Nonlinear Functional Analysis and Applications
Vol. 30, No. 4 (2025), pp. 1119-1139
ISSN: 1229-1595(print), 2466-0973(online)

https://doi.org/10.22771/nfaa.2025.30.04.09
http://nfaa.kyungnam.ac.kr/journal-nfaa

DEVELOPMENT OF TIVI: A NOVEL HYBRID METHOD INTEGRATING TOPSIS AND VIKOR FOR MULTI-CRITERIA DECISION MAKING

Vijaya Krishna Gembali[1], G V V Jagannadha Rao[2], Tejaswini Pradhan[3] and S. Hanumantha Rao[4]

[1]Department of Mathematics, Kalinga University, Chhattisgarh-492101, India
Assistant Professor, Department of Mathematics,
Sasi Institute of Technology and Engineering, Tadepalligudem, India
e-mail: vijayakrishna@sasi.ac.in

[2]Department of Mathematics, Faculty of Science & Technology, The ICFAI University,
Raipur, Chhattisgarh-490042, India
e-mail: gvvjagan1@gmail.com

[3]Department of Mathematics, Kalinga University, Raipur, Chhattisgarh-492101, India
e-mail: tejaswini.pradhan@kalingauniversity.ac.in

[4]Department of Mathematics & Statistics, Vignans Foundation in Science,
Technology and Research, Vadlamudi-522213, Andhra Pradesh, India
e-mail: vijayakrishna@sasi.ac.in

Abstract. The field of Multi-Criteria Decision Making (MCDM) constantly evolves to address the intricate challenges of decision-making across diverse sectors. Despite significant advancements, yet there remains a lack of a unified framework that leverages the strengths of both TOPSIS and VIKOR. This study introduces TOPSISVIKOR Integration (TIVI), a new hybrid MCDM method that combines TOPSISs ideal-solution approach with VIKORs compromise-ranking capability. TIVI is developed through a systematic methodology and applied to a case study on selecting smart forming technology. Results show strong positive correlations with TOPSIS and CODAS, along with high robustness and adaptability across different α-levels.

[0]Received May 19, 2025. Revised July 26, 2025. Accepted August 14, 2025.
[0]2020 Mathematics Subject Classification: 47H09, 54H25, 47H10.
[0]Keywords: TOPSIS-VIKOR integration(TIVI), techniques for order of preference by similarity to ideal solution(TOPSIS), Vlse Kriterijumska optimizacija I compromisno resenje(VIKOR), multi-criteria decision making(MCDM), hybrid method, decision analysis.
[0]Corresponding author: G V V. Jagannadha Rao(gvvjagan1@gmail.com).

1. Introduction

The realm of Multi-Criteria Decision Making (MCDM) has witnessed significant evolution over the years, adapting to the increasing complexity of decision-making scenarios across various sectors. At the heart of this evolution is the integration of robust MCDM techniques that enhance decision-making precision and applicability. Among the plethora of MCDM methods, Techniques for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Vlse Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR) have stood out for their ability to handle complex decision-making problems by approximating the ideal solution. The literature boasts a rich tapestry of applications and developments within the MCDM framework, including watershed management frameworks Ali et al. [1], sustainable assessment models for solar hydrogen production Mahmoud et al. [21], material handling equipment selection, supplier selection ([36]), and speech recognition product supplier selection ([34]). Furthermore, studies have extended to the banking performance evaluation in the Balkan countries ([4]), benchmarking in Indian service industries ([33]), electric vehicle charging station selection ([27]), hospital site selection ([38]), and the nuanced analysis of decision-making frameworks in neutrosophic soft sets ([26]).

Despite these advancements, the literature reveals gaps in developing a hybrid approach that seamlessly integrates the strengths of TOPSIS and VIKOR, particularly in creating a unified framework that leverages the comparative advantage and compromise ranking capabilities of both methods. The studies by Taherdoost and Madanchian [35], Hwang and Yoon [15], Opricovic and Tzeng [23], and DPrabha [25] highlight the individual strengths and application scenarios of TOPSIS and VIKOR but fall short of proposing an integrated approach that combines these methods' benefits. Moreover, the recent contributions in the field, including the works by Koaket al. [17] and Kumar [18], have introduced frameworks integrating VIKOR and TOPSIS with other decision-making tools, yet a comprehensive methodology that directly merges the core principles of TOPSIS and VIKOR into a singular, cohesive decision-making framework remains elusive.

This research paper aims to bridge these gaps by proposing the development of TIVI (TOPSIS-VIKOR Integration), a novel hybrid MCDM method that synergizes the TOPSIS and VIKOR techniques into a unified framework. The justification for selecting this research topic stems from the identified need for a method that combines the ideal solution approximation capability of TOPSIS with the compromise ranking proficiency of VIKOR, offering a more robust decision-making tool that can be applied across a wide range of decision-making scenarios.

In essence, the current work introduces TIVI as an innovative solution to the limitations of existing MCDM methods when applied independently. By integrating the TOPSIS and VIKOR methods, TIVI aims to enhance decision-making accuracy, flexibility, and comprehensiveness. This hybrid approach not only promises to contribute significantly to the MCDM literature but also to practical decision-making across various fields, by providing a tool that is both methodologically sound and practically applicable. In summary, TIVI emerges as a pioneering hybrid MCDM method, poised to set a new benchmark in the field of decision-making.

2. Basic preliminaries and definitions

The application of MCDM methods spans a broad spectrum of fields, evidencing their critical role in navigating complex decision-making landscapes. These methodologies facilitate the evaluation and selection of the optimal choice among alternatives by integrating and analyzing multiple criteria. This comprehensive review explores various MCDM techniques and their applications across different sectors, illustrating the depth and adaptability of these methods.

Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) are foundational in MCDM, allowing for the consideration of interdependencies among decision elements, a feature particularly relevant in complex systems ([30]). The TOPSIS is distinguished by its approach of identifying options closest to the ideal solution, thereby facilitating decisions with quantifiable and comparable criteria ([15]).

The Elimination and Choice Translating Reality (ELECTRE) method is utilized in scenarios where alternatives may be incomparable, employing outranking relations to guide decision-making, notably within environmental and public policy spheres ([29]). Similarly, the Preference Ranking Organization Method for Enrichment Evaluations (PROME THEE) and Geometrical Analysis for Interactive Aid (GAIA) offer a user-friendly approach to ranking alternatives, often applied in environmental impact assessments and financial evaluations ([3]).

Multi-Attribute Utility Theory (MAUT) assists in decision-making under uncertainty, maximizing expected utility in applications ranging from healthcare to investment decisions ([16]). Goal Programming (GP) focuses on minimizing deviation from predetermined goals, useful in resource allocation and project scheduling to harmonize various objectives ([6]).

The Additive Ratio Assessment (ARAS) method is noteworthy for its emphasis on maximizing efficiency ratios, proving beneficial in supply chain management and product selection Zavadskas and Turskis, [41]. Similarly, the

Evaluation Based on Distance from Average Solution (EDAS) ranks alternatives based on their proximity to an average solution, applicable in supplier selection and performance evaluations ([13]).

Techniques such as the Weighted Aggregated Sum Product Assessment (WASPAS), Grey Relational Analysis (GRA), Complex Proportional Assessment (COPRAS), and VIKOR focus on compromise solutions, catering to decisions in engineering and energy planning ([23]). The Best-Worst Method (BWM) and Decision-Making Trial and Evaluation Laboratory (DEMATEL) elucidate the relationships among criteria, aiding in complex scenarios like ecosystem management and organizational strategy ([12], [28]).

Moreover, Data Envelopment Analysis (DEA), Multi-Objective Optimization by Ratio Analysis (MOORA), and MULTI-MOORA facilitate efficiency and performance optimization, employed in educational, healthcare, and manufacturing sectors for benchmarking and improvement ([6], [41]).

These diverse MCDM methods, with their unique algorithms and philosophies, are tailored to a wide array of decision-making scenarios. From renewable energy selection and addressing sustainability challenges to material selection in engineering and policy formulation in education, MCDM techniques have underscored their utility in providing structured, rational, and transparent decision-making frameworks. The adaptability and efficiency of these methods in handling modern decision-making complexities ensure that the decisions made are informed, balanced, and aligned with overarching goals and constraints.

2.1. **Related works on TOPSIS and VIKOR.** The recent advancements in MCDM methodologies, particularly TOPSIS and VIKOR, underscore their significance in optimizing complex systems across various sectors. The summarized literature highlights innovative applications and enhancements of these methodologies.

Sharaf [31] introduces a novel approach integrating spherical fuzzy sets with TOPSIS and VIKOR, aimed at improving decision-making in the evaluation of hydrogen storage systems. This methodology addresses the challenges of uncertainty and fuzziness, showcasing the flexibility of MCDM techniques in complex decision environments ([31]). Similarly, Chen [7] employs spherical fuzzy sets in TOPSIS and VIKOR, validating their effectiveness in handling imprecise data within hydrogen storage evaluations ([7]).

Taherdoost and Madanchian[35] propose a compromising ranking technique that enhances decision-making processes by offering a nuanced approach to resolving conflicts and ranking alternatives ([35]). Amini et al. [2] integrates

TOPSIS, VIKOR, and DEA with belief structures under uncertainty, presenting a comprehensive evaluation method that enriches alternative ranking by accommodating various forms of uncertainty ([2]).

Uzun and Ozsahin [37] explore Vlse Criterion Optimization and Compromise Solution (VIKOR), emphasizing its flexibility in decision-making scenarios across different contexts ([37]). Quek et al. [26] introduce a framework combining VIKOR and TOPSIS with a truthful-distance measure for interval-valued neutrosophic soft sets, offering a new perspective on evaluating decision-making criteria under uncertainty ([26]). Zhao and Qiu [42] enhance the TOPSIS method through relative entropy, improving the method's discrimination ability between alternatives, thus increasing decision accuracy ([42]. Zhi-geng [44] develops a stochastic VIKOR method based on prospect theory, adapting VIKOR to better manage decisions under risk and uncertainty ([44]).

Si et al. [32] extend TOPSIS and VIKOR for decision-making problems with picture fuzzy numbers, enabling more nuanced decisions by incorporating picture fuzzy numbers into evaluations ([32]). Malathy and Muthuswamy [22] perform a comparative analysis between TOPSIS and VIKOR in the context of Quality of Service (QoS)-based network selection, providing insights into their practical applications in telecommunications ([22]). Xie and Zhang [40] introduced a TOPSIS-based comprehensive measure to evaluate variable importance in predictive modeling. This innovative approach enhances model interpretability and accuracy by prioritizing influential variables, demonstrating TOPSIS's adaptability to complex predictive scenarios ([40]).

Fallahpour and Moghassemn [10] explored the VIKOR method's effectiveness in optimizing parameter selection for rotor spinning, highlighting its utility in improving textile manufacturing efficiency. Their work exemplifies VIKOR's application in industrial optimization processes ([10]).

Li and Jiang [20] expanded the VIKOR methodology through Interval-Valued Intuitionistic Fuzzy Sets (IVIFS), enabling more nuanced decision-making under uncertainty. This extension facilitates a refined analysis of alternatives in imprecise or unclear decision environments ([20]). Wang and He [39] developed a TOPSIS-based robust optimization methodology for quality characteristics in manufacturing. Their approach underscores TOPSIS's capability to manage multiple quality variables simultaneously, aiming for optimal product quality ([39]).

Zhao et al. [43] proposed an extended VIKOR method incorporating cross-entropy measures with IVIFS for group decision-making. This methodology enhances the group decision-making process by accounting for opinion diversity and uncertainty, showcasing the method's flexibility ([43]). Fakhrehosseini

[8] applied TOPSIS, VIKOR, and COPRAS methods for optimal industrial investment selection, illustrating these MCDM methods' value in financial decision-making contexts ([8]).

Prabha [25] integrated fuzzy VIKOR and TOPSIS systems to address sustainability challenges, presenting a harmonized approach to sustainable development objectives. This integration showcases the synergistic potential of combining MCDM methods to tackle complex sustainability issues ([25]). Fei et al. [11] introduced DS-VIKOR, a new MCDM method combining DempsterShafer theory with VIKOR for supplier selection, improving decision reliability and effectiveness in supply chain management ([11]). Ceballos et al. [5] conducted a comparative analysis of MCDM methods, including TOPSIS and VIKOR, providing insights into selecting appropriate MCDM methods based on specific decision contexts ([5]). Falch and de Silva [9] enhanced the VIKOR method for multi-objective design problems, demonstrating its application in engineering design and optimization, further evidencing the method's versatility ([9]).

This synthesis demonstrates the evolving landscape of MCDM, marked by methodological innovations in TOPSIS and VIKOR techniques, highlighting their potential in enhancing decision-making across various fields through the integration of fuzzy sets, belief structures, and entropy measures.

2.2. **Related works on integrated MCDM methods.** The integration of MCDM methods has emerged as a promising area of research, aiming to capitalize on the strengths of individual methods to address complex decision-making scenarios more effectively. This synthesis examines several notable attempts at integrating MCDM methodologies, highlighting their innovative approaches and the outcomes of these integrations.

Prabha [25] combined fuzzy VIKOR and TOPSIS techniques to tackle sustainable development challenges. This integrated framework was pivotal in evaluating and prioritizing sustainable development goals, showcasing the synergistic potential of combining fuzzy logic with MCDM methods to enhance decision-making in sustainability contexts. The approach underscored the utility of method integration in dealing with the complexities and uncertainties inherent in sustainability-related decisions ([25]).

Fei et al. [11] introduced DS-VIKOR, an innovative integration of the DempsterShafer theory with the VIKOR method for supplier selection. This combination improved decision-making accuracy and reliability by managing uncertainty and imprecision in supplier evaluation, demonstrating the effectiveness of integrating evidence theory with MCDM methods to optimize supply chain management decisions ([11]).

Zhao et al. [43] developed an extended VIKOR method that includes cross-entropy measures with Interval-Valued Intuitionistic Fuzzy Sets (IVIFS) for group decision-making. This method effectively addressed the diversity of opinions and uncertainty in group decision scenarios, illustrating the benefits of method integration in achieving consensus and precision in group decisions ([43]).

Ceballos et al. [5] conducted a comparative analysis of MCDM methods, providing a foundation for future research on method integration. Their study, while focusing on comparing individual MCDM techniques, identified complementary strengths and weaknesses, suggesting potential synergistic combinations to enhance decision-making outcomes ([5]). Falch and de Silva [9] enhanced the VIKOR method for multi-objective design problems, indicating the potential for integrating such improved methods with other MCDM techniques to address complex engineering design challenges more effectively ([9]).

These integrations of MCDM methods have demonstrated promising outcomes across various domains, from sustainable development and supply chain management to group decision-making and engineering design. The reviewed efforts highlight the potential of method integration to leverage the complementary strengths of different MCDM techniques, thereby enhancing decision-making processes' robustness, reliability, and comprehensiveness.

2.3. **Identification of research gaps (potential of a TOPSIS-VIKOR hybrid).** The exploration of integrating MCDM methodologies, specifically TOPSIS and VIKOR, presents a promising avenue for enhancing decision-making processes in complex and uncertain environments. Despite the individual strengths of TOPSIS and VIKOR in facilitating robust decision-making, literature reveals notable research gaps, particularly in the optimal combination of criteria weighting methods, handling uncertainty and ambiguity, application in complex systems, and dynamic decision-making scenarios ([5], [11], [25], [43]).

The potential of a TOPSIS-VIKOR hybrid model lies in its capacity to offer a more comprehensive decision-making framework that marries the closeness to the ideal solution characteristic of TOPSIS with the compromise solution focus of VIKOR. Such integration could provide a nuanced mechanism for dealing with uncertainties, enhancing adaptability to complex system analyses, and facilitating dynamic decision-making processes. Addressing these research gaps through the development of a hybrid model not only opens new research directions but also promises significant advancements in decision sciences, aiming for more reliable, robust, and comprehensive decision-making outcomes.

3. Main result

3.1. **TIVI: Topological Integration of TOPSIS and VIKOR for Multi-Criteria Decision Making.** The TIVI method represents an innovative approach in the field of Multi-Criteria Decision-Making (MCDM), aiming to synergize the strengths of TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) and VIKOR (Vlse Kriterijumska Optimizacija I Kompromisno Resenje). This integration seeks to combine TOPSIS's ability to identify options that are closest to the ideal solution and farthest from the nadir solution with VIKOR's focus on compromise solutions that minimize regret for the opposition and maximize the group utility. The conceptual framework of TIVI revolves around enhancing decision-making robustness by leveraging the complementary advantages of both methods, thereby offering a more comprehensive and balanced evaluation of alternatives under complex and uncertain conditions.

TIVI is new method developed by integrating two popular methods in Multi-Criteria Decision Making (MCDM) TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) and VIKOR (Vlse Kriterijumska Optimizacija I Kompromisno Resenje) to enhance the quality of decision making. The algorithm for this method is defines as follows:

Theorem 3.1. (Topological integration of TOPSIS and VIKOR for MCDM) *Let $A = \{A_1, A_2, ..., A_n\}$ be a finite set of alternatives evaluated against a set of criteria $C = \{C_1, C_2, ..., C_m\}$, and let $D = [d_{ij}] \in \mathbb{R}^{n\times m}$ be the decision matrix, where d_{ij} denotes the performance value of alternative A_i with respect to criterion C_j. Let $W = \{w_j\}$ be the set of normalized weights associated with each criterion. Suppose the normalized decision matrix $N = [n_{ij}]$ is constructed such that it preserves the topological ordering of the alternatives under both the TOPSIS and VIKOR frameworks. Then, there exists a topological space (X, τ), where $X = A$ and τ is a topology induced by the composite closeness coefficient C_i^*, defined as a convex combination of the relative closeness coefficient from TOPSIS and the Q-index from VIKOR such that*

$$C_i^* = \lambda \cdot C_i^{TOPSIS} + (1 - \lambda) \cdot (1 - Q_i^{VIKOR})$$

for some $\lambda \in [0, 1]$, and the induced order $\succ_\tau$ over X is a linear extension of the partial orders defined individually by TOPSIS and VIKOR.

Proof.

(1) **TOPSIS Basis:** Define the relative closeness coefficient as

$$C_i^{\text{TOPSIS}} = \frac{S_i^-}{S_i^- + S_i^+},$$

where S_i^- and S_i^+ are the separation measures from the negative and positive ideal solutions, respectively.

(2) **VIKOR Basis:** Define the Q-index from VIKOR as

$$Q_i = v \cdot \frac{S_i - S^*}{S^- - S^*} + (1 - v) \cdot \frac{R_i - R^*}{R^- - R^*},$$

where S_i and R_i are the utility and regret measures, and $v \in [0, 1]$ is the weight of the majority rule.

(3) **Topological Mapping:** Define a function $f : X \to [0, 1]$ given by

$$f(A_i) = C_i^*,$$

which induces a topology τ on X such that open sets correspond to upper contour sets $\{A_i \in X \mid f(A_i) > \alpha\}$ for $\alpha \in [0, 1]$.

(4) **Order Preservation:** The linear order induced by f respects the ranking relations from both TOPSIS and VIKOR when $\lambda \in (0, 1)$, due to the continuity and monotonicity of both components in C_i^*.

Hence, the topology τ integrates the structural preferences of both methods, and (X, τ) becomes a topological space where the decision-making process benefits from the robustness of dual-method integration. □

The following example demonstrates the Topological Integration of TOPSIS and VIKOR for Multi-Criteria Decision Making.

Example 3.2. A manufacturing company wants to select the best supplier among four candidates A_1, A_2, A_3, A_4 based on the following criteria:

(C_1) : Cost (minimize),
(C_2) : Quality (maximize),
(C_3) : Delivery Time (minimize),
(C_4) : Customer Service (maximize).

Table 1. Decision Matrix

Supplier	Cost ($)	Quality (110)	Delivery Time (days)	Customer Service (110)
A_1	220	8	6	9
A_2	200	6	5	7
A_3	250	9	7	8
A_4	230	7	4	6

Step 1: Normalize the Matrix: Primarily, we will normalize the matrix using vector normalization, adjusting for beneficial and non-beneficial criteria. Denote normalized values as n_{ij}. Then we apply weights, which we will assume equal weights for simplicity: $w_j = 0.25$ for all $j \in \{1, 2, 3, 4\}$.

Step 2: Calculation of TOPSIS Scores and VIKOR Scores:

TOPSIS Scores:

- Identify the positive and negative ideal solutions.
- Compute S_i^+ and S_i^- for each alternative.
- Compute the relative closeness coefficient:

$$C_i^{\text{TOPSIS}} = \frac{S_i^-}{S_i^- + S_i^+}.$$

VIKOR Scores:

- Compute the utility measure S_i and regret measure R_i.
- Compute the Q-index using:

$$Q_i = v \cdot \frac{S_i - S^*}{S^- - S^*} + (1 - v) \cdot \frac{R_i - R^*}{R^- - R^*}.$$

Assume $v = 0.5$.

Step 3: Apply Topological Integration Theorem:

Use the convex combination of TOPSIS and VIKOR rankings:

$$C_i^* = \lambda \cdot C_i^{\text{TOPSIS}} + (1 - \lambda) \cdot (1 - Q_i^{\text{VIKOR}}).$$

Assume $\lambda = 0.6$. This value determines the trade-off between proximity (TOPSIS) and compromise (VIKOR). Rank the alternatives based on descending order of C_i^*. The higher the value, the better the performance of the alternative.

Therefore, our theorem ensures that:

(1) The final ranking C_i^* respects both the closeness-to-ideal and compromise principles.
(2) The resulting topology on the decision space is consistent and preference-preserving.
(3) Sensitivity to decision-maker priorities is possible by tuning λ.

By integrating TOPSIS and VIKOR through a topological framework, this method offers a robust and theoretically grounded approach to multi-criteria decision-making. It is particularly useful when decision-makers value both proximity to the ideal and a balanced trade-off among criteria.

Corollary 3.3. *If the composite closeness coefficient*

$$C_i^* = \lambda \cdot C_i^{TOPSIS} + (1 - \lambda) \cdot (1 - Q_i^{VIKOR})$$

is strictly monotonic over all $A_i \in A$, then the topology τ induced on the alternative set $X = A$ is Hausdorff and the induced order $\succ_\tau$ is total.

Proof. Strict monotonicity implies that for any two alternatives $A_i \neq A_j$, we have $C_i^* \neq C_j^*$. Hence, the function $f : A \to [0,1]$ defined by $f(A_i) = C_i^*$ is injective. In a topological space, an injective order-preserving function induces a Hausdorff topology. Moreover, because all elements are comparable under C_i^*, the order is total. Thus, the topology τ over X is both Hausdorff and linearly ordered. □

This corollary follows from the theorem by assuming strict monotonicity no ties in C_i^*, which guarantees that:

(1) Every pair of alternatives can be separated in the topology.
(2) The order induced is a linear order, that is, totally ordered.

Corollary 3.4. *If the individual rankings from TOPSIS and VIKOR remain consistent over a set of criterion weights $W = \{w_j\}$, then the composite ranking*

$$C_i^* = \lambda \cdot C_i^{TOPSIS} + (1 - \lambda) \cdot (1 - Q_i^{VIKOR})$$

remains invariant for all $\lambda \in [\lambda_1, \lambda_2] \subset [0,1]$, provided C_i^{TOPSIS} and Q_i^{VIKOR} are continuous in λ.

Proof. If the rankings from both methods are stable under changes in criteria weights, and if both C_i^{TOPSIS} and Q_i^{VIKOR} are continuous functions of these weights and of λ, then their convex combination will preserve the same order. Hence, for any $\lambda \in [\lambda_1, \lambda_2]$, the ordinal ranking of C_i^* does not change, ensuring ranking robustness. □

The above corollary tells that if the rankings from both methods are not sensitive to small changes in weights, then their convex combination will also produce a stable ranking over the same interval of λ. This is practically useful for sensitivity analysis, showing that decisions based on the integrated method are robust.

Corollary 3.5. *In a group decision-making setting, if each decision-maker d_k applies the integrated ranking*

$$C_{i,k}^* = \lambda_k \cdot C_{i,k}^{TOPSIS} + (1 - \lambda_k) \cdot (1 - Q_{i,k}^{VIKOR}).$$

With $\lambda_k \approx \lambda$ for all k, then the aggregated group ranking (using mean, median, or majority vote) will converge to a consensus ranking that respects the topology induced by the integrated model.

Proof. Since λ_k values are similar, and both TOPSIS and VIKOR scores are bounded and continuous, the resulting individual $C_{i,k}^*$ values will lie close together. Under standard aggregation (e.g., averaging or Borda count), small differences cancel out, leading to a common ranking. The shared topological structure ensures preference consistency across the group. □

The above corollary implies that when decision-makers adopt the same integration logic (even with small variations in λ), their final rankings of alternatives will be topologically aligned, making consensus formation easier and more natural. This supports the use of the integrated method in collaborative settings such as committee evaluations, multi-expert systems, or panel-based assessments.

3.2. **Application of TIVI method.** In this section, we apply the proposed methodology to evaluate smart farming solutions, represented by technologies T1 through T9. Our study encompasses data collection for nine smart farming technologies across seven distinct criteria. These criteria are bifurcated into beneficial and non-beneficial categories. The non-beneficial criteria consist of Initial Investment (C1), Technical Challenges (C2), and Data Privacy Concerns (C3). Conversely, the beneficial criteria include Tech Adoption Level (C4), Cost Efficiency (C5), User Friendliness (C6), and Crop Yield Increase (C7).

This categorization allows for a nuanced analysis of each technology's potential impact on smart farming operations, ensuring a comprehensive evaluation within the decision-making framework. The decision matrix, as presented in Table 1, is constructed based on a range of alternatives and selection criteria pertinent to smart farming solutions. This matrix serves as the foundation for evaluating the various smart farming options, facilitating a systematic approach to determine the most suitable technology for implementation.

TIVI algorithm Process: In the first step of the TIVI method, a decision matrix is constructed based on various alternatives and criteria. The decision matrix is presented in Table 1.

TABLE 2. Decision Matrix

Technology	Initial Investment	Tech Challenges	Data Privacy Concerns	Tech Adoption Level	Cost Efficiency	User Friendliness	Crop Yield Increase
Technology 1	50000	5	2	8	20000	8	20
Technology 2	45000	3	3	7	15000	7	15
Technology 3	60000	2	1	9	25000	9	25
Technology 4	40000	7	4	6	10000	6	12
Technology 5	70000	1	2	10	30000	10	30
Technology 6	35000	9	5	5	5000	5	10
Technology 7	55000	4	1	8	18000	7	18
Technology 8	48000	6	3	7	12000	6	14
Technology 9	65000	3	2	9	22000	9	22

In the second step, the criteria weights are measured using the *Standard Deviation* method, with these weights presented in Table 2.

Table 3. Weights for Evaluation Criteria of Technology

Technology	Initial Investment	Tech Challenges	Data Privacy Concerns	Tech Adoption Level	Cost Efficiency	User Friendliness	Crop Yield Increase
Weight	0.15	0.19	0.15	0.13	0.13	0.11	0.14

In the third step, we normalize the decision matrix utilizing equations (1) and (2), resulting in the normalized matrix as shown in Table 3.

Table 4. Normalized Criteria Values for Each Technology

Technology	C1	C2	C3	C4	C5	C6	C7
T1	0.4286	0.5000	0.2500	0.6000	0.6000	0.6000	0.5000
T2	0.2857	0.2500	0.5000	0.4000	0.4000	0.4000	0.2500
T3	0.7143	0.1250	0.0000	0.8000	0.8000	0.8000	0.7500
T4	0.1429	0.7500	0.7500	0.2000	0.2000	0.2000	0.1000
T5	1.0000	0.0000	0.2500	1.0000	1.0000	1.0000	1.0000
T6	0.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000
T7	0.5714	0.3750	0.0000	0.6000	0.5200	0.4000	0.4000
T8	0.3714	0.6250	0.5000	0.4000	0.2800	0.2000	0.2000
T9	0.8571	0.2500	0.2500	0.8000	0.6800	0.8000	0.6000
min	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
max	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

In the fourth step we Calculate the TOPSIS score for each alternative using equation (3). The results of these calculations shown in Table 4:

Table 5. TOPSIS Scores for Each Technology

Technology	C1	C2	C3	C4	C5	C6	C7	TOPSIS Score
T1	0.0270	0.0473	0.0095	0.0209	0.0210	0.0179	0.0347	0.4222
T2	0.0120	0.0118	0.0378	0.0470	0.0472	0.0402	0.0782	0.5237
T3	0.0751	0.0030	0.0000	0.0052	0.0052	0.0045	0.0087	0.3189
T4	0.0030	0.1064	0.0851	0.0835	0.0839	0.0714	0.1125	0.7389
T5	0.1472	0.0000	0.0095	0.0000	0.0000	0.0000	0.0000	0.3958
T6	0.0000	0.1892	0.1513	0.1305	0.1311	0.1116	0.1389	0.9235
T7	0.0481	0.0266	0.0000	0.0209	0.0302	0.0402	0.0500	0.4647
T8	0.0203	0.0739	0.0378	0.0470	0.0680	0.0714	0.0889	0.6383
T9	0.1081	0.0118	0.0095	0.0052	0.0134	0.0045	0.0222	0.4181

In step 5 of the TIVI Method, we calculate the "Q" index for each alternative using Equation (4) as a means to quantify the compromise between the best and worst solutions. The outcomes of the Q index calculation are presented in Table 5.

Table 6. Q Index Values for Each Technology

Technology	Q Index
T1	0.8290
T2	0.6613
T3	1.0000
T4	0.3052
T5	0.8728
T6	0.0000
T7	0.7587
T8	0.4717
T9	0.8359

In Step 6, we calculate the VIKOR score for each alternative using the Q index as per Equation (6), setting α to 0.4. Subsequently, the alternatives are ranked based on their VIKOR scores, with the smallest score receiving a rank of 1. The calculated VIKOR scores and their corresponding ranks are presented in Table 6.

TABLE 7. VIKOR Scores and Ranks for Each Technology

Technology	VIKOR Score	Rank
T1	0.43419	4
T2	0.46775	6
T3	0.40000	1
T4	0.53896	8
T5	0.42545	2
T6	0.60000	9
T7	0.44826	5
T8	0.50566	7
T9	0.43281	3

From the Table, it is observed that, Technology T3 emerged as the most preferred, securing the first rank. It was closely followed by Technology T5, which was ranked second. Technology T9 took the third position, demonstrating its competitive performance. Technology T1 was ranked fourth, indicating its strong standing among the evaluated technologies. Technology T7 achieved the fifth rank, while Technology T2 was placed sixth. Technologies T8 and T4 were ranked seventh and eighth, respectively. Finally, Technology T6, despite its attributes, was ranked last, in ninth position. These rankings provide insight into the relative preference and performance of each technology according to the VIKOR method.

4. Sensitivity analysis

In this section we examine the influence of varying α (alpha) values on the rankings of technologies using the VIKOR multi-criteria decision-making method, as detailed in Table 7and Fig.1. It highlights how preferences between maximizing group utility and minimizing individual regret significantly affect technology evaluations, offering insights into the adaptability and strategic implications of technology selection decisions.

Table 8. Comparative Ranking of Technologies Across Different α (Alpha) Values

Technology	$\boldsymbol{\alpha = 0.2}$	$\boldsymbol{\alpha = 0.4}$	$\boldsymbol{\alpha = 0.6}$	$\boldsymbol{\alpha = 0.8}$
T1	4	4	6	6
T2	6	6	4	4
T3	1	1	9	9
T4	8	8	2	2
T5	2	2	8	8
T6	9	9	1	1
T7	5	5	5	5
T8	7	7	3	3
T9	3	3	7	7

In a VIKOR multi-criteria decision-making analysis, Table 1 presents the impact of varying α values (0.2, 0.4, 0.6, and 0.8) on the rankings of nine technologies (T1 through T9). The study aimed to understand how preferences between maximizing group utility (at lower α values) and minimizing individual regret (at higher values) influence the evaluation of technologies.

At α values of 0.2 and 0.4, Technologies T3, T5, and T9 consistently ranked as the top performers, though their exact rankings varied slightly between these settings. Notably, Technology T6, which ranked lower at $\alpha = 0.2$ and $\alpha = 0.4$, ascended to the top position when α was increased to 0.6 and 0.8. This shift highlights a significant change in preference towards T6 under scenarios emphasizing the minimization of individual regret.

The dynamics between Technologies T1 and T2 revealed that T1 initially outranked T2 at lower α levels but was subsequently surpassed as α increased, indicating a preference shift favoring T2 in scenarios that prioritize minimizing individual regret. Conversely, Technology T4 demonstrated substantial improvements in ranking at higher α values, moving from lower rankings at $\alpha = 0.2$ and $\alpha = 0.4$ to among the top two at $\alpha = 0.6$ and $\alpha = 0.8$, which underscores its adaptability across varying decision-maker preferences.

Technology T7 maintained a consistent performance across all α values, ranking in the middle and suggesting its characteristics offer a balanced compromise under different emphases on group utility versus individual regret.

Meanwhile, Technology T8 remained in the lower half of the rankings across all α values, indicating less variability in its performance across different decision-making scenarios. This analysis, as depicted in Table 7, underscores the critical role of the α parameter in the VIKOR decision-making process, highlighting the significant influence of decision-making preferences on the evaluation and ranking of technologies.

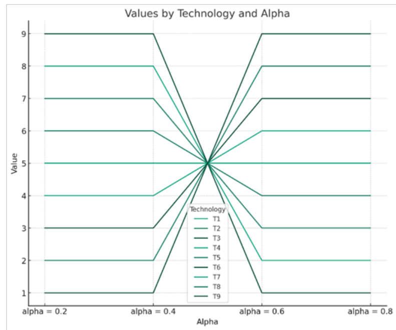

Figure 1. Values by Technology and Alpha

5. Comparative analysis of proposed method and existing MCDM techniques

In this section, we assess the correlation of the proposed method with other established multi-criteria decision-making (MCDM) methods such as TOPSIS, CODAS, and VIKOR techniques. From Table 8, it is observed that Correlation analysis reveals a very strong positive relationship between TIVI and TOPSIS scores (r = 0.9833), a strong positive correlation with CODAS (r = 0.8833), and a significant negative correlation with VIKOR (r = -0.7333). These correlations are statistically significant, as evidenced by P-values indicating a high level of significance for TOPSIS (p ¡ .000), moderate significance for CODAS (p = .0015), and significance for VIKOR (p = .0246), thus confirming the reliability of the ranking patterns across the decision-making models.

Table 9. Ranking Comparison of Technologies Across Different MCDM Methods

Technology	TIVI	TOPSIS	CODAS	VIKOR
T1	4	5	5	2
T2	6	6	6	4
T3	1	1	1	6
T4	8	8	8	5
T5	2	2	2	9
T6	9	9	7	1
T7	5	4	3	8
T8	7	7	9	3
T9	3	3	4	7
Correlation with TIVI P-Value	—	0.9833	0.8833	-0.7333
		$<$ .000	0.0015	0.0246

6. Conclusion and future work

The research culminated in the development of TIVI, a novel hybrid Multi-Criteria Decision-Making (MCDM) method that integrates the strengths of TOPSIS and VIKOR. This innovative approach was thoroughly tested and validated against existing MCDM techniques, showing remarkable potential for comprehensive decision analysis. Empirical evidence from the comparative study highlights TIVI's efficacy, with a very strong positive correlation to TOPSIS and a strong positive correlation to CODAS, while exhibiting a notable negative correlation to VIKOR. The statistical significance of these correlations further bolsters the validity of TIVI's utility in various decision-making scenarios.

TIVI's unique contribution lies in its dual capacity to approximate the ideal solution and to provide a compromise ranking, an attribute not found in the methods individually. This positions TIVI as a superior decision-making tool, especially in scenarios where decision-makers are faced with prioritizing alternatives that not only come close to the ideal but also present a balanced trade-off among conflicting criteria. The sensitivity analysis demonstrated TIVI's robustness and flexibility under changing decision-making preferences, particularly regarding group utility and individual regret minimization. For instance, in healthcare, TIVI could assist in selecting treatment plans that balance cost, effectiveness, and patient preferences. Similarly, in environmental planning, TIVI could support policy decisions that involve trade-offs between economic development and ecological sustainability.

As with any novel methodological approach, TIVI is not without limitations, which future research should aim to address. Subsequent studies could refine the weighting mechanisms, explore applications in various complex systems, and test the model in dynamic decision-making environments. Nevertheless, TIVI emerges as a pioneering framework that promises to enrich the MCDM literature and practice, potentially setting a new standard for robust decision-making in numerous fields.

References

[1] N. Ali, K. Nasiri, M.V. Khiavi, M. Vafakhah and S.H. Sadeghi, *Comparative applicability of MCDM-SWOT based techniques for developing integrated watershed management framework,* Natural Resource Mode., **36**(4) (2023), e 12380. doi.org/10.1111/nrm.12380.

[2] A. Amini, A. Alinezhad and F. Yazdipoor, *A TOPSIS, VIKOR and DEA integrated evaluation method with belief structure under uncertainty to rank alternatives*, Int. J. Adv. Oper. Management, **11**(3) (2019), 171–188.

[3] J.P. Brans and P. Vincke, *A preference ranking organization method: The PROMETHEE method for MCDM,* Management Sci., **31**(6) (1985), 647–656.

[4] M. Canakcoglu, *Evaluation of banking performance of the Balkan countries with an integrated MCDM approach consist of entropy and OCRA techniques,* Economy Business J., **13**(1) (2019), 341–366.

[5] B. Ceballos, M.T. Lamata and D.A. Pelta, *A comparative analysis of multi-criteria decision-making methods,*Progress Art. Intel., **5**(4) (2016), 295-309.

[6] A. Charnes, W.W. Cooper and E. Rhodes, ıMeasuring the efficiency of decision-making units, European J. Oper. Res., **2**(6) (1978), 429-444.

[7] W. Chen, *A new approach for spherical fuzzy TOPSIS and spherical fuzzy VIKOR applied to the evaluation of hydrogen storage systems,* Soft Comput., **27** (2023), 4403-4423.

[8] S.F. Fakhrehosseini, *Selecting the optimal industrial investment by multi-criteria decision-making methods with emphasis on TOPSIS, VIKOR, and COPRAS (case study of Guilan province),* Int. J. Res. Indu. Eng., **8**(4) (2019), 312-324.

[9] L. Falch and C.W.de Silva, *Improvement of VIKOR Method With Application to Multi-Objective Design Problems,* Int. J. Infor. Tech. Dec. Making, **21**(3) (2022), 897-920.

[10] A. Fallahpour and R. Moghassem, *Evaluating the applicability of the VIKOR method of multi-criteria decision making for parameter selection problem in rotor spinning,* Fibers and Polymers, **13** (2012), 802–808.

[11] L. Fei, Y. Deng and Y. Hu, *nDS-VIKOR: A New Multi-criteria Decision-Making Method for Supplier Selection,* Int. J. Fuzzy Syst., **21**(1) (2019), 291-303.

[12] A. Gabus and E. Fontela, *World problems, an invitation to further thought within the framework of DEMATEL,* Battelle Geneva Research Centre, (1972), ID:148882619.

[13] M.K. Ghorabaee, E.K. Zavadskas, L. Olfat and Z.Turskis, *Multi-criteria inventory classification using a new method of Evaluation Based on Distance from Average Solution (EDAS),* Informatica, **26**(3) (2015), 435-451.

[14] S.S. Goswami, & D.K. Behera (2021). Solving material handling equipment selection problems in an industry with the help of entropy integrated COPRAS and ARAS MCDM techniques, doi.org/10.1007/S41660-021-00192-5.

[15] C.L. Hwang and K. Yoon (1981), *Multiple attribute decision making: Methods and applications a state-of-the-art survey*, Springer-Verlag, 1981.

[16] R.L. Keeney and H. Raiffa, (1976). *Decisions with multiple objectives: Preferences and value tradeoffs*, John Wiley and Sons, 1976.

[17] S. Koçak, Y. Tanseliç, K.D. Atalay, M. Sert and B. Dengiz, *The development of a reviewer selection method: a multi-level hesitant fuzzy VIKOR and TOPSIS approaches,* J. Ambient Intel. Humanized Comput., **14** (2023), 3275–3302.

[18] R. Kumar, *A Combined VIKOR-TOPSIS Method with Application in Cloud Services Provider Selection,* Proc. Int. Conf. Comput. Comm. and Control, (2022), 293–302.

[19] R. Kumar, *An Empirical Comparison of TOPSIS and VIKOR for Ranking Decision-Making Models,* Intel. Cloude Computing, (2022), 429–437.

[20] C. Li and H. Jiang, *Extension of VIKOR Method with Interval-Valued Intuitionistic Fuzzy Sets,* Proc. Int. Conference on Manag. and Serv. Sci. (ICMSS), (2011), doi.org/10.1109/ICMSS.2011.5999210.

[21] I. Mahmoud, S.S. Zaki and M.M. Ibrahim, *Development of sustainable assessment model of solar hydrogen production techniques: An integrated MCDM approach,* J. Intel. Syst. Inter. Things, **6**(1) (2022), 20–29.

[22] E.M. Malathy and V. Muthuswamy, *A comparative evaluation of QoS-based network selection between TOPSIS and VIKOR. In: Proc. Int. Conference*, (2018), doi.org/10.1007/978-981-13-2354-6-13.

[23] S. Opricovic and G.H. Tzeng, *Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS,* Euro. J. Oper. Res., **156**(2) (2024), 445-455.
[24] J. Papathanasiou, N. Ploskas, T. Bournaris and B. Manos, *A Decision Support System for Multiple Criteria Alternative Ranking Using TOPSIS and VIKOR: A Case Study on Social Sustainability in Agriculture,* Lect. Note. Bus Infom Pros., (2016), 3–15.
[25] H.M. Prabha, *Integrated fuzzy VIKOR and TOPSIS system for the sustainable development in Islam,* Nucleation and Atmospheric Aerosols, (2022), 1–9.
[26] S.G. Quek, H. Garg, G. Selvachandran, M. Palanikumar, K. Arulmozhi and F. Smarandache, *VIKOR and TOPSIS framework with a truthful-distance measure for the (t, s)-regulated interval-valued neutrosophic soft set,* Soft Computing, (2023), doi.org/10.1007/s00500-023-08338-y.
[27] P. Rani and A.R. Mishra, *Fermatean fuzzy Einstein aggregation operators-based MULTIMOORA method for electric vehicle charging station selection*, Expert Syst. Appl., **182** (2021), ID: 115267.
[28] J. Rezaei, *Best-worst multi-criteria decision-making method*, Omega, **53** (2015), 49-57.
[29] B. Roy, *Classement et choix en présence de points de vue multiples (la méthode ELECTRE),* Revue franaise d'informatique et de recherche oprationnelle, **8**(1) (1968), 57-75.
[30] T.L. Saaty, *Decision making with dependence and feedback: The Analytic Network Process*, RWS Publications, 1996, ISBN 0-9620317-9-8.
[31] I.M. Sharaf, *A new approach for spherical fuzzy TOPSIS and spherical fuzzy VIKOR applied to the evaluation of hydrogen storage systems,* Soft Computing, **27**(3) (2023), 1–21.
[32] A. Si, S. Das and S. Kar, *Extension of TOPSIS and VIKOR method for decision-making problems with picture fuzzy number,* Adv. Intel. Syst. Comput., (2019), 563–577.
[33] B. Singh, S. Grover and V. Singh, *Integrated MCDM for benchmarking techniques in Indian service industries,* Int. J. Innov. Tech. Manag., **13**(6) (2016), ID:1750005. doi.org/10.1142/S0219877017500055.
[34] A. Taghipour, B.D. Rouyendegh, A.T. Ünal and S. Piya, *Selection of suppliers for speech recognition products in IT projects by combining techniques with an integrated fuzzy MCDM*, Sustainability, **14**(3) (2022), ID:1777, *Sustainability*, doi.org/10.3390/su14031777.
[35] H. Taherdoost and M. Madanchian, *An effective compromising ranking technique for decision making*, Macro Manage. Public Policies, **5**(2) (2023), 27–33.
[36] A. Ulutaş, D. Stanujkic, D. Karabasevic, G. Popovic, E.K. Zavadskas, F. Smarandache and W.K. Brauers, *Developing of a novel integrated MCDM Multimoosral approach for supplier selection,* Inform. (Lithuanian Academy of Sciences), **32**(1) (2021), 146–161.
[37] B. Uzun and D.U. Ozsahin, *Vlse criterion optimization and compromise solution in Serbian (VIKOR)*, Appl. Multi-Criteria Decis. Anal. Envir. Civil Eng., (2021), 43–46.
[38] S. Wang, G. Wei, J. Lu, J. Wu, C. Wei and X. Chen, *GRP and CRITIC method for probabilistic uncertain linguistic MAGDM and its application to site selection of hospital constructions,* Soft Computing, **26**(5) (2022), 1-15.
[39] Y. Wang and Z. He, *A TOPSIS based robust optimization methodology for multivariable quality characteristics,* Proc. Int. Confe. Service Oper. Logi. Infor., (2008), doi.org/10.1109/SOLI.2008.4682967.
[40] S. Xie and J. Zhang, *TOPSIS-based comprehensive measure of variable importance in predictive modelling,* Expert Syst. Appl., **232** (2023), ID: 120682, doi.org/10.1016/j.eswa.2023.120682.
[41] E.K. Zavadskas and Z. Turskis, *A new additive ratio assessment (ARAS) method in multicriteria decision-making,* Tech. Econo. Develo. Economy, **16**(2), 159-172.

[42] M. Zhao and W. Qiu, *Improved TOPSIS method based on relative entropy,* Proc. the 2010 Int. Conf. Elect. Electronics Eng., (ICEEE), (2010), doi.org/10.1109/ICEEE.2010.5660925.

[43] X. Zhao, S. Tang, S. Yang and K. Huang, *Extended VIKOR method based on cross-entropy for interval-valued intuitionistic fuzzy multiple criteria group decision making*, J. Intel. Fuzzy Syst., **25**(1) (2013), 215-225.

[44] F. Zhi-geng, *Stochastic VIKOR method based on prospect theory*, Comput. Eng. Appl., (2012).