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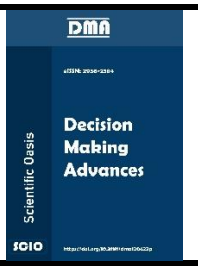

Strategies for Effective Regional Technical and Vocational Education and Training Integration via an Interval-Valued Spherical Fuzzy Approach

Simeng Dong [1], Ahmet Aytekin[2], Mouhamed Bayane Bouraima[1,*]

[1] International School of Technical Education, Sichuan University of Architectural Technology, Deyang, China
[2] Department of International Trade and Business, Faculty of Political Sciences, Samsun University, Samsun, Turkey

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ABSTRACT

This article explores the current challenges of the technical and vocational education and training (TVET) system in West African countries and identifies strategies for effective integration within the Economic Community of West African States (ECOWAS). The study proposed a decision-making approach including the interval-valued spherical fuzzy (IVSF) Stepwise Weight Assessment Ratio Analysis (SWARA)-the Nearest Solution to References (REF), marking the first application of these techniques in combination to investigate regional TVET system integration within ECOWAS. Furthermore, this study introduces the FF-REF into the decision-making literature for the first time. The findings indicated that while limited funding and fragmentation of TVET programs are the two most critical challenges to effective regional TVET integration, the harmonization of TVET programs is the most appropriate strategy to overcome them. This study contributes to the literature by providing a new integrated framework for assessing TVET system integration at the regional level. It also offers practical insights for regional institutions and policymakers by prioritizing key challenges and actionable strategies to strengthen cooperation and harmonization of TVET systems across ECOWAS member states.

1. Introduction

Technical and Vocational Education and Training (TVET) plays an essential role in developing skilled labor and easing the transition of young people from education to the workforce. Positioned at the intersection of education and the labor market, TVET equips learners with hands-on skills to enhance their competitiveness and address the challenges of workforce supply and demand imbalances [1]. In West Africa, the rapid growth of TVET initiatives and the increasing need for skilled professionals on the global stage underline its significance in fostering youth employment, personal development, and regional economic growth [2]. The global focus on skills development highlights its importance in addressing youth unemployment by ensuring that training programs align with

* *Corresponding author.*
E-mail address: mouba121286@yahoo.fr

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labor market requirements and promote equitable access to decent work opportunities [3]. In West Africa, industrial growth has led to a rising demand for a competent workforce, emphasizing the need for an effective TVET system to sustain economic advancement [4]. Regional efforts are underway to harmonize TVET programs, enabling workers to gain the necessary skills. However, significant barriers, such as limited alignment between training and labor market expectations, continue to hinder the successful integration of TVET graduates into the workforce [5].

The state of the TVET system in West Africa has been the subject of numerous studies, examining its challenges and opportunities both regionally and within specific countries. For instance, Odjo *et al.* [6] highlighted how quality assurance in TVET plays a critical role in driving economic growth, boosting labor market competitiveness, and meeting industry expectations, emphasizing its significance for regional development. Building on this, Osidipe [7] explored the connection between TVET and skills development, identifying strategies to align TVET with regional development priorities and goals. In Ghana, Odoom *et al.* [8] demonstrated how a strong TVET framework contributes to industrial and economic progress, reinforcing the broader idea that technical and vocational education is key to achieving higher living standards. This theme is echoed in Nigeria, where Ayonmike *et al.* [9] investigated the barriers to delivering quality TVET programs in tertiary institutions and proposed solutions to enhance their effectiveness. Harris [10] examined Sierra Leone's post-conflict context, revealing how structural factors have shaped public perceptions of TVET, contributing to its diminished appeal. Meanwhile, Nouatin *et al.* [11] provided a detailed exploration of Benin's TVET landscape, offering insights into both formal and non-formal programs, their stakeholders, and institutional structures. Although various studies have looked into the challenges of TVET in West Africa, none have successfully pinpointed the key barriers or prioritized actionable strategies. The research of Odjo [12] stands out for its mixed-methods approach, which explores the integration of TVET systems within the Economic Community of West African States (ECOWAS). However, it does not effectively identify the most critical challenges or offer viable solutions. To address these issues, a strong managerial framework is needed for integrating TVET systems into ECOWAS, utilizing a multi-criteria decision-making (MCDM) approach to enhance decision-making by considering various complex factors [13].

This paper seeks to examine the diverse challenges to integrating TVET systems in ECOWAS and propose effective strategies for addressing them. It introduces an approach that combines the SWARA method and the REF approach with an IVSF framework. This innovative methodology, applied for the first time in this context, aims to identify the most appropriate strategies for TVET integration by assigning different weights to various criteria. In particular, this study clearly highlights the novelty of being the first application of the integrated IVSF–SWARA–REF framework to analyze and prioritize the challenges and strategies for regional TVET integration within the ECOWAS context, thereby contributing a new methodological perspective to decision-making studies under uncertainty.

Fuzzy sets (FSs) have become increasingly important in a variety of scientific domains since their introduction [14]. Expanding on this concept, Kutlu Gündoğdu and Kahraman [15] developed spherical fuzzy sets (SFSs), which articulate uncertainty more effectively. In addition to SFSs, various other extensions of fuzzy sets have been introduced to better apprehend various forms of uncertainty in the procedure of making decisions [16]. For instance, interval-valued fuzzy sets (IVFSs) permit the representation of membership degree as an interval rather than precise value, while intuitionistic fuzzy sets (IFSs) include both membership and non-membership degrees to model hesitation. Similarly, type-2 fuzzy sets (T2FSs) offer an additional layer of uncertainty by permitting the membership function itself to be fuzzy, and Fermatean fuzzy sets (FFSs) extend IF theory by providing a larger domain for modeling membership and non-membership relationships [17]. Interval-valued fuzzy sets (IVFSs) enhance this flexibility by enabling DMs to represent decisions using

ranges rather than fixed values [18]. This characteristic makes interval-valued spherical fuzzy sets (IVSFSs) particularly suitable for addressing uncertainty in linguistic evaluations. While SFSs require more space for membership values, the use of intervals significantly improves their capacity to manage uncertainty [19]. Additionally, IVSFSs overcome certain drawbacks of earlier fuzzy set models and better account for neutral hesitation [20], making them advantageous for capturing uncertainty through intervals instead of single points [21]. In summary, IVSFSs provides a robust framework for incorporating DM judgments into decision-making processes while effectively handling uncertainty. Therefore, integrating IVFSs with MCDM techniques allows a more adequate representation of the opinions of experts in complicated decision environments determined by hesitation and vagueness.

Criteria weighting methods are essential for evaluating and prioritizing factors based on decision-makers' insights. The Analytical Hierarchy Process (AHP) involves experts making pairwise comparisons and assigning values from one to nine to reflect each criterion's importance [22]. The Best Worst Method (BWM) offers a more efficient alternative, requiring fewer comparisons while achieving better results [23]. The Full Consistency Method (FUCOM) assesses importance but requires further validation in practice [24, 25]. In contrast, SWARA focuses on prioritizing only the most critical criteria [26]. Compared with other weighting techniques, SWARA allows experts to straightly reveal their choices in a stepwise manner, diminishing the number of comparisons and simplifying the assessment procedure. This benefit makes SWARA especially appropriate for studies incorporating expert-based evaluations and complicated socio-economic decisions situations. Therefore, this study employs the SWARA method for weighting criteria under IVSF environment.

Most methods fail to yield robust results when faced with changing option sets or data formats. The rank reversal problem refers to the change in the rank order of existing options as a result of an option set modification. TOPSIS, VIKOR, SAW, PROMETHEE, ELECTRE and AHP are popular methods, but all of them cause rank reversal problems [27]. At this point, REF appears out as an effective solution tool, allowing for the problem of rank reversal problem and the flexible assessment of the optimal solution [28-30]. Moreover, REF enables the evaluation of alternatives according to their distance from predefined reference values, which enhance the reliability and stability of the ranking results. This characteristic makes the approach particularly beneficial for decision-making issues where guaranteeing the consistency of ranking is crucial.

Various significant contributions to ECOWAS, scientific community, and society:

- Broad Applicability: In a variety of industries and other African regional economic blocks, the integrated strategy may handle complicated MCDM challenges.
- Integrated MCDM Methodology: By prioritizing ideas for successful TVET regional integration, the integrated MCDM Methodology improves academic literature.
- Awareness Raising: It highlights the main obstacles to TVET integration for ECOWAS officials and practitioners, as well as solutions.
- Decision-Making Tool: Scholars and professionals can use it as a useful tool to help them make well-informed judgments about TVET integration.

Five sections remained in our study as follows. Section 2 related to literature review, Section 3 presents the methodology, Section 4 is about the application, the discussion is presented in Section 5, while Section 6 provides the conclusions and future recommendations of the study.

2. Literature Review

TVET is vital for supporting economic growth, boosting employability, and providing practical skills, especially in developing countries. There has been a rise in research in recent years. For instance, Li and Pilz [31] analyzed policy transfer across VET, political economy, education, and HR management, identifying key parallels and differences. McGrath *et al.* [32] explored a recent VET

research approach, highlighting its role in advancing sustainable human development. Jayalath and Esichaikul [33] designed a blended eLearning model for TVET, incorporating gamification to boost learner motivation and success. Dahalan *et al.* [34] explored new trends within the VET sector. Igberaharha [35] conducted a study to enhance university-level TVET for Nigeria's sustainable growth and development. Adams and Baddianaah [36] examined TVET enrollment trends. Wudneh *et al.* [37] investigated CT practices, focusing on the roles of companies, TVET colleges, and trainers, and compared the perspectives of trainers and trainees to identify any significant. Muchira *et al.* [38] applied social cognitive career theory to assess the alignment of Kenya's TVET curricula with labor market needs and identified challenges in delivering practical, industry-driven programs. Kinega [39] used a quantitative approach to compare TVET practices in Tanzania and China. In the area of MCDM applications, Chairungruang *et al.* [40] proposed a framework for ranking digital vocational education, focusing on learner, teacher, curriculum, participation, and fundamentals using the MCDM method. Conejero *et al.* [41] classified Spain's TVET from 2009–2016 by integrating detailed data on graduates and their employment outcomes into a comprehensive database. Hong *et al.* [42] developed two models from TVET instructors and students. Xia [43] used a technique for teaching quality assessment. Gou [44] developed an intuitionistic fuzzy method in vocational colleges. Peng *et al.* [45] analyze measurement differences in higher vocational colleges in Zhejiang province.

3. Methodology

The problem will be solved utilizing the IVSF-SWARA-REF methodology. The next subsections will provide explanations of IVSF-SWARA and IVSF-REF [46-48].

3.1 The IVSF-SWARA methodology

The IVSF-SWARA method is carried out in nine steps, outlined as follows.

Step 1. The problem is assessed based on various criteria.

Step 2. Experts evaluate the criteria in order of importance using an IVSF set linguistic scale, which accommodates the uncertainty of real-world issues. The evaluation scale is displayed by Kutlu Gündoğdu and Kahraman [15].

Accordingly, $\tilde{\iota}_j^{(p)}$ denotes the IVSF importance value of j-th criterion, where $j = 1,2, \dots, n$; $p = 1, 2 \dots \dots, t$.

Step 3. After all experts provide their relative importance scores, the scores are averaged to combine their assessments. In this context, experts' evaluations are integrated and $\tilde{\iota}_j$ values are obtained as $\tilde{\iota}_j = \left(\left[\tilde{a}_j, \tilde{b}_j\right], \left[\tilde{c}_j, \tilde{d}_j\right], \left[\tilde{e}_j, \tilde{f}_j\right]\right)$.

Step 4. The positive score values are derived by applying the score function for IVSF weights.

$$\mathrm{s}_j = \mathcal{S}\left(\tilde{\iota}_j\right) + 1 \tag{1}$$

Step 5. The criteria are ranked according to their positive score values.

Step 6. The relative importance c_j is calculated by comparing the positive scores of criteria j and $j - 1$.

Step 7. Calculation of coefficient k_j.

$$k_j = \begin{cases} 1 & j = 1 \\ \mathrm{c}_j + 1 & j > 1 \end{cases} \tag{2}$$

Step 8. Unnormalized weights q_j determination.

$$q_j = \begin{cases} 1 & j = 1 \\ \dfrac{q_{j-1}}{\mathrm{k}_j} & j > 1 \end{cases} \tag{3}$$

Step 9. The unnormalized weights are normalized to obtain their relative weights.

$$w_j = \frac{q_j}{\sum_{j=1}^{n} q_k} \tag{4}$$

3.2 The IVSF-REF method

Five steps have characterized the IVSF-REF implementation process.

Step 10. Experts employ the linguistic terms listed in [15] to evaluate options based on their performance, desirability, or priority. Accordingly, $\tilde{x}_{ij}^{(p)}$ denotes the IVSF value of i-th option in j-th criterion, where $i = 1, \dots, m; j = 1,2, \dots, n; p = 1, 2 \dots \dots, t$.

Step 11. Experts' evaluations are integrated, and $\tilde{x}_{ij}$ values are obtained, where $\tilde{x}_{ij} = \left([\tilde{a}_{ij}, \tilde{b}_{ij}], [\tilde{c}_{ij}, \tilde{d}_{ij}], [\tilde{e}_{ij}, \tilde{f}_{ij}]\right)$.

Step 12. The IVSF reference value of each criterion is determined. The reference can be assigned as an IVSFN; $\tilde{x}_{rj} = \left([\tilde{a}_{rj}, \tilde{b}_{rj}], [\tilde{c}_{rj}, \tilde{d}_{rj}], [\tilde{e}_{rj}, \tilde{f}_{rj}]\right)$. On the other hand, the reference can be determined as an interval including a lower bound and an upper bound. In this context, the lower bound of the reference is denoted by $\tilde{x}_{rj}^{(L)} = \left([\tilde{a}_{rj}^{(L)}, \tilde{b}_{rj}^{(L)}], [\tilde{c}_{rj}^{(L)}, \tilde{d}_{rj}^{(L)}], [\tilde{e}_{rj}^{(L)}, \tilde{f}_{rj}^{(L)}]\right)$, while the upper bound is depicted by $\tilde{x}_{rj}^{(U)} = \left([\tilde{a}_{rj}^{(U)}, \tilde{b}_{rj}^{(U)}], [\tilde{c}_{rj}^{(U)}, \tilde{d}_{rj}^{(U)}], [\tilde{e}_{rj}^{(U)}, \tilde{f}_{rj}^{(U)}]\right)$.

Step 13. If the reference of j-th criterion is defined as an interval, Eq. (5) is used to calculate the distances between options and the reference. On the other hand, if the reference is a point, Eq. (6) is applied.

$$d_{(i,r)j} = \begin{cases} \frac{1}{4}\left(\begin{array}{l} \left|(\tilde{a}_{ij})^2 - (\tilde{a}_{rj}^{(U)})^2\right| + \left|(\tilde{b}_{ij})^2 - (\tilde{b}_{rj}^{(U)})^2\right| + \left|(c_{ij})^2 - (\tilde{c}_{rj}^{(U)})^2\right| + \\ \left|(\tilde{d}_{ij})^2 - (\tilde{d}_{rj}^{(U)})^2\right| + \left|(\tilde{e}_{ij})^2 - (\tilde{e}_{rj}^{(U)})^2\right| + \left|(\tilde{f}_{ij})^2 - (\tilde{f}_{rj}^{(U)})^2\right| \end{array}\right) & , \ \mathcal{S}(x_{ij}) > \mathcal{S}(\tilde{x}_{rj}^{(U)}) \\ 0 & , \ \mathcal{S}(\tilde{x}_{rj}^{(L)}) \le \mathcal{S}(x_{ij}) \le \mathcal{S}(\tilde{x}_{rj}^{(U)}) \\ \frac{1}{4}\left(\begin{array}{l} \left|(\tilde{a}_{ij})^2 - (\tilde{a}_{rj}^{(L)})^2\right| + \left|(\tilde{b}_{ij})^2 - (\tilde{b}_{rj}^{(L)})^2\right| + \left|(c_{ij})^2 - (\tilde{c}_{rj}^{(L)})^2\right| + \\ \left|(\tilde{d}_{ij})^2 - (\tilde{d}_{rj}^{(L)})^2\right| + \left|(\tilde{e}_{ij})^2 - (\tilde{e}_{rj}^{(L)})^2\right| + \left|(\tilde{f}_{ij})^2 - (\tilde{f}_{rj}^{(L)})^2\right| \end{array}\right) & , \ \mathcal{S}(x_{ij}) < \mathcal{S}(\tilde{x}_{rj}^{(L)}) \end{cases} \tag{5}$$

$$d_{(i,r)j} = \frac{1}{4}\left(\begin{array}{c} \left|(\tilde{a}_{ij})^2 - (\tilde{a}_{rj})^2\right| + \left|(\tilde{b}_{ij})^2 - (\tilde{b}_{rj})^2\right| + \\ \left|(c_{ij})^2 - (\tilde{c}_{rj})^2\right| + \left|(\tilde{d}_{ij})^2 - (\tilde{d}_{rj})^2\right| + \left|(\tilde{e}_{ij})^2 - (\tilde{e}_{rj})^2\right| + \left|(\tilde{f}_{ij})^2 - (\tilde{f}_{rj})^2\right| \end{array}\right) \tag{6}$$

Step 14. The weighted total distance of each option ξ_i is calculated using Eq. (7).

$$\xi_i = \sum_{j=1}^{n} w_j d_{(i,r)j} \tag{7}$$

Based on their ξ_i values, the options are ranked in ascending order.

4. Application

This study focuses on six core challenges impacting the integration of TVET in the ECOWAS region, alongside five proposed strategies. The challenges and strategies were drawn from existing research and enriched by expert insights. Consulting experts plays a crucial role in understanding complex issues, evaluating challenges, and identifying actionable strategies. These experts brought diverse qualifications, professional experience, and perspectives to the table. For this study, TVET experts from the ECOWAS region were selected based on substantial academic experience, a history of publishing high-quality TVET research, and a minimum of five years of professional expertise. Out of ten invited professionals, four agreed to participate. Their contributions were gathered through online consultations, providing valuable input that shaped the study's findings.

4.1 Challenges and strategies definition

Table 1 indicated various challenges along with strategies for TVET in ECOWAS [49-54].

Table 1
Criteria and alternatives definition.

Criteria	References
Outdated infrastructure and inadequate facilities (C1)	[12]
Quality and relevance of TVET programs (C2)	[49]
Limited funding (C3)	[50]
Gender disparities (C4) Shortage of qualified teachers or trainers (C5) Fragmentation of TVET systems (C6)	[51]
Alternatives	**References**
Promoting inclusivity and gender equality (S1)	[52]
Enhancement of quality and relevance (S2) Harmonization of TVET programs (S3)	[12]
Policy development and coordination (S4)	[53]
Capacity building and resource mobilization (S5)	[54]

4.1.1 Weight of criteria determination

Step 1. Assessment of six challenges to TVET in ECOWAS.

Step 2. Four experts assessed the challenges from Table A1 in Appendix to determine their respective weights.

Step 3. The linguistic terms from [15] are conveyed into mathematical expressions. Subsequently, experts' inputs are consolidated in Table A2, with equal weighting assigned to each expert.

Step 4. Table 2 presents the positive score values (s_j) for each criterion derived using the IVSF set framework. After experts assign their relative importance scores, their evaluations are aggregated through averaging to obtain a collective IVSF representation. The positive scores are then calculated using the IVSF score function, where higher values indicate greater importance and influence of a criterion in the decision-making process.

Table 2
Positive scores of criteria

	C1	C2	C3	C4	C5	C6
s_j	1.3678	0.7316	1.7209	0.3527	1.2312	1.5705

Step 5. The rank order of criteria is $C3 \succ C6 \succ C1 \succ C5 \succ C2 \succ C4$.

Step 6. Table 3 presents the relative importance values c_j of the criteria in the IVSF framework. As indicated in Step 6, these values are obtained by comparing the positive score of each criterion (j) with that of the preceding criterion (j−1).

Table 3
Criteria importance

	C3	C6	C1	C5	C2	C4
c_j	-	0.150	0.203	0.137	0.500	0.379

Step 7. Table 4 presents the coefficient values (k_j) for each criterion in the IVSF framework. According to Step 7, k_j is equal to 1 for the first criterion and calculated as k_j=

c_j+1 for the remaining criteria. These coefficients represent the adjusted importance of the criteria based on their relative importance values.

Table 4
Criteria coefficient

	C3	C6	C1	C5	C2	C4
k_j	1	1.150	1.203	1.136	1.499	1.378

Step 8. Table 5 presents the unnormalized weights (q_j) of the criteria in the IVSF framework. According to Step 8, the first criterion is assigned q_j =1, while the remaining weights are calculated using $q_j = q_j - 1/\ k_j$. These values represent the preliminary weights of the criteria before normalization.

Table 5
Criteria weight

	C3	C6	C1	C5	C2	C4
q_j	1	0.869	0.723	0.636	0.424	0.308

Step 9. Figure 1 indicated the final weights of challenges.

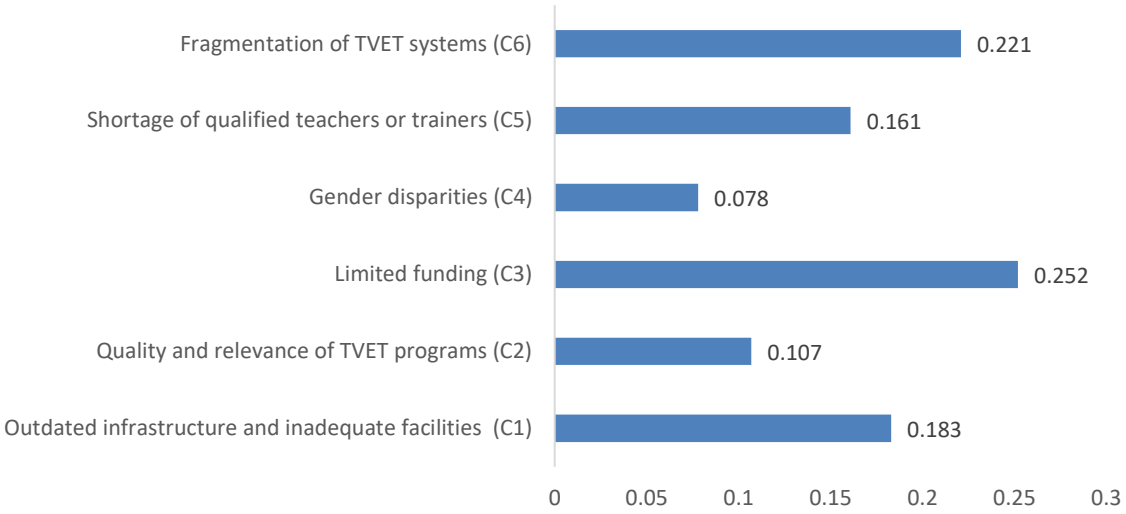


Fig. 1. Challenges related to effective regional TVET

As can be seen from Figure1, limited funding (C3) and fragmentation of TVET systems (C6) are the most critical challenges to TVET systems in the ECOWAS region.

4.1.2 Ranking the strategies to overcome the challenges to effective regional TVET system

The strategies are assessed against predefined criteria. The evaluations provided by the four experts are presented in Table A3. Table A4 displays the IVSF integrated decision matrix and the reference values.

In this study, the linguistic term “very low (VL)” was determined as the reference for C3, while the linguistic term “very high (VH)” was determined as the reference for the remaining criteria. The distances of the options from the local references are given in Table 6. In addition, the total distance value calculated using the criterion weights is also given in Table 6.

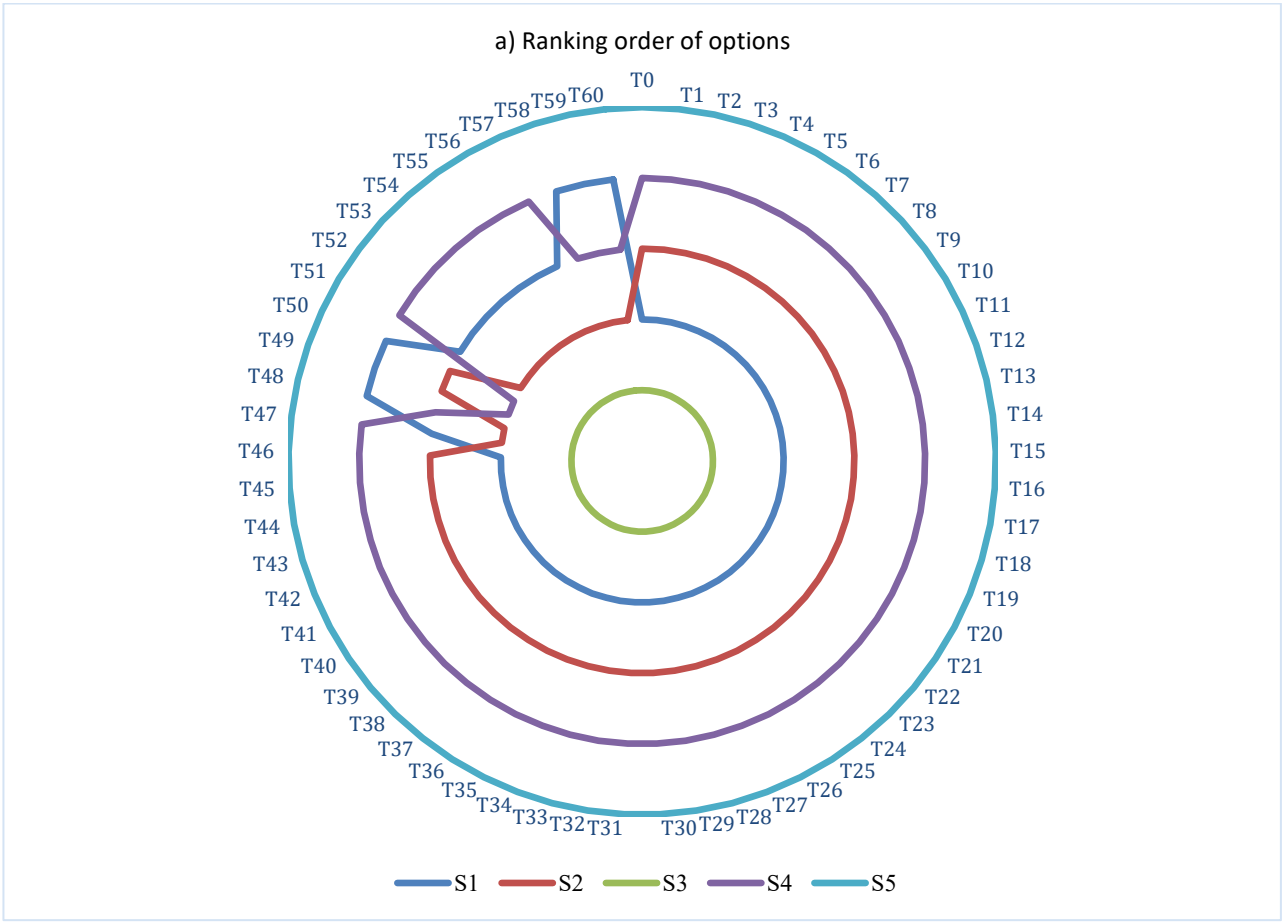
Table 6
Results of the IVSF-REF

	C1	C2	C3	C4	C5	C6	ξ_i	Ranking
S1	0.5806	0.0716	0.7395	0.7490	0.1254	0.0716	0.3945	2
S2	0.5309	0.0716	0.5823	0.7074	0.1610	0.3004	0.3984	3
S3	0.3962	0.0985	0.5412	0.5053	0.1076	0.1610	0.3114	1
S4	0.5309	0.4494	0.2916	0.7490	0.4876	0.3677	0.4359	4
S5	0.7074	0.7074	0.2916	0.0716	0.7490	0.7490	0.5688	5

As seen from Table 6, the final ranking is determined as S3 ≻ S1 ≻ S2 ≻ S4 ≻ S5. Accordingly, the Harmonization of TVET Programs (S3) took first place.

4.2 Sensitivity analysis and comparative analysis

In this section, how the methodology proposed in the study responds to changes in the criteria weight values, whether it causes a rank reversal problem, and comparisons with the results obtained with different methods will be carried out. In the first phase, each criterion's reduced weight coefficient was added to the weight coefficients of the remaining criteria. Accordingly, the weight coefficient of each criterion will be reduced by 10%, 20%, ..., 100% respectively and distributed equally to remaining criteria [55]. 60 distinctive scenarios (T1, T2,…,T60) were produced, each satisfying the constraint that the sum of the criteria weight coefficients equaled 1. Table A5 presents these scenarious with the criteria weight coefficients. Here, T0 represents the main findings of this study provied in Figure 1. Figure 2 depicts the findings of these scenarios.



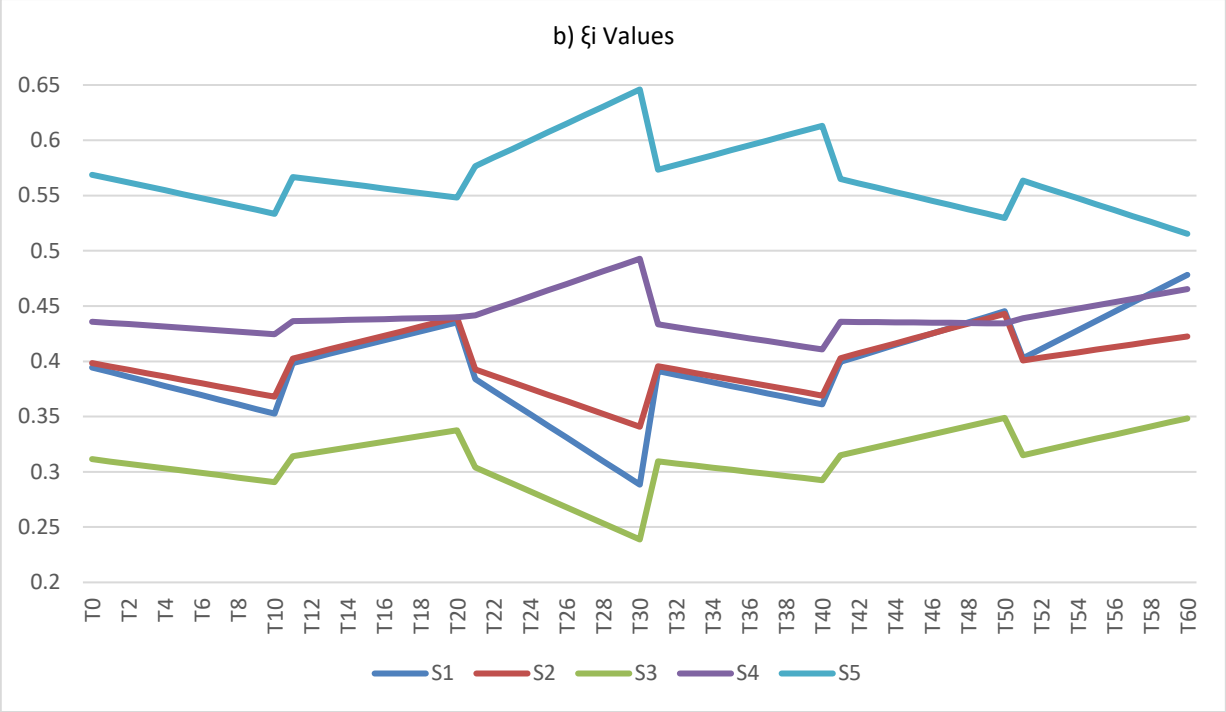


Fig. 2. The results of the weight coefficient fluctuations scenarios

The sensitivity of ranking solutions was tested across 60 different weighting scenarios (T1–T60), as shown in Figure 2. The results shown in Figure 2a indicate that rankings are highly stable, with the lowest pairwise Spearman rank correlation coefficient between scenarios being 0.60. Moreover, the best (S3) and the worst (S5) alternatives remain unchanged across all scenarios, indicating that variations in the criteria weights have only a limited impact on the overall ranking structure. Moreover, Figure 2b illustrates the variation of the weighted total distance (ξ_i) values of the alternatives across 60 weighting scenarios. Although the ξ_i values fluctuate slightly with changes in the criteria weights, the relative positions of the alternatives remain largely stable. In particular, S3 consistently has the lowest ξ_i values. It maintains the best rank, while S5 exhibits the highest ξ_i values across all scenarios, indicating that the overall ranking structure is robust to variations in criteria weights.

When the changes in ξ_i values and the rankings of the options are examined in Figure 2, it is seen that there is a reflection in the variation of criteria weights during the procedure. In addition, the fact that S3 is ranked first throughout all scenarios indicates a stable solution.

In the second stage, the problem will be solved using the renowned methods in the literature. These solutions will be compared with those obtained with the proposed methodology. In this context, Table 7 includes the results obtained with the IVSF-TOPSIS, IVSF-WASPAS, IVSF-VIKOR, and IVSF-CODAS methods.

Table 7
Results of different methods

Options	IVSF-REF	IVSF-TOPSIS	IVSF-VIKOR	IVSF-CODAS	IVSF-WASPAS
S1	2	3	4	3	2
S2	3	2	3	2	3
S3	1	1	1	1	1
S4	4	4	2	4	4
S5	5	5	5	5	5

The results in Table 7 indicate that S3 is ranked first and that there is a general agreement between the rankings of the methods. In the third stage, Table 8 assessed the issue related to rank reversal. In this context, one option at a each step will be removed from the problem, starting from the last one in the ranking obtained with the proposed methodology. Then, the rankings of the remaining options will be checked among themselves.

Table 8
The rank reversal examination results

		Removed Options		
Options	-	S5	S5, and S4	S5, S4, and S2
S1	2	2	2	2
S2	3	3	3	-
S3	1	1	1	1
S4	4	4	-	-
S5	5	-	-	-

The results in Table 8 show that the rankings among the remaining options did not change as a result of the options elimination process. Accordingly, there is no any notice related to rank reversal issue. As a result of the sensitivity analysis and comparisons, our proposed approach is robust and reliable.

5 Discussion

Experts and literature suggest that limited funding (C3) is the most pressing challenge to the effectiveness of regional TVET. Kemevor and Kassah [56] emphasized that financial constraints are impediments, which undermines the quality of vocational training. Similarly, Mack [57] pointed out that the economic difficulties faced by governments hinder their capacity to adequately fund TVET programs, impacting their administration and organizational efficiency. Isaac [58] further highlighted that the lack of sufficient funding exacerbates infrastructure challenges within TVET institutions, limiting the overall effectiveness of vocational education. To address this funding issue, regional funding mechanisms, such as a dedicated TVET fund, should be established, and public-private partnerships should be encouraged to attract additional resources. Harmonizing TVET policies across member states can help attract more investment and optimize resource allocation. Additionally, ECOWAS can collaborate with international organizations for both financial and technical support, explore innovative financing options, and enhance financial management within TVET institutions to ensure better utilization of available resources. Advocacy and awareness campaigns underscoring the role of TVET in economic growth can also help generate greater investment from governments and stakeholders. These findings suggest that, in practice, prioritizing funding interventions can directly improve the quality, accessibility, and sustainability of TVET programs across the ECOWAS region, guaranteeing that member states can implement harmonized policies effectively.

The fragmentation of TVET programs (C6) emerges as the second most critical challenge to the effectiveness of regional TVET, as highlighted by Odjo *et al.* [6], who noted that the lack of standardized curricula and certifications leads to inconsistencies in training quality, which limits the comparability of skills across member states. This lack of standardization impedes the free movement of skilled workers within the region, as qualifications are not universally recognized, thus undermining ECOWAS's objective of economic integration. Moreover, Osidipe [7] points out that the duplication of programs and misalignment with labor market needs results in inefficiencies, contributing to rising unemployment. Additionally, Odjo [12] emphasizes that fragmentation prevents collaboration and knowledge sharing among countries, further hindering regional progress.

Therefore, harmonizing TVET curricula and standardizing qualifications across ECOWAS is essential to address these challenges, enabling labor mobility and promoting regional economic growth. Practically, this means that polciymakers and TVET instituions should focus on aligning programs and certifications to regional labor market needs, which will facilitate employment opportunities and economic integration for graduates across member states.

This methodology tackles the key challenges to the effectiveness of regional TVET by emphasizing the most appropriate strategy which is the harmonization of TVET programs (S3), which ensures consistency and standardization across member states, thereby enhancing the quality and comparability of training. By establishing a unified curriculum and certification system, graduates from across the region will acquire similar skills, simplifying the process for employers to assess qualifications and improving labor mobility within ECOWAS. This standardization also promotes the mutual recognition of qualifications, enabling skilled workers to move freely across borders without facing obstacles due to varying educational standards. Moreover, harmonized TVET programs foster collaboration among countries, allowing them to pool resources, and share best practices. Ultimately, this approach strengthens regional integration and supports a skilled, mobile workforce. In practice, implementing this harmonization strategy can lead to a more competitive regional workforce, reduce skill gaps, and allow ECOWAS member states to collectively respond to labor market demands and economic development goals.

6 Conclusions and Future Recommendations

This study introduces a hybrid approach to pinpoint the challenges to effectiveness of regional TVET and identify the most appropriate strategies to tackle them. This hybrid approach offers reduced uncertainty and streamlined calculations compared to other methods. The finidngs of the study indicated that limited funding and the fragmentation of TVET programs are the most critical challenges to the TVET program at regional level, while the harmonization of TVET programs is the most appropriate strategy to overcome them.

From a practical perspective, these findings provide important guidance for policymakers and regional organizations responsible for TVET development. Addressing the issue of limited funding requires governments and regional bodies to strengthen financial support mechanisms and encourage partnerships with the private sector and international development agencies. In addition, the identification of fragmentation of TVET programs highlights the need for stronger coordination among member countries, including the development of common qualification frameworks, standardized curricula, and mutual recognition of skills across the region. The prioritization of harmonization of TVET programs as the most suitable strategy suggests that regional institutions should promote collaborative policy frameworks and capacity-building initiatives to ensure more coherent and effective implementation of TVET systems.

Despite some contributions through our study, it has been noticed there are some limitations. First, the number of experts is very limited. Second, the study is conducted at regional level, while the TVET situation is different from one country to another. In future, it is recommended to collect data from a larger and more diverse group of experts. Also, it is advisable to conduct the study at national level and conducted a comparative analysis between them. The study can be applied in other regional economic blocks since they have different situations. Our approach could be applied in other environments such as Fermatean fuzzy sets [59], interval-valued spherical fuzzy sets (IVSFs) [60]. Moreover, it can be implemented in studies related to digital technologies [61], education sector [62], and student pedagogical evaluation [63]. Future studies could also adopted the proposed IVSF-SWARA-REF framework to other fields related to circular economy, renewable energy sources, transportation decarbonization, and climate change impacts.

Appendix

Table A1
Challenges evaluation

Criteria/challenges	E-1	E-2	E-3	E-4
C1	HI	HI	SMI	SMI
C2	EI	SLI	LI	LI
C3	VHI	AMI	AMI	VHI
C4	LI	VLI	ALI	ALI
C5	HI	EI	EI	SMI
C6	AMI	HI	HI	HI

Table A2
Aggregated evaluations of criteria

Crit.	a	b	c	d	e	f
C1	0.6044	0.7052	0.2236	0.2739	0.0505	0.0751
C2	0.3206	0.3685	0.5687	0.6697	0.0611	0.1021
C3	0.8072	0.9141	0.1225	0.1732	0.0106	0.0310
C4	0.1439	0.1924	0.7704	0.8709	0.0172	0.0373
C5	0.5568	0.6387	0.3172	0.3881	0.0690	0.1127
C6	0.7205	0.8363	0.1682	0.2200	0.0262	0.0498

Table A3
Experts' evaluations on options

Option	Expert	C1	C2	C3	C4	C5	C6
S1	E1	M	VH	VH	L	VH	VH
S1	E2	L	H	H	VL	H	H
S1	E3	L	H	VH	VL	H	H
S1	E4	L	VH	H	VL	H	H
S2	E1	M	VH	H	L	H	H
S2	E2	M	H	M	VL	H	H
S2	E3	L	VH	M	L	M	M
S2	E4	L	H	H	VL	VH	M
S3	E1	H	VH	H	M	VH	VH
S3	E2	M	H	M	M	VH	H
S3	E3	L	M	L	VL	L	M
S3	E4	M	VH	H	M	H	H
S4	E1	M	M	M	L	M	H
S4	E2	M	M	L	VL	M	M
S4	E3	L	M	L	VL	L	M
S4	E4	L	M	L	VL	M	M
S5	E1	L	L	M	VH	L	L
S5	E2	VL	VL	L	H	VL	VL
S5	E3	L	L	L	VH	VL	VL
S5	E4	VL	VL	L	H	VL	VL

Table A4
The IVSF integrated decision matrix

	C1						C2					
Options	a	b	c	d	e	f	a	b	c	d	e	f
S1	0.2890	0.3596	0.5757	0.6777	0.2550	0.3344	0.7744	0.8908	0.1414	0.1936	0.1259	0.1971
S2	0.3536	0.4374	0.5099	0.6124	0.2949	0.3880	0.7744	0.8908	0.1414	0.1936	0.1259	0.1971
S3	0.4790	0.5759	0.3798	0.4653	0.2857	0.3686	0.7524	0.8763	0.1682	0.2303	0.1642	0.2287
S4	0.3536	0.4374	0.5099	0.6124	0.2949	0.3880	0.4500	0.5500	0.4000	0.5000	0.3500	0.4500
S5	0.1585	0.2067	0.7433	0.8441	0.1474	0.2078	0.1585	0.2067	0.7433	0.8441	0.1474	0.2078
Reference	0.8500	0.9500	0.1000	0.1500	0.0500	0.1500	0.8500	0.9500	0.1000	0.1500	0.0500	0.1500
	C3						C4					
Options	a	b	c	d	e	f	a	b	c	d	e	f
S1	0.7744	0.8908	0.1414	0.1936	0.1259	0.1971	0.1326	0.1807	0.7949	0.8955	0.1106	0.1817
S2	0.5669	0.6690	0.2828	0.3536	0.2762	0.3487	0.1585	0.2067	0.7433	0.8441	0.1474	0.2078
S3	0.5377	0.6366	0.3193	0.3913	0.2450	0.3131	0.3977	0.4910	0.4829	0.5870	0.3153	0.4190
S4	0.2890	0.3596	0.5757	0.6777	0.2550	0.3344	0.1326	0.1807	0.7949	0.8955	0.1106	0.1817
S5	0.2890	0.3596	0.5757	0.6777	0.2550	0.3344	0.7744	0.8908	0.1414	0.1936	0.1259	0.1971
Reference	0.1000	0.1500	0.8500	0.9500	0.0500	0.1500	0.8500	0.9500	0.1000	0.1500	0.0500	0.1500
	C5						C6					
Options	a	b	c	d	e	f	a	b	c	d	e	f
S1	0.7205	0.8363	0.1682	0.2200	0.1620	0.2232	0.7744	0.8908	0.1414	0.1936	0.1259	0.1971
S2	0.6919	0.8138	0.2000	0.2617	0.2000	0.2626	0.5669	0.6690	0.2828	0.3536	0.2762	0.3487
S3	0.7385	0.8661	0.1899	0.2549	0.1217	0.2064	0.6919	0.8138	0.2000	0.2617	0.2000	0.2626
S4	0.4058	0.4990	0.4516	0.5533	0.3256	0.4246	0.5141	0.6158	0.3364	0.4204	0.3131	0.3986
S5	0.1326	0.1807	0.7949	0.8955	0.1106	0.1817	0.1326	0.1807	0.7949	0.8955	0.1106	0.1817
Reference	0.8500	0.9500	0.1000	0.1500	0.0500	0.1500	0.8500	0.9500	0.1000	0.1500	0.0500	0.1500

Table A5
The scenarios for weight coefficient fluctuations.

Scenarios	C1	C2	C3	C4	C5	C6
T0	0.1825	0.1071	0.2526	0.0777	0.1606	0.2195
T1	0.1643	0.1107	0.2562	0.0813	0.1643	0.2232
T2	0.1460	0.1144	0.2599	0.0850	0.1679	0.2268
T3	0.1278	0.1180	0.2635	0.0886	0.1716	0.2305
T4	0.1095	0.1217	0.2672	0.0923	0.1752	0.2341
T5	0.0913	0.1253	0.2708	0.0959	0.1789	0.2378
T6	0.0730	0.1290	0.2745	0.0996	0.1825	0.2414
T7	0.0548	0.1327	0.2781	0.1032	0.1862	0.2451
T8	0.0365	0.1363	0.2818	0.1069	0.1898	0.2487
T9	0.0183	0.1400	0.2854	0.1105	0.1935	0.2524
T10	0.0000	0.1436	0.2891	0.1142	0.1971	0.2560
T11	0.1847	0.0964	0.2547	0.0798	0.1627	0.2217
T12	0.1868	0.0857	0.2568	0.0820	0.1649	0.2238
T13	0.1890	0.0750	0.2590	0.0841	0.1670	0.2260
T14	0.1911	0.0643	0.2611	0.0862	0.1692	0.2281
T15	0.1932	0.0535	0.2633	0.0884	0.1713	0.2302
T16	0.1954	0.0428	0.2654	0.0905	0.1735	0.2324
T17	0.1975	0.0321	0.2676	0.0927	0.1756	0.2345
T18	0.1997	0.0214	0.2697	0.0948	0.1777	0.2367
T19	0.2018	0.0107	0.2718	0.0969	0.1799	0.2388
T20	0.2040	0.0000	0.2740	0.0991	0.1820	0.2410
T21	0.1876	0.1121	0.2273	0.0827	0.1657	0.2246
T22	0.1926	0.1172	0.2020	0.0878	0.1707	0.2296

Table A5
Continued

Scenarios	C1	C2	C3	C4	C5	C6
T23	0.1977	0.1222	0.1768	0.0928	0.1758	0.2347
T24	0.2027	0.1273	0.1515	0.0979	0.1808	0.2397
T25	0.2078	0.1324	0.1263	0.1029	0.1859	0.2448
T26	0.2128	0.1374	0.1010	0.1080	0.1909	0.2498
T27	0.2179	0.1425	0.0758	0.1130	0.1960	0.2549
T28	0.2229	0.1475	0.0505	0.1181	0.2010	0.2599
T29	0.2280	0.1526	0.0253	0.1231	0.2061	0.2650
T30	0.2331	0.1576	0.0000	0.1282	0.2111	0.2701
T31	0.1841	0.1086	0.2541	0.0699	0.1622	0.2211
T32	0.1856	0.1102	0.2557	0.0621	0.1637	0.2226
T33	0.1872	0.1118	0.2572	0.0544	0.1653	0.2242
T34	0.1888	0.1133	0.2588	0.0466	0.1668	0.2258
T35	0.1903	0.1149	0.2603	0.0388	0.1684	0.2273
T36	0.1919	0.1164	0.2619	0.0311	0.1699	0.2289
T37	0.1934	0.1180	0.2634	0.0233	0.1715	0.2304
T38	0.1950	0.1195	0.2650	0.0155	0.1730	0.2320
T39	0.1965	0.1211	0.2665	0.0078	0.1746	0.2335
T40	0.1981	0.1226	0.2681	0.0000	0.1761	0.2351
T41	0.1858	0.1103	0.2558	0.0809	0.1445	0.2228
T42	0.1890	0.1135	0.2590	0.0841	0.1285	0.2260
T43	0.1922	0.1167	0.2622	0.0873	0.1124	0.2292
T44	0.1954	0.1199	0.2654	0.0905	0.0964	0.2324
T45	0.1986	0.1232	0.2686	0.0937	0.0803	0.2356
T46	0.2018	0.1264	0.2718	0.0969	0.0642	0.2388
T47	0.2050	0.1296	0.2750	0.1002	0.0482	0.2420
T48	0.2082	0.1328	0.2783	0.1034	0.0321	0.2452
T49	0.2114	0.1360	0.2815	0.1066	0.0161	0.2484
T50	0.2147	0.1392	0.2847	0.1098	0.0000	0.2517
T51	0.1869	0.1115	0.2569	0.0821	0.1650	0.1976
T52	0.1913	0.1159	0.2613	0.0864	0.1694	0.1756
T53	0.1957	0.1203	0.2657	0.0908	0.1738	0.1537
T54	0.2001	0.1247	0.2701	0.0952	0.1782	0.1317
T55	0.2045	0.1290	0.2745	0.0996	0.1826	0.1098
T56	0.2089	0.1334	0.2789	0.1040	0.1869	0.0878
T57	0.2133	0.1378	0.2833	0.1084	0.1913	0.0659
T58	0.2177	0.1422	0.2877	0.1128	0.1957	0.0439
T59	0.2221	0.1466	0.2921	0.1172	0.2001	0.0220
T60	0.2264	0.1510	0.2965	0.1216	0.2045	0.0000

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Conflicts of Interest
The authors declare no conflicts of interest.

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