UtilitasMathematica

ISSN 0315-3681 Volume 122 (2), 2025

An Extended Fuzzy VIKOR Method with Dynamic Criteria Weight Adjustment for Sustainable Decision Making under Uncertainty with a case study on green supplier selection for sustainable manufacturing

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Abstract— This paper proposes an extended Fuzzy VIKOR method designed to enhance decision-making in uncertain and complex environments. The approach integrates a hybrid criteria weighting scheme preferences by introducing a dynamic criteria weight adjustment mechanism that integrates both subjective expert judgment and objective entropy-based information. A tunable parameter is employed to balance the influence of subjective and objective weights. Interval-Valued Fuzzy Numbers (IVFNs) are employed to capture linguistic uncertainty in the evaluation process. The method is applied to a green supplier selection problem involving four alternatives and five sustainability criteria, demonstrating its applicability to sustainable supply chain management. A sensitivity analysis with respect to the compromise parameter validates the robustness and consistency of the model. The results highlight its practical applicability for sustainability-driven decisions under uncertain conditions

Index Terms— VIKOR, Dynamic Weight Adjustment, Interval-Valued Triangular Fuzzy Numbers, Green Supplier Selection, Multi-Criteria Decision Making, Sustainability

I. INTRODUCTION

In recent years, the integration of sustainability into supply chain management has become a critical strategic goal for organizations striving to minimize environmental impact while maintaining competitiveness. Among various dimensions of sustainable supply chain practices, green supplier selection (GSS) stands as a key decision-making area that directly influences the environmental footprint of the manufacturing process. However, selecting the most appropriate green supplier involves multiple, often conflicting criteria such as cost, environmental compliance, resource efficiency, technological capability, and regulatory adherence.

These criteria are frequently evaluated under uncertainty, imprecision, or subjectivity—arising from human judgment, incomplete data, or fluctuating market dynamics.

To address these challenges, Multi-Criteria Decision Making (MCDM) methods under fuzzy environments have gained widespread attention. Among them, the Fuzzy VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje) method is widely used for its ability to identify a compromise solution that reflects the group utility and individual regret of alternatives. While classical Fuzzy VIKOR provides an effective compromise ranking, it lacks mechanisms to dynamically adapt to evolving decision contexts and expert preference uncertainty.

Motivation and Research Gap

Despite the popularity of fuzzy-based VIKOR methods in supplier evaluation, existing approaches are often limited by:

- Static or rigid criteria weights, which do not reflect real-time changes in decision environments.
- Exclusive reliance on either subjective or objective weighting mechanisms.
- Inability to model hesitation or vagueness in expert input.

Research Contributions

To address the above gaps, this paper proposes an Extended Fuzzy VIKOR Method with Dynamic Criteria Weight Adjustment (DCWA) for sustainable decision-making. The main contributions of this study are as follows:

1. Dynamic Criteria Weight Adjustment (DCWA): A novel mechanism that updates the fuzzy weights of evaluation criteria based on feedback loops or variations in expert confidence levels.
2. Hybrid Weighting Scheme: A fusion of subjective (expert-driven) and objective (fuzzy entropy-based) criteria weighting through a tunable balancing parameter α.
3. Interval-Valued Fuzzy Numbers (IVFNs): Representation of linguistic ratings to capture uncertainty and hesitation in expert judgments more comprehensively.
4. Sensitivity Analysis on VIKOR's Strategy Weight (v): In-depth examination of how varying the compromise parameter $v \in [0,1]$ influences final rankings under uncertain conditions.
5. Real-World Case Study: Application of the proposed model to evaluate and rank green suppliers for a sustainable manufacturing enterprise, showcasing practical relevance and model robustness.

The rest of this paper is organized as follows: Section 2 provides a literature review on fuzzy MCDM and green supplier evaluation. Section 3 outlines the basic concepts and definitions. Section 4 presents the proposed methodology in detail. Section 5 demonstrates the application through a real-life case study. Section 6 discusses the results and implications. Finally, Section 7 concludes with findings and future research directions.

II. LITERATURE REVIEW

The problem of green supplier selection has gained growing importance within the broader scope of sustainable supply chain management (SSCM). A substantial body of research has explored various techniques for evaluating and ranking suppliers based on multiple criteria, often under uncertainty. This section reviews the relevant literature on:

I. Green Supplier Selection (GSS),
II. Multi-Criteria Decision Making (MCDM) techniques in GSS, and
III. The evolution and limitations of the Fuzzy VIKOR method.

2.1 Green Supplier Selection in Sustainable Manufacturing:

Green Supplier Selection refers to the process of evaluating and choosing suppliers that align with environmental, economic, and social sustainability goals. Traditional supplier selection focused predominantly on cost, quality, and delivery. However, in recent years, sustainable manufacturing has introduced new criteria such as:

- Environmental compliance
- Waste management practices
- Energy efficiency
- Use of recyclable or biodegradable materials
- Corporate social responsibility (CSR)

Researchers such as Sarkis (2006) and Govindan et al. (2013) have demonstrated that incorporating green criteria into supplier selection improves long-term value creation and mitigates environmental risk [7]. However, these criteria are typically qualitative and subject to human judgment, necessitating decision-making models capable of handling fuzziness and imprecision.

2.2 MCDM Approaches for Green Supplier Evaluation:

Various MCDM approaches have been applied in the green supplier selection domain, including:

- Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP): Often used to derive weights based on pairwise comparisons, but they may suffer from consistency and scalability issues under fuzzy environments [5].
- Technique for Order Preference by Similarity to Ideal Solution (TOPSIS): Used to rank suppliers based on distance from the ideal solution, but it assumes criteria independence and equal importance unless otherwise specified [5] ,[6].

- ELimination Et Choice Translating REality (ELECTRE) and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE): Applied in outranking scenarios but often criticized for being computationally complex and hard to interpret in fuzzy environments.
- VIKOR: Specifically developed to identify compromise solutions where decision makers face conflicting criteria. Its fuzzy extensions make it suitable for sustainability-oriented evaluations where subjective judgments are prevalent.

2.3 Fuzzy VIKOR Method: Development and Gaps:

The Fuzzy VIKOR method extends the classical VIKOR by integrating fuzzy set theory, allowing decision makers to express preferences using linguistic variables, such as “high,” “medium,” or “low,” represented by fuzzy numbers. This extension addresses uncertainty in human judgment effectively [4].
Key advancements in fuzzy VIKOR include:

- Linguistic term modeling: Using triangular or trapezoidal fuzzy numbers.
- Aggregation of expert opinions: Using fuzzy averaging or OWA operators.
- Ranking alternatives: Based on closeness to fuzzy ideal and anti-ideal solutions.

However, critical limitations remain:
1. Static Weights: Most models use fixed weights for criteria throughout the evaluation, ignoring context-based or evolving decision needs.
2. Lack of Objective-Subjective Balance: Relying solely on expert opinion introduces bias, while using only objective data may overlook experiential knowledge.
3. Inadequate Handling of Hesitation: Current models often assume crisp or triangular fuzzy inputs, insufficient to model hesitation or conflict in expert opinions.
4. Insensitivity to Parameter v: The compromise parameter v, which balances group utility and individual regret, is usually fixed without considering its impact on ranking robustness.

2.4 Research Direction and Need for an Extended Model:

In light of the above limitations, recent studies Rezaei et al., 2021; Tseng et al., 2022 have emphasized the need for hybrid and dynamic fuzzy MCDM methods that can adapt to complex decision environments. To meet this need, the current research proposes a novel extended fuzzy VIKOR method that dynamically adjusts criteria weights, incorporates both subjective and objective knowledge, and models uncertainty using interval-valued fuzzy numbers. This approach aims to improve the robustness, adaptability, and interpretability of green supplier selection decisions under sustainability objectives.

III. PRELIMINARIES

This section provides the essential theoretical background and fuzzy set concepts used in the proposed extended fuzzy VIKOR model. Specifically, it introduces interval-valued fuzzy numbers (IVFNs), fuzzy aggregation operators, fuzzy entropy, and the basic framework of the traditional fuzzy VIKOR method.

3.1 Interval-Valued Fuzzy Numbers (IVFNs) :

An Interval-Valued Fuzzy Number (IVFN) is a generalization of a fuzzy number where the membership value at each point is given by an interval rather than a crisp number. This helps capture hesitation or uncertainty in expert opinions more effectively than traditional fuzzy numbers.

Definition :
An IVFN $\tilde{A}$ is denoted as:

$$\widetilde{\mathrm{A}} = [\, [a_1^L, a_1^U], [a_1^L, a_1^U,], [a_3^L, a_3^U]]$$

- $[a_1^L, a_1^U]$: *lower and upper bounds of the left endpoint,*
- $[a_2^L, a_2^U]$,: *lower and upper bounds of the peak (mode),*
- $[a_3^L, a_3^U]$: *lower and upper bounds of the right endpoint.*

3.2 Aggregation of Expert Opinions :

If multiple experts provide evaluations in terms of IVFNs, their opinions are aggregated using the average operator:

$$\tilde{A}_{agg} = \frac{1}{k}\sum_{i=1}^{k}\tilde{A}_i$$

where $\tilde{A}_i$ is the IVFN from the i^{th} expert and k is the total number of experts.

3.3 Fuzzy Entropy for Objective Weight Calculation:

Fuzzy entropy is used to determine the objective weights of criteria based on the information dispersion in the decision matrix. A criterion with more dispersed values contributes more information and thus should be assigned a higher weight.

Let $\tilde{x}_{ij}$ be the aggregated IVFN rating of alternative i under criterion j. The entropy of criterion j is computed using:

$$E_j = -k\sum_{i=1}^{m} p_{ij}\, log(p_{ij})$$

Where p_{ij} is the normalized fuzzy membership for criterion j.

The objective weight W_j^{obj} then given by:

$$W_j^{obj} = \frac{1 - E_j}{\sum_{j=1}^{n} 1 - E_j}$$

3.4 Hybrid Weighting Mechanism:

To reflect both subjective judgments and objective data, the final weight of each criterion is determined using a hybrid method:

$$w_j = \alpha \cdot w_j^{sub} + (1-\alpha)\cdot w_j^{obj},\ \ 0 \le \alpha \le 1$$

w_j^{sub}: $Subjective\ weight\ from\ expert\ opinion.$

w_j^{obj} : $Objective\ weight\ from\ fuzzy\ entropy.$

α : $A\ tunable\ parameter\ to\ balance\ subjective\ and\ objective\ perspectives.$

3.5 Basic Steps of Traditional Fuzzy VIKOR:

The traditional fuzzy VIKOR method involves the following steps:

I). Construct the fuzzy decision matrix.

II). Determine fuzzy best (f_j^*) and fuzzy worst (f_j^-) values.

III). Compute the normalized fuzzy values

IV). Calculate the aggregated fuzzy distances:
S_i : Group utility R_i : Individual regret.

V). Compute the VIKOR index Q_i:

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

where $v \in [0,1]$ is the strategy weight (typically set to 0.5).

VI). Rank the alternatives based on Q_i

IV. PROPOSED METHODOLOGY:

The model is designed to enhance adaptability, reflect both expert judgment and data-driven insights, and manage uncertainty in green supplier selection.

4.1 Framework Overview

The proposed methodology consists of the following steps:

1. Define criteria and alternatives.
2. Collect expert evaluations using IVFNs.
3. Normalize the fuzzy decision matrix.
4. Compute both subjective and objective weights.
5. Dynamically adjust the criteria weights.
6. Determine fuzzy best and worst values.
7. Compute fuzzy S, R, and Q indices.
8. Rank alternatives and perform sensitivity analysis.

4.2 Step-by-Step Procedure

Step 1: Define Decision Problem
Let:

$$A = \{A_1 A_2, \dots A_m\}\ \text{be the set of alternatives}.$$

$$C = \{C_1, C_2, \dots C_m\}\ \text{be the set of evaluation criteria}$$

Step 2: Construct the Interval-Valued Fuzzy Decision Matrix
Let $\tilde{x}_{ij}$ denote the interval-valued fuzzy rating of alternative A_i under criterion C_j, aggregated across experts using the average operator.

$$\tilde{X} = \left[\tilde{x}_{ij}\right]_{m \times n}$$

Step 3: Normalize the Fuzzy Decision Matrix
Normalization ensures that all values are comparable.
For a benefit criterion:

$$\tilde{r}_{ij} = \frac{\tilde{x}_{ij} - \tilde{x}_j^{min}}{\tilde{x}_j^{max} - \tilde{x}_j^{min}}$$

For a cost criterion:

$$\tilde{r}_{ij} = \frac{\tilde{x}_j^{max} - \tilde{x}_{ij}}{\tilde{x}_j^{max} - \tilde{x}_j^{min}}$$

Step 4: Determine Subjective and Objective Weights
Subjective Weight (w_j^{sub}): Derived from expert pairwise comparison or direct rating.
Objective Weight (w_j^{obj}): Calculated using fuzzy entropy (as described in Section 3.3).

Step 5: Apply Dynamic Criteria Weight Adjustment (DCWA)
To incorporate dynamic adaptability, we define:

$$w_j = \alpha \cdot w_j^{sub} + (1 - \alpha) \cdot w_j^{obj}, \ \ 0 \le \alpha \le 1$$

α : Control parameter, adjusted based on:

- Feedback loops (e.g., performance feedback).
- Time-dependent scenarios.
- Changes in expert confidence levels.

This makes the model responsive to shifting conditions and decision-maker preferences.

Step 6: Identify Fuzzy Best and Worst Values
For each criterion C_j, determine:

- $Fuzzy\ best\ value\ \tilde{f}_j^{*} = \max \tilde{r}_{ij}$
- $Fuzzy\ worst\ value\ \tilde{f}_j^{-} = min\ \tilde{r}_{ij}$

Step 7: Calculate S_i, R_i and Q_i Indices

- Group utility measure:

$$S_i = \sum_{j=1}^{n} w_j \cdot d(\tilde{r}_i, \tilde{f}_j^*)$$

- Individual regret measure:

$$R_i = max_i\left[w_j \cdot d(\tilde{r}_i, \tilde{f}_j^*)\right]$$

- Compromise index:

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

where:

- $v \in [0,1]$: Strategy coefficient.
- $S^* = minS_i,\ S^- = max\ S_i$
- $R^* = min\ R_i,\ \ R^- = max\ R_i$

Distance metric (d) between IVFNs can be computed using average Euclidean-based measures on interval endpoints.
Step 8: Rank the Alternatives
Rank alternatives based on ascending values of Q_i. The lowest Q_i indicates the best compromise solution.
Step 9: Sensitivity Analysis
To test model robustness, vary parameters such as:

- α: Weighting balance between subjective and objective data.
- v: Strategy weight from 0 (maximum individual regret) to 1 (maximum group utility).

V. CASE STUDY: GREEN SUPPLIER SELECTION FOR SUSTAINABLE MANUFACTURING

5.1 Problem Description

A sustainable manufacturing firm is looking to select the most appropriate green supplier for its raw material procurement. The decision involves multiple conflicting criteria, and the evaluation is influenced by uncertainty and expert subjectivity. Hence, the Extended Fuzzy VIKOR with Dynamic Criteria Weight Adjustment (DCWA) model is applied.

5.2 Alternatives and Criteria

Alternatives (Suppliers):

- A_1: Supplier Alpha
- A_2: Supplier Beta
- A_3: Supplier Gamma
- A_4: Supplier Delta

Criteria:

- C_1: Environmental Certification Compliance (Benefit)
- C_2: Cost Efficiency (Cost)
- C_3: Timely Delivery (Benefit)
- C_4: Green Innovation Capability (Benefit)
- C_5 :Waste Management Practices (Benefit)

5.3 Expert Evaluation Using Linguistic Terms:

Three decision-makers evaluate the suppliers using linguistic variables (e.g., Very High, High, Medium, Low, Very Low), each mapped to Interval-Valued Triangular Fuzzy Numbers (IVTFNs):

Linguistic Term	IVTFN
Very Low (VL)	([0.0, 0.1], [0.1, 0.2], [0.2, 0.3])
Low (L)	([0.2, 0.3], [0.3, 0.4], [0.4, 0.5])
Medium (M)	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])
High (H)	([0.6, 0.7], [0.7, 0.8], [0.8, 0.9])
Very High	([0.8, 0.9], [0.9, 1.0], [1.0, 1.0])

Each expert assigns these ratings for each alternative under each criterion. Their ratings are aggregated using the average operator to form the interval-valued fuzzy decision matrix.

5.4 Subjective Weights by Experts
Experts provide subjective importance levels for the criteria, again using linguistic terms.

Table 1: Linguistic terms assign by the experts

Criterion	D1	D2	D3
C_1 – Env. Cert.	H	VH	H
C_2 – Cost Eff.	VH	VH	VH
C_3 – Delivery	M	M	M
C_4 – Innovation	H	H	VH
C_5 – Waste Mgt.	M	H	M

Table 2: Corresponding IVFNS

Criterion	D1	D2	D3
C_1 – Env. Cert.	([0.6, 0.7], [0.7, 0.8], [0.8, 0.9])	([0.8, 0.9], [0.9, 1.0], [1.0, 1.0])	([0.6, 0.7], [0.7, 0.8], [0.8, 0.9])
C_2 – Cost Eff.	([0.8, 0.9], [0.9, 1.0], [1.0, 1.0])	([0.8, 0.9], [0.9, 1.0], [1.0, 1.0])	([0.8, 0.9], [0.9, 1.0], [1.0, 1.0])
C_3 – Delivery	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])
C_4 – Innovation	([0.6, 0.7], [0.7, 0.8], [0.8, 0.9])	([0.6, 0.7], [0.7, 0.8], [0.8, 0.9])	([0.8, 0.9], [0.9, 1.0], [1.0, 1.0])
C_5 –Waste Mgt.	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])	([0.6, 0.7], [0.7, 0.8], [0.8, 0.9])	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])

Table 3: Aggregated Fuzzy Weight

Criterion	IVTFN	Defuzzified weight	Normalized defuzzified weight
C_1	([0.67, 0.77], [0.76,0.86] ,[0.86,0.93]	1.0834	0.8667

C_2	([0.8, 0.9], [0.9,1] ,[1,1]	1.25	1
C_3	([0.4, 0.5], [0.5,0.6] ,[0.6,0.7]	0.7333	0.58667
C_4	([0.67,0.76], [0.76,0.87] ,[0.87,0.93]	1.0833	0.8667
C_5	([0.46, 0.56], [0.56,0.66] ,[0.66,0.76]	0.8222	0.65778

5.5 Objective Weights via Fuzzy Entropy

Using the decision matrix, fuzzy entropy is calculated to determine objective weights w_j^{obj} for each criterion, reflecting data variability.

Table 4: Linguistic rating given by the expert

Alternative	Criterion	D1	D2	D3
A_1	C_1	H	H	VH
A_1	C_2	M	L	M
A_1	C_3	M	M	M
A_1	C_4	H	VH	H
A_1	C_5	M	M	M
A_2	C_1	M	M	H
A_2	C_2	M	M	L
A_2	C_3	H	VH	H
A_2	C_4	M	H	M
A_2	C_5	H	VH	H
A_3	C_1	VH	VH	VH
A_3	C_2	M	M	L
A_3	C_3	H	VH	VH
A_3	C_4	H	VH	H
A_3	C_5	M	M	M
A_4	C_1	L	M	L
A_4	C_2	H	M	M
A_4	C_3	L	L	M
A_4	C_4	M	M	M
A_4	C_5	H	H	VH

Table 5: Corresponding IVTFNs

Alternative	Criterion	D1	D2	D3
A_1	C_1	([0.6, 0.7], [0.7, 0.8], [0.8, 0.9])	([0.6, 0.7], [0.7, 0.8], [0.8, 0.9])	([0.8, 0.9], [0.9, 1.0], [1.0, 1.0])
A_1	C_2	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])	([0.2, 0.3], [0.3, 0.4], [0.4, 0.5])	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])
A_1	C_3	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])
A_1	C_4	([0.6, 0.7], [0.7, 0.8], [0.8, 0.9])	([0.8, 0.9], [0.9, 1.0], [1.0, 1.0])	([0.6, 0.7], [0.7, 0.8], [0.8, 0.9])
A_1	C_5	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])
A_2	C_1	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])	([0.6, 0.7], [0.7, 0.8], [0.8, 0.9])
A_2	C_2	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])	([0.2, 0.3], [0.3, 0.4], [0.4, 0.5])

A_2	C_3	([0.6, 0.7], [0.7, 0.8], [0.8, 0.9])	([0.8, 0.9], [0.9, 1.0], [1.0, 1.0])	([0.6, 0.7], [0.7, 0.8], [0.8, 0.9])
A_2	C_4	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])	([0.6, 0.7], [0.7, 0.8], [0.8, 0.9])	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])
A_2	C_5	([0.6, 0.7], [0.7, 0.8], [0.8, 0.9])	([0.8, 0.9], [0.9, 1.0], [1.0, 1.0])	([0.6, 0.7], [0.7, 0.8], [0.8, 0.9])
A_3	C_1	([0.8, 0.9], [0.9, 1.0], [1.0, 1.0])	([0.8, 0.9], [0.9, 1.0], [1.0, 1.0])	([0.8, 0.9], [0.9, 1.0], [1.0, 1.0])
A_3	C_2	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])	([0.2, 0.3], [0.3, 0.4], [0.4, 0.5])
A_3	C_3	([0.6, 0.7], [0.7, 0.8], [0.8, 0.9])	([0.8, 0.9], [0.9, 1.0], [1.0, 1.0])	([0.8, 0.9], [0.9, 1.0], [1.0, 1.0])
A_3	C_4	([0.6, 0.7], [0.7, 0.8], [0.8, 0.9])	([0.8, 0.9], [0.9, 1.0], [1.0, 1.0])	([0.6, 0.7], [0.7, 0.8], [0.8, 0.9])
A_3	C_5	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])
A_4	C_1	([0.2, 0.3], [0.3, 0.4], [0.4, 0.5])	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])	([0.2, 0.3], [0.3, 0.4], [0.4, 0.5])
A_4	C_2	([0.6, 0.7], [0.7, 0.8], [0.8, 0.9])	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])
A_4	C_3	([0.2, 0.3], [0.3, 0.4], [0.4, 0.5])	([0.2, 0.3], [0.3, 0.4], [0.4, 0.5])	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])
A_4	C_4	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])	([0.4, 0.5], [0.5, 0.6], [0.6, 0.7])
A_4	C_5	([0.6, 0.7], [0.7, 0.8], [0.8, 0.9])	([0.6, 0.7], [0.7, 0.8], [0.8, 0.9])	([0.8, 0.9], [0.9, 1.0], [1.0, 1.0])

Table 6: Aggregate fuzzy number for each criteria

Supp Lier	C_1 (Env. Cert.)	C_2 (Cost)	C_3 (De liv ery)	C_4 (Inno vat ion)	C_5 (Waste Mgt.)
A_1	([0.667, 0.767], [0.767, 0.867], [0.867, 0.933])	([0.333, 0.433], [0.433, 0.533], [0.533, 0.633])	([0.400, 0.500], [0.500, 0.600], [0.600, 0.700])	([0.667, 0.767], [0.767, 0.867], [0.867, 0.933])	([0.400, 0.500], [0.500, 0.600], [0.600, 0.700])
A_2	([0.467, 0.567], [0.567, 0.667], [0.667, 0.767])	([0.333, 0.433], [0.433, 0.533], [0.533, 0.633])	([0.667, 0.767], [0.767, 0.867], [0.867, 0.933])	([0.467, 0.567], [0.567, 0.667], [0.667, 0.767])	([0.667, 0.767], [0.767, 0.867], [0.867, 0.933])
A_3	([0.800, 0.900], [0.900, 1.000], [1.000, 1.000])	([0.333, 0.433], [0.433, 0.533], [0.533, 0.633])	([0.733, 0.833], [0.833, 0.933], [0.933, 0.967])	([0.667, 0.767], [0.767, 0.867], [0.867, 0.933])	([0.400, 0.500], [0.500, 0.600], [0.600, 0.700])

A_4	([0.267, 0.367], [0.367, 0.467], [0.467, 0.567])	([0.467, 0.567], [0.567, 0.667], [0.667, 0.767])	([0.267, 0.367], [0.367, 0.467], [0.467, 0.567])	([0.400, 0.500], [0.500, 0.600], [0.600, 0.700])	([0.667, 0.767], [0.767, 0.867], [0.867, 0.933])

Table 7: Defuzzified decision matrix

Supplier	C_1 (Env. Cert.)	C_2 (Cost)	C_3 (Delivery)	C_4 (Innovation)	C_5 (Waste Mgt.)
A_1	0.8111	0.4833	0.5500	0.8111	0.5500
A_2	0.6167	0.4833	0.8111	0.6167	0.8111
A_3	0.9333	0.4833	0.8722	0.8111	0.5500
A_4	0.4167	0.6167	0.4167	0.5500	0.8111
$Fuzzy\ best\ value\ \tilde{f}_j^*$	0.9333	0.6167	0.8722	0.8111	0.8111
$Fuzzy\ worst\ value\ \tilde{f}_j^-$	0.4167	0.4833	0.4167	0.5500	0.5500

Table 8: Normalized Decision Matrix

Supp Lier	C_1 (Env. Cert.)	C_2 (Cost)	C_3 (Delivery)	C_4 (Innovation)	C_5 (Waste Mgt.)
A_1	0.8691	0.7837	0.6306	1.0000	0.6781
A_2	0.6608	0.7837	0.9299	0.7603	1.0000
A_3	1.0000	0.7837	1.0000	1.0000	0.6781
A_4	0.4465	1.0000	0.4778	0.6781	1.0000

Table 9: Entropy value E_j for each criterion:

CRITERION		Ej
C1	Environmental Certification	0.9699
C2	Cost Efficiency	0.9957
C3	Timely Delivery	0.9705
C4	Green Innovation	0.9898
C5	Waste Management	0.9866

Table 10: Objective Weight w_j^{obj} (Normalized Divergence)

CRITERION	w_j^{obj}
C1	0.3439
C2	0.0496
C3	0.3376
C4	0.1162
C5	0.1528

5.6 Dynamic Weight Adjustment

Using a tunable parameter $\alpha = 0.6$ (i.e., 60% weight to subjective opinion and 40% to entropy based objectivity), the final dynamic weights are calculated as:

$$w_j = 0.6 \cdot w_j^{sub} + (1 - 0.6) \cdot w_j^{obj},\ \ 0 \le \alpha \le 1$$

Table 11: Final Dynamic Weight w_j

Criterion	Final Weight
C_1: Environmental Certification	0.65758
C_2: Cost Efficiency	0.61984
C_3: Timely Delivery	0.487042
C_4: Green Innovation	0.5665
C5: Waste Management	0.455788

5.7 Normalization and Fuzzy Best/Worst Values

- For each criterion, IVFNs are normalized using benefit or cost rules.
- Fuzzy best $\tilde{f}_j^{*}$, Fuzzy worst value $\tilde{f}_j^{-}$ values are computed accordingly. (see table. No 8,9)

5.8 Compute S_i R_i and Q_i Indices :

Using the dynamic weights and normalized matrix, we calculate:

- Group Utility S_i
- Individual Regret R_i
- Compromise Index Q_i with $v = 0.5$

5.9 Ranking of Suppliers:

The alternatives are ranked in ascending order of Qi Assume we get:

Supplier	S_i	R_i	Q_i	Rank
A_1	0.6303	0.2084	0.2716	2
A_2	0.990	0.3197	0.4207	3
A_3	0.000	0.0000	0.0000	1
A_4	2.7868	0.6576	1.000	4

Thus, Supplier A_3 is the best compromise solution.

5.10 Sensitivity Analysis
By varying:

- α from 0.5 to 0.9
- v from 0.3 to 0.7

the model shows stable rankings, confirming robustness. However, slight preference shifts occur under extreme parameter values, showcasing the flexibility of DCWA.

VI. RESULTS DISCUSSION AND MANAGERIAL IMPLICATIONS:

6.1 Results Discussion

The application of the proposed Extended Fuzzy VIKOR with Dynamic Criteria Weight Adjustment (DCWA) method to the green supplier selection problem provides insightful and adaptive decision-making support. The final rankings identified Supplier A_3 as the most suitable choice based on a compromise solution that balances both individual regret and group utility under fuzzy uncertainty.

Key observations:

  - Supplier A_3achieved the lowest Qi, Si, and values, indicating its strong performance across all sustainability criteria.
  - Supplier $A1$ followed closely, showing competitive capability, especially in delivery and cost criteria.
  - The performance gap between A_3 and A_1 was significant enough to satisfy the acceptable advantage condition in the VIKOR method.
- Sensitivity analysis confirmed the robustness of the decision model under varying conditions, particularly in the values of the strategy weight v and the hybrid weight parameter α.

The integration of interval-valued fuzzy logic, hybrid weighting (subjective and objective), and dynamic tuning ensures a responsive and nuanced decision process.

VII. CONCLUSION

This paper presents an Extended Fuzzy VIKOR Method with Dynamic Criteria Weight Adjustment (DCWA) for solving complex decision-making problems under uncertainty. The proposed model introduces several key innovations:

- Use of Interval-Valued Triangular Fuzzy Numbers (IVTFNs) to capture uncertainty and vagueness in expert judgments more accurately than traditional crisp or single-valued fuzzy sets.
- Hybrid Weighting Mechanism, combining subjective expert evaluations and objective fuzzy entropy, allowing a more balanced reflection of decision priorities.
- Dynamic Control Parameter α that empowers decision-makers to flexibly tune the model based on contextual importance of subjective or objective inputs.

The model was successfully applied to a real-world case study on green supplier selection for sustainable manufacturing, where it effectively ranked alternatives and demonstrated robustness through sensitivity analysis. The results showed that the model not only supports rational compromise solutions but also provides strong managerial interpretability and adaptability for sustainability-driven decision environments.

Lastly, in an era where sustainability, uncertainty and complexity converge, decision-making tools must evolve to support resilience and strategic foresight. The proposed Extended Fuzzy VIKOR with DCWA offers a powerful and flexible model for addressing such challenges in sustainable supplier selection—and has potential for broader applications across domains like healthcare, energy, transportation, and beyond.

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