Real Comparative Analysis; MEREC- MEthod based on the Removal Effects of Criteria; RS- Ratio System approach; WENSLO- Weight by Envelope and Slope; WSM-Weighted Sum Model.

3. Problem definition

Table 3 outlines the challenges and solutions to SD in Africa based on experts' opinions and previous studies [43-47], each paired with targeted approaches designed to address and overcome these issues.

Table 3
Definition of evaluation criteria and strategic alternatives considered in the study

Criteria	References
Widespread ignorance, indifference, and denial of development realities (C1) High incidence of activities that undermine development efforts (C2) Entrenched and widespread poverty (C3)	[43-45]
Deep socio-economic divides within the country (C4) Persistent international inequalities and external dependency (C5) Increasing degradation of agricultural and production systems (C6)	Expert opinion
Alternative	
Scale up national social protection programs with conditional cash support (S1)	Expert opinion
Boost and broaden locally based value-addition industries (S2)	[47]
Roll out extensive agroforestry initiatives in degraded farmlands (S3)	[46]
Create community-led security and development groups to curb anti-development actions (S4)	Expert opinion

4. Methodology

An Integrated fuzzy SIWEC-RAWEC methodology is adopted to assess the challenges as well as the strategies to SD in Africa. The first stage is the fuzzy SIWEC application through following steps.

Step 1. The relative significance of each criterion is assessed by experts by attributing fuzzy linguistic variables and corresponding triangular memberships functions from Table 4 to represent the opinion of experts.

Table 4
Fuzzy linguistic variables and corresponding triangular memberships functions

Linguistic terms	Membership function
Absolutely bad (AB)	(1,1,1)
Very bad (VB)	(1,2,3)
Bad (B)	(2,3,4)
Medium-bad (MB)	(3,4,5)
Equal (E)	(4,56)
Medium-good (MG)	(5,6,7)
Good (G)	(6,7,8)
Extremely good (EG)	(7,8,9)
Absolutely good (AG)	(8,9,10)
Perfect (P)	(9,10,10)

Step 2. Experts offered linguistic evaluations which are transferred to triangular fuzzy numbers, which are defined as lower, middle, and upper bounds, thereby capturing the subjectivity in experts' opinions.

$$\tilde{x}_{ij} = \left(x_{ij}^{l}, x_{ij}^{m}, x_{ij}^{u}\right) \quad (1)$$

Step 3. The original fuzzy decision matrix is established according to fuzzy numbers obtained from the assessment of the experts. Each parameter represents the observed significance of a defined criterion, including the ambiguity captured through the evaluation of linguistics. This matrix represents the foundation for criteria weights computation using the F-SIWEC technique.

$$\begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ . & . & \cdots & . \\ . & . & \cdots & . \\ . & . & \cdots & . \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \quad (2)$$

Step 4. In this stage, there is a normalization of fuzzy values from the decision matrix by dividing them by the greater upper bound ($\max x_{ij}^{u}$) seen through all criteria and experts.

$$\tilde{n}_{ij} = \frac{x_{ij}^{l}}{\max x_{ij}^{u}}, \frac{x_{ij}^{m}}{\max x_{ij}^{u}}, \frac{x_{ij}^{u}}{\max x_{ij}^{u}} \quad (3)$$

Step 5. There is a calculation of standard deviation (std.dev_j) according to fuzzy numbers obtained from experts. This calculation represents consistency or variation in the criteria assessment, permitting the approach to highlight criteria where the judgments of experts indicate higher differentiation, an important characteristic of the F-SIWEC technique for apprehending the associated importance under ambiguity.

Step 6. A multiplication of normalized fuzzy rating by related values of standard deviation is made to reflect the normalized fuzzy rating.

$$\tilde{v}_{ij} = \tilde{n}_{ij} \times st.dev_j \quad (4)$$

Step 7. An aggregation of fuzzy weighted values for each parameter is made through the summation of weighted fuzzy assessment offered by all experts. This produced a general representation of each parameter's significance, allowing both independent expert opinions and the ambiguity captured in antecedent steps. The results are an integrated fuzzy weight for each parameter, which becomes a foundation for finding the final significance rankings.

$$\tilde{S}_{ij} = \sum_{j=1}^{n} \tilde{v}_j \quad (5)$$

Step 8. There is a division of each independent fuzzy value by total sum of all fuzzy values to acquire the normalized fuzzy weight for each parameter. During this procedure, it is important to guarantee that the lower bound is less than or equal to the middle value. This is possible only if the logical order of the fuzzy numbers is maintained.

$$\widetilde{w}_{ij} = \frac{S_{ij}^{l}}{\sum_{j=1}^{n} S_{ij}^{u}}, \frac{S_{ij}^{m}}{\sum_{j=1}^{n} S_{ij}^{m}}, \frac{S_{ij}^{u}}{\sum_{j=1}^{n} S_{ij}^{l}} \quad (6)$$

Step 9. There is a retention of the final fuzzy weights of each criterion through their fuzzy form or de-fuzzified into crisp values, based on the analytical necessities. In this study, there is a defuzzified of fuzzy weights by employing a suitable defuzzification approach to transfer each fuzzy number into a unique representative value.

$$w_{jdef} = \frac{w_{ij}^{l} + 4 \times w_{ij}^{m} + w_{ij}^{l}}{6} \quad (7)$$

The second stage is related to the application of the fuzzy RAWEC approach through the following steps:

Step 1. The decision-makers evaluate the alternative strategies using the linguistic variables in Table 4, which are later transformed into the associated fuzzy numbers to create individual fuzzy evaluation matrices. The numbers in the matrices are averaged to produce the averaged fuzzy decision matrix.

Step 2. Normalization calculated for both maximum and minimum normalization using the average fuzzy decision matrix. The benefit and cost criteria are normalized using Eq. s (8) and (9) respectively for the maximum normalization process. Minimum normalization is performed by normalizing the benefit and cost criteria using Eq. (10) and Eq. (11).

For maximum normalization

$$n_{ij} = \frac{x_{ij}^{l}}{\max x_j^u}, \frac{x_{ij}^{m}}{\max x_j^u}, \frac{x_{ij}^{u}}{\max x_j^u}, for\ benefit\ criteria \quad (8)$$

$$n_{ij} = \frac{\min x_j^l}{x_{ij}^{u}}, \frac{\min x_j^l}{x_{ij}^{m}}, \frac{\min x_j^l}{x_{ij}^{l}}, for\ cost\ criteria \quad (9)$$

For maximum normalization

$$n'_{ij} = \frac{\min x_j^l}{x_{ij}^{u}}, \frac{\min x_j^l}{x_{ij}^{m}}, \frac{\min x_j^l}{x_{ij}^{l}}, for\ benefit\ criteria \quad (10)$$

$$n'_{ij} = \frac{x_{ij}^{l}}{\max x_j^u}, \frac{x_{ij}^{m}}{\max x_j^u}, \frac{x_{ij}^{u}}{\max x_j^u}, for\ cost\ criteria \quad (11)$$

While x_j^{min} and x_j^{max} denotes the minimum and maximum value of a given criterion respectively.

Step 3. The criteria derived from the F-SEWIC method are applied to compute the weighted deviation values. Subsequently, the aggregate deviation for all alternatives is determined using Eq. s (12) and (13), respectively.

$$\tilde{v}_{ij} = \sum_{i=1}^{n} \tilde{w}_j.(1 - \tilde{n}_{ij}) \quad (12)$$

$$\widetilde{v'}_{ij} = \sum_{i=1}^{n} \tilde{w}_j.(1 - \widetilde{n'}_{ij}) \quad (13)$$

While $\tilde{w}_j$ refers to the weight of the criterion j.

Step 4. The fuzzy numbers are converted into crisp values through a defuzzification process, using Eq. s (14) and (15) respectively.

$$v_{ij} = \frac{v_i^l + 4v_i^m + v_i^u}{6} \quad (14)$$

$$v'_{ij} = \frac{v'^{l}_i + 4v'^{m}_i + v'^{u}_i}{6} \quad (15)$$

Step 5. The ranking of the alternatives is measured using Eq. (16).

$$Q_i = \frac{v'_{ij} - v_{ij}}{v'_{ij} + v_{ij}} \quad (16)$$

5. Application

In this study, an integrated SIWEC-RAWEC approach is adopted for assessing the challenges and solutions for SD in Africa. To collect data, four experts from both academia and industry have participated. The foundation of the fuzzy weight calculation is the linguistic decision-making matrix, obtained through the expert assessments for each criterion. This matrix, detailed in Table 5, captures the linguistic decision-making representing experts' qualitative assessments of alternatives with respect to each criterion.

Table 5
Linguistic decision-making represents experts' qualitative assessments of alternatives

	C1	C2	C3	C4	C5	C6
E1	B	MG	AG	EG	AG	G
E2	VB	MG	EG	G	EG	G
E3	B	B	AG	G	EG	MG
E4	B	B	AG	G	G	MG

To create the initial fuzzy decision matrix based on the expert judgments, it was necessary to first normalize the data in order to be able to compare it using a consistent scale basis. As stipulated in the F-SEWIC methodology, the normalization was undertaken by dividing each triangular fuzzy number by the highest upper-bound number for each of the expert assessments with respect to all criteria. This process reorganized the entire range of data into a [0, 1] normalized range. It is important to emphasize that this step maintains the proportional relationships of the original expert assessments, leaving the relative value of importance intact with no distortions in the results. The initial fuzzy decision matrix of expert assessment and the normalized, fuzzy decision matrix appears in Table 6 and this process is corrected for bias based on the scale of the number and establishes a strong consistent baseline for the subsequent stage of deriving weights for each criterion and therefore provides the direct input for stage 2 of the process. To illustrate the mathematical computational steps of the F-SIWEC method, a detailed numerical calculation for Criterion C1 is provided. First, the linguistic evaluations from the four experts (E1–E4) for C1, as presented in Table 5, are converted into TFNs using the conversion scale in Table 4, the TFNs are {(2,3,4),(1,2,3),(2,3,4),(2,3,4)}. These values are normalized by dividing each TFN by the maximum scale value (10), resulting in the set {(0.2,0.3,0.4),(0.1,0.2,0.3),(0.2,0.3,0.4),(0.2,0.3,0.4)}.

Table 6
Normalized fuzzy decision-making matrix derived from the linguistic evaluations

	C1	C2	C3	C4	C5	C6
E1	(0.2,0.3,0.4)	(0.5,0.6,0.7)	(0.8,0.9,1.0)	(0.7,0.8,0.9)	(0.8,0.9,1.0)	(0.6,0.7,0.8)
E2	(0.1,0.2,0.3)	(0.5,0.6,0.7)	(0.7,0.8,0.9)	(0.6,0.7,0.8)	(0.7,0.8,0.9)	(0.6,0.7,0.8)
E3	(0.2,0.3,0.4)	(0.2,0.3,0.4)	(0.8,0.9,1.0)	(0.6,0.7,0.8)	(0.7,0.8,0.9)	(0.5,0.6, 0.7)
E4	(0.2,0.3,0.4)	(0.2,0.3,0.4)	(0.8,0.9,1.0)	(0.6,0.7,0.8)	(0.6,0.7,0.8)	(0.5,0.6, 0.7)

Following normalization, the F-SEWIC method moves forward by incorporating the degree of consensus among the experts by taking the normalized fuzzy values and multiplying them by the standard deviation of each criterion. This action incorporates the variations in experts' opinion directly into the weighting process of the criteria, giving greater weight to criteria where disagreement was higher. This suggests that such criteria are either central to key debates or highly context dependent. In the next stage, the summed values are calculated. Table 7 shows the sum of the normalized fuzzy weight and expert's opinion variability in the weighting calculation. The sum of the weighted value produces the first level fuzzy weights for each criterion as quantified by the expert team while recognizing and representing embedded uncertainty. During this arithmetic stage, care was taken to maintain the three-step fuzzy number sequence that maintains that (lower bound ≤mode ≥ upper bound) is true for each fuzzy weight quantity produced. For instance, the standard deviation for C1 is calculated and it is approximately equal to (0.04,0.07,0.12). Following Eq. (5), the aggregated fuzzy weight is derived by incorporating this deviation. The final normalized fuzzy weight is then defuzzified using Eq. (7) to obtain a crisp value. This process yields the final weight for C1 as w C1 =0.075.

Table 7
Computation of fuzzy criterion importance values and final fuzzy weights obtained using fuzzy SIWEC method

Criterion	$\tilde{s}_{ij}$	$\tilde{w}_{ij}$
C1	(0.17,0.26,0.36)	(0.04,0.07,0.12)
C2	(0.33,0.42,0.52)	(0.08,0.12,0.17)
C3	(0.74,0.83,0.93)	(0.18,0.23,0.31)
C4	(0.59,0.69,0.78)	(0.14,0.19,0.26)
C5	(0.66,0.76,0.85)	(0.16,0.21,0.28)
C6	(0.52,0.62,0.71)	(0.13,0.17,0.24)

The resulting crisp weights establish the hierarchy of challenges in Figure 1, demonstrating a clear consensus among specialists. Entrenched and widespread poverty (C3) emerged as the most significant challenge, possessing the highest crisp weight of 0.0236, underscoring its critical role in impeding development interventions. Closely following are persistent international inequalities and external dependency (C5) at 0.2153. Conversely, widespread ignorance, indifference, and denial of development realities (C1) received the lowest weight (0.0753).

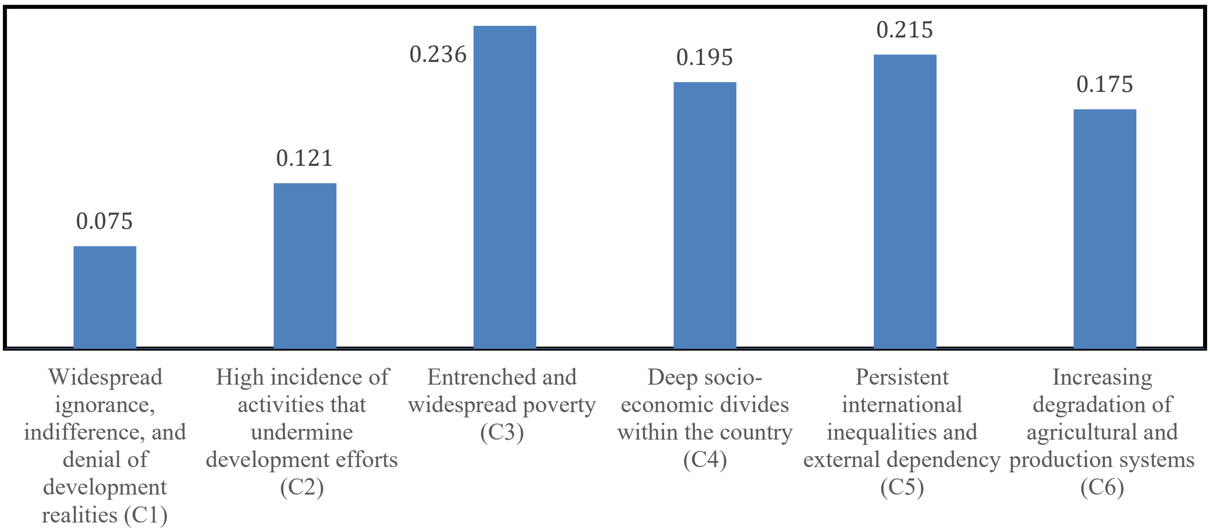

Fig. 1. Defuzzified value of the weights of achievements

Following the determination of criterion weights using the F-SIWEC methodology, the F-RAWEC approach was employed to evaluate the most sustainable strategy. In the initial phase of the F-RAWEC process, decision makers assessed the alternatives utilizing the linguistic variables from very high (VH) to very low (VL). These individual evaluations are compiled in Table 8. An average fuzzy decision matrix was subsequently constructed by aggregating the decision makers' ratings, with the results presented in Table 8.

Table 8
Initial linguistic decision matrices for alternatives under different strategic scenarios

Strategy 1	C1	C2	C3	C4	C5	C6
E1	M	H	L	ML	M	VH
E2	L	L	H	H	H	L
E3	L	M	VH	M	M	M
E4	L	MH	H	M	MH	M
Strategy 2	C1	C2	C3	C4	C5	C6
E1	H	VH	M	L	L	L
E2	MH	MH	M	H	H	MH
E3	L	M	MH	M	VH	M
E4	L	MH	M	M	H	M
Strategy 3	C1	C2	C3	C4	C5	C6
E1	VH	M	VH	MH	VH	MH
E2	H	MH	H	H	MH	M
E3	L	H	MH	M	M	H
E4	L	VH	MH	M	ML	H
Strategy 4	C1	C2	C3	C4	C5	C6
E1	VH	VH	L	L	ML	ML
E2	H	H	H	MH	H	H
E3	L	VH	VH	H	MH	H
E4	L	H	H	MH	MH	MH

Note: VL-Very Low, L-Low, ML-Medium Low, M-Medium, MH-Medium High, H-High, VH-Very High.

The fuzzy decision Matrix $\tilde{X}$ indicated in Table 9 derived by aggregating the raw linguistic ratings from the experts, establishes the performance data for the F-RAWEC ranking process. Each element $\tilde{x}_{ij}$ is a TFN that quantitatively represents the effectiveness of strategy S_i in mitigating criteria C_j. As all criteria are designated as cost type, a strategy with a lower TFN in this matrix is considered more effective. This matrix is subsequently normalized and combined with the F-SIWEC weights to determine the final strategy rank.

Table 9
Average fuzzy decision matrix obtained by aggregating expert evaluations for each strategy

Strategy	C1	C2	C3	C4	C5	C6
S1	(2.0,3.50,8.0)	(2.0,5.25,8.0)	(2.0,6.25,9.0)	(3.0,5.25,8.0)	(4.0,5.75,8.0)	(2.0,5.25,9.0)
S2	(2.0,4.75,8.0)	(4.0,6.25,9.0)	(4.0,5.25,7.0)	(2.0,5.00,8.0)	(2.0,6.25,9.0)	(2.0,4.75,7.0)
S3	(2.0,5.25,9.0)	(4.0,6.50,9.0)	(5.0,6.75,9.0)	(4.0,5.75,8.0)	(3.0,5.75,9.0)	(4.0,6.25,8.0)
S4	(2.0,5.25,9.0)	(6.0,7.50,9.0)	(2.0,6.25,9.0)	(2.0,5.50,8.0)	(3.0,5.75,8.0)	(3.0,6.00,8.0)

The normalized matrices from Table 10 serve as the critical function of rescaling the fuzzy decision matrix $\tilde{X}$ into two directly comparable measures, revealing each strategy's relative proximity to the optimal and worst-case fuzzy solutions. Since all criteria are designated as cost type, the performance goal is to achieve the lowest possible TFN rating. The $\tilde{n}_{ij}$ matrix measures the closeness of a strategy to the fuzzy anti-ideal solution (FAIS) (the worst performance), where a lower TFN is desired. Conversely, the $\widetilde{n'}_{ij}$ matrix measures the closeness to the fuzzy ideal solution (FIS) (the best performance), where a higher TFN is favorable. Analysis of these matrices immediately highlights performance differences: strategies S1 and S2 consistently exhibit lower $\tilde{n}_{ij}$ values and higher $\widetilde{n'}_{ij}$ values against key criteria like C5 (persistent international inequalities and external dependency), indicating superior efficiency in mitigating those challenges compared to S3 and S4. These normalized

TFNs are then multiplied by the F-SIWEC weights to quantify the final weighted deviations, which ultimately determine the relative ranking of the strategies.

Table 10
Normalized fuzzy matrices used for calculating deviations from criterion weights

S#	C1	C2	C3	C4	C5
$S1\ \tilde{n}_{ij}$	(0.22,0.67,4.00)	(0.22,0.70,1.33)	(0.22,0.93,1.80)	(0.38,0.91,2.00)	(0.44,0.92,2.00)
$S2\ \tilde{n}_{ij}$	(0.22,0.91,4.00)	(0.44,0.83,1.33)	(0.44,0.78,1.40)	(0.25,0.87,2.00)	(0.22,1.00,2.25)
$S3\ \tilde{n}_{ij}$	(0.22,1.00,4.50)	(0.44,0.87,1.33)	(0.56,1.00,1.80)	(0.50,1.00,2.00)	(0.33,0.92,2.25)
$S4\ \tilde{n}_{ij}$	(0.22,1.00,4.50)	(0.67,1.00,1.50)	(0.22,0.93,1.80)	(0.25,0.96,2.00)	(0.33,0.92,2.00)
$S1\ \widetilde{n'}_{ij}$	(0.25,1.00,4.00)	(0.25,1.00,4.00)	(0.29,0.84,3.50)	(0.25,0.95,2.67)	(0.25,1.00,2.00)
$S2\ \widetilde{n'}_{ij}$	(0.25,0.74,4.00)	(0.25,0.84,2.00)	(0.29,1.00,3.50)	(0.25,1.00,4.00)	(0.22,0.92,4.00)
$S3\ \widetilde{n'}_{ij}$	(0.22,0.67,4.00)	(0.22,0.81,2.00)	(0.22,0.78,1.40)	(0.25,0.87,2.00)	(0.22,1.00,2.67)
$S4\ \widetilde{n'}_{ij}$	(0.22,0.67,4.00)	(0.22,0.70,1.33)	(0.29,0.84,3.50)	(0.25,0.91,4.00)	(0.25,1.00,2.67)

The final ranking phase of the F-RAWEC method in Table 11 synthesized the complex fuzzy deviations into a single, crisp $Q_i$score, establishing the definitive hierarchy among the four intervention strategies. Since all criteria were defined as cost type, the ranking rule dictates that the alternative with the lowest Q_i score is the most preferred, as it achieves the optimal balance between minimizing the distance from the fuzzy ideal solution V_i' and maximizing the distance from the fuzzy anti-ideal solution V_i. Strategy S1 (Scale up national social protection programs with conditional cash support) emerged as the unequivocally optimal solution, securing Rank 1 with the lowest Q_i score of 0.514, driven by its favorable V_i' (0.301), which indicates the smallest weighted distance from the ideal (best) outcome. This result established a clear strategic hierarchy of S1>S2>S3>S4, with S4 (Create community-led security and development groups to curb anti-development actions) being the least suitable option, reflecting the highest Q_i score of 0.568. This final data-driven ranking provides a robust recommendation for prioritizing strategies focused on scaling up national social protection programs with conditional cash support (S1) over purely industrial growth (S4) in the context of the defined development challenges. From a policy perspective, these results offer clear guidance for governments and development agencies by identifying priority intervention areas, supporting evidence-based allocation of limited public resources, and informing the formulation of targeted social protection policies aimed at accelerating sustainable development outcomes in developing countries. The numerical values for Strategy S1 in Table 11 are obtained by first calculating the weighted deviations from the normalized fuzzy decision matrix. These deviations, representing the distance from the fuzzy anti-ideal solution (0.284) and the fuzzy ideal solution (0.301), are defuzzified using Eq. (14) and Eq. (15). To derive the final ranking score, Eq. (16) is applied, which calculates the ratio of the distance to the ideal solution relative to the total distance. Thus, the final score for S1 is computed as 0.301/(0.301+0.284)=0.514.

Table 11
Defuzzified deviation measures, final preferences values, and ranking of strategies

Strategy	V_i	V'_i	Q_i	Rank
S1	0.284	0.301	0.514	1
S2	0.232	0.266	0.534	2
S3	0.231	0.28	0.548	3
S4	0.257	0.338	0.568	4

Overall, the results reported in Table 11 demonstrate that socially focused interventions are more effective than growth-centered strategies for addressing SD challenges. The well-defined separation of Q_i values highlight the robustness of the fuzzy SIWEC–RAWEC framework, making it a valuable tool for policymakers when prioritizing SD strategies in developing countries.

6. Conclusions and future recommendations

In this study, an integrated fuzzy SIWEC-RAWEC methodology is adopted for assessing the challenges and solutions for sustainable development in developing countries. For that six challenges as well as four strategies were identified. To collect the data, four experts are involved. The results indicated that entrenched and widespread poverty and persistent international inequalities and external dependency are the most critical challenges to SD. The findings also indicated that scaling up national social protection programs with conditional cash support remains the most appropriate strategies to overcome these challenges.

From a methodological perspective, this study makes a clear contribution by demonstrating how the integrated fuzzy SIWEC–RAWEC approach can effectively handle uncertainty, expert subjectivity, and inter-criteria trade-offs when evaluating complex SD challenges, thereby extending the application of fuzzy multi-criteria decision-making methods to the SD domain. In practical terms, the proposed framework offers a structured and transparent tool that enables policymakers and development practitioners to systematically prioritize SD challenges and select high-impact strategies, directly linking methodological outcomes to actionable policy insights consistent with the challenges and solutions identified.

Despite the study's contributions, it has some limitations. First, a small number of experts participated. Second, since Africa is comprised of 54 countries, the findings cannot be generalized because every country may have specific characteristics. Future studies should consider increasing the number of experts, conducting studies at national or regional levels. In addition, future research should explore conceptual links between the broader SD challenges identified in this study and governance-and leadership related dimensions, as examined in Zimbabwe’s state-owned transport sector [48]. Moreover, the methodology proposed in this paper can be further extended using frameworks such as Neutrosophic Sets [49], Plithogenic Sets [50], hyper fuzzy Sets [51], super hyper fuzzy Sets [52], maximal entropy ordered weighted average (MEOWA) approach [53, 54], and linear programming approach [55].

Conflict of Interest

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