RESEARCH ARTICLE

Sustainable supplier selection based on VIKOR with single-valued neutrosophic sets

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Abstract

Considering economic, environmental, and social issues, the sustainability of the supply chain has drawn considerable attention due to societal and environmental changes within the supply chain network. The strategic study of the entire supply chain process and maximizing an organization's competitive advantage depend heavily on supplier selection based on sustainable indicators. Selecting sustainable suppliers for the supply chain is challenging since it is a multi-criteria decision-making (MCDM) problem with significant uncertainty in the decision-making process. This study uses the VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) technique and single-valued neutrosophic sets (SVNS) to deal with the challenge of choosing a sustainable supplier with insufficient information. This method reduces the influence of personal experience and preference on the final evaluation results and the problem of excessive individual regret caused by factor correlation and improves the consistency of evaluation results. Finally, the method's success and adaptability are demonstrated by sensitivity analysis and additional comparison analysis, and the benefits and drawbacks of the suggested framework are examined. Compared to other approaches, it can assist decision-makers in communicating fuzzy and uncertain information, offering a perspective and approach for MCDM in the face of such situations, and helping them select suppliers of high caliber and who practice sustainable business practices.

1 Introduction

A number of issues, including global warming and natural disasters, have evolved as a result of the rapid development of economic globalization and industrialization [1]. Globalization will continuously bring various economic changes, making these circumstances almost challenging to stop. However, it is worth considering that the direction we should be taking should provide a healthy environment and sustainable economy with fewer harmful effects [2]. Supply chain management (SCM) has historically been used to a considerable extent to forward economic objectives at the expense of society and the environment. It is essential to include environmental and social issues in the SCM metrics due to current environmental and resource concerns and the general expectations of social subjects and stakeholders for sustainability and

ecological responsibility [3]. In today's globalized businesses, sustainability is seen as a source of organizational advantage, and any unfavorable effects on sustainability that upstream suppliers feel will pass it down to downstream industries. For instance, suppliers to fashion companies like H&M and Next release dangerous chemicals into rivers, substantially harming the business's reputation and customers' purchase intentions [4].

Therefore, when choosing suppliers, businesses take into account both the direct economic benefits that suppliers contribute at the commercial level as well as whether their sustainable growth can result in indirect economic benefits [5]. SSCM, or sustainable supply chain management, has drawn much interest from businesses and the industry [6] and evolved into the primary business strategy [7]. From a system and integration standpoint, SSCM is a valuable management technique for resolving the conflict between a company and its environment and is extensively used at the same time [8].

The foundation of SSCM and the core of supplier management are excellent sustainable suppliers [9–11]. As the input of the supply chain, suppliers play an essential role in products, services, organizations, and sustainable performance [12–14]. To integrate all supply chain processes, businesses need an effective SCM. Selecting and evaluating suppliers is the first stage, but this process takes time and resources [15]. By choosing the suppliers with the greatest potential, a firm can benefit from a number of benefits, optimize financial rewards, and reduce costs and risks [16]. IKEA, for instance, controls its supply chain using socially and environmentally responsible methods while expanding its market share and attaining corporate success [17].

Traditionally, the economic aspect is regarded as the primary basis of supplier selection [18]. In addition to economic factors, green image, social concern, and economic policy are forcing companies to integrate SSCM [19]. Therefore, in the sustainable supplier selection process, evaluating and selecting suitable suppliers is an arduous task [1]. Confusion commonly develops when choosing sustainable providers due to multiple constraints, a lack of knowledge, complicated human cognitive processes, and the issue's inconsistency. Several multi-criteria decision-making (MCDM) models are offered to evaluate potential suppliers; nevertheless, accurate and reliable information is insufficient to represent real-world, natural problems [20,21]. Academics and professionals pay attention to SSC-related concerns because they call for creating a systematic process that simultaneously handles competing for quantifiable and non-quantifiable aspects. A rigorous decision-making process goes into choosing sustainable suppliers. The evaluation procedure requires numerous qualitative and quantitative markers involving inaccurate and unclear data. By improving various MCDM practices, where a set number of suppliers are assessed following the quantitative and qualitative criteria taken into account by MCDM procedures, people attempt to solve such issues.

The economic, environmental, and social factors are combined to create the evaluation criteria for sustainable suppliers, and AHP and entropy weight is used to calculate the total importance. By extending the VIKOR approach to SVNS, SVNS is used to simplify the process. The measurement formula is considered, and the "relative distance" is adopted. The effectiveness of the method is measured by sensitivity analysis and method comparison. This paper subsequently identified numerous objectives after thoroughly evaluating relevant studies as follows:

1. Determine sustainable supplier selection criteria and evaluation measures, and effectively identify and evaluate supplier qualification.

2. How to deal with the uncertainty and inconsistency of evaluation information.

3. Assess the eligibility weight of the measures and select the most likely sustainable supplier.

4. How to develop a useful tool to select the best sustainable suppliers.

The remainder of this paper is organized as follows. The pertinent research on sustainable suppliers and MCDM techniques are found in Section 2, while the approaches are covered in Section 3. The development of a sustainable supplier evaluation approach is also covered in section 4. The mathematical analysis in Section 5 thoroughly explains the chosen tactics. Sensitivity analysis, discussion, and technique comparison serve to validate the model's accuracy and reliability. Section 6 concludes by summarizing the findings and suggesting a course for further investigation.

2 Literature review

The external environment of businesses is unstable because of ongoing changes in consumer behaviour, technological development, and political climate. For the long-term growth of companies, especially the supply chain, it is crucial to assess and choose sustainable suppliers in an uncertain environment. As a result, the decision-making capabilities of the supplier have long been a subject of interest for academic research. Identification, screening, evaluation, analysis, and contract signing with suppliers are all parts of the supplier selection process [22]. The solution to the dilemma of sustainable supplier decision-making lies in the identification and selection of criteria. In the early supplier selection research paradigm, academics considered conventional metrics like cost/price, quality, service level, delivery time, flexibility, and delivery [23]. With the ongoing evolution of the economy and society, the supplier selection process have changed significantly. Environmental considerations are typically overlooked when choosing suppliers in the traditional manner. Green suppliers become more visible in SCM as a result of rising customer awareness of environmental issues and stakeholder pressure on companies to take these issues into account throughout their supply chains [24,25]. Green suppliers have successfully solved the supply chain issue by taking ecological concerns into account, however this approach ignores the social components in the supply chain network, and SSC was established to address this issue [26]. Seuring and müller [27] were the first to suggest the idea of SSC. Economy, environment, society, and product recycling are the primary research areas of SSC.

As a means of giving businesses a competitive edge, sustainability refers to balancing financial success with social and environmental concerns. Therefore, environmental and social factors must be included in the supplier selection criteria of businesses in addition to the traditional economic reasons [28]. The main goal of supply chain planning is to maximize economic gain [29], and the two most popular optimization indicators are profit [30] and cost [31,32]. Similar to how economic benefits are often considered when making decisions, many researchers also believe in environmental aspects of sustainability. For example, building a tactical supply chain planning model [33] to study the balance between the economy and the environment and using carbon emissions as an indicator of environmental components [34,35] are just two examples. More scholars and practitioners are examining SSC concerns to balance economic, environmental, and social benefits due to consumer attention to environmental and social issues and strengthening government regulation in this area [36].

After selecting appropriate evaluation criteria for suppliers, the distribution of weights is also critical, mainly including subjective and objective weighting methods, which can also be obtained through the combination of these methods [37]. The primary purpose of weight is to distinguish the importance of different criteria according to people's will. Therefore, subjective weighting is the most commonly used weight setting method [38]. The most widely used method in this category, AHP, is frequently used in supplier selection [15]. It enables the decision-maker to gauge the consistency of their judgments. Additionally, it is user-friendly and

appropriate for group choices [39]. On the other hand, subjective approaches rely on individual tastes and struggle with consistency [37]. The objective weighing approach, such as the entropy weight method, is frequently employed to address this issue and make up for the drawbacks of the subjective weight-setting method. The above two methods are sometimes adopted simultaneously for more comprehensive results [40].

Many studies have adopted quantitative methods, focusing on supplier evaluation and selection, and most methods include MCDM, artificial intelligence, and mathematical programming [26]. Govindan pointed out that as a decision-making tool to deal with this problem, MCDM methods are still more popular than mathematical programming and artificial intelligence methods [41]. There will always be some degree of uncertainty in the decision-making process. Because information is sometimes delayed and inconsistent, it can be challenging to determine the criteria [17]. To solve the criteria difficulties, various MCDM approaches have been created. These can be categorized into two groups: integrated MCDM and singular working MCDM methods [42]. Data envelopment analysis (DEA) [2], multi-objective linear programming method [43], analytic hierarchy process (AHP) [44], mathematical programming method [45], the technique for order preference by similarity to ideal solutions (TOPSIS) [46], and decision-making trial and evaluation laboratory (DEMATEL) [47] are examples of single working MCDM methods. Two independent functioning MCDM methods are combined to create integrated MCDM methods [48]. A separate functioning MCDM technique may also be combined with auxiliary algorithms, such as genetic algorithms [49], artificial neural networks [50], cluster analyses [51], and fuzzy theory [52], to form an integrated MCDM method. The integrated MCDM technique can lessen or even eliminate away with the drawbacks of the single MCDM method [42]. Choosing an appropriate MCDM method when solving a multi-attribute decision-making problem is essential. Different MCDM models have their own characteristics, and no MCDM method is superior to the others in all aspects [53].

With the complexity of economic activities, uncertain information increasingly impacts enterprise management. In practice, sustainable supplier selection usually involves decision makers in different departments, such as purchasing, production, quality control departments, etc., and there are many conflicts in the standards of sustainability and risk. Therefore, selecting sustainable suppliers is a frequent and difficult MCDM challenge [54,55]. Several evaluation criteria have altered the evaluation process: the evaluation information's complexity and the evaluation criteria' uncertainty [56]. Due to the complexity of actual decision-making situations and the limitations and incomplete data of decision-makers subjective cognition, it is challenging to define decision-makers' evaluation preferences with precise values [57]. To better deal with such problems, the uncertainty theory has also been utilized [58] in various methods [59]. Regarding the supplier selection process, its advantage is to reduce uncertainty [60] and significantly help decision maker's deal with inaccurate, ambiguous, and subjective data.

Fuzzy sets and fuzzy logic have since been widely employed to handle uncertainty issues in daily life [61,62]. Scholars have successively optimized fuzzy sets [63,64], such as Fuzzy Sets of Type-2 [65], standard fuzzy sets [66], hesitant fuzzy sets [67], interval-valued intuitionistic fuzzy values [20], and complex Pythagorean fuzzy sets [48]. In conjunction with MCDM techniques like AHP, ANP, DEA, and TOPSIS, fuzzy set theory and its extension have been used to solve supplier selection decision-making problems [68,69]. However the fuzzy set theory is unable to cope with the ambiguous and inconsistent standards of information that exist in reality, and it is also unable to address information discontinuity and consistency. Thus, neutrosophic sets were created by Smarandache [70]. It is a discipline of philosophy, and a mathematical instrument used to investigate the beginning, character, range, and relationship of their various conceptual contents. In contrast to other uncertainty sets, the neutrosophic sets

take into account the idea of three parameters and employ three membership degrees to represent ambiguous and inconsistent information. More importantly, there is no relationship between these ideas [71]. Since it is challenging to apply neutrosophic sets to actual engineering and research, neutrosophic sets are expanded to SVNS for the flaws of non-standard subsets of neutrosophic sets. Ye defines the idea of simplified neutrosophic sets and uses an exact number between [0,1] to express its truth value, uncertainty, and fallacy to overcome the problems of inaccurate, uncertain, and inconsistent data [72].

In MCDM tools [73], such as AHP [74], DEMATEL [75], multi-objective optimization based on ratio analysis (MULTIMOORA) [76], and TOPSIS [77,78], methods employing Neutrosophic Sets have been employed. MCDM is a suitable approach to handle supplier selection. One of the most well-known of them is the VIKOR approach (multi-criteria compromise ranking method), which was developed by Opricovic (1998) to address discrete choice problems [79]. It is capable of figuring out a compromise solution to the MCDM issue and maintaining equilibrium between overall happiness and personal regrets [80]. The VIKOR method aids decision-makers in figuring out a compromise solution to the decision-making problem to arrive at a more accurate final decision [39]. It focuses on ranking alternatives and choosing the best from a set of these alternatives, which can include many conflicting and non-commensurable criteria. The VIKOR approach is frequently employed to address issues in management and decision-making [81,82].

Solving sustainability-related problems has become more difficult today due to natural disasters, diseases, climate change, social responsibility, and other variables disrupting the corporate environment. The literature review of suppliers suggests that the idea of sustainability has been independently researched in the context of supplier selection. This research identifies several indicators based on the economic, social, and environmental sustainability elements discussed in the literature. In reality, judgments depend on qualitative data, and decision-makers' subjective preferences frequently affect how supplier preferences and criteria are weighted [83]. AHP can measure the proportional importance of criteria, and its flexibility and ability to check for inconsistencies can help decision-makers integrate subjectivity, experience, and knowledge into the decision-making process. The entropy weight method is regarded as influential in determining the weight of criteria in an uncertain decision-making environment. Entropy describes the uncertainty of information, increasing the utilization of practical knowledge and ensuring decision-making accuracy.

Therefore, this paper considers the importance of human judgment and the information provided by the original data and uses the AHP and entropy weight methods to obtain the indicators' total weight. VIKOR method is also increasingly used to quantitatively assess complex economic, social, and environmental processes. In the VIKOR method, the selected best alternative considers the relative closeness to the ideal and harmful solutions and the defined acceptable advantage and acceptable stability in decision-making with three parameters [84]. VIKOR method achieves the optimal ranking of limited alternative decision-making schemes by maximizing the group utility and minimizing the individual regret degree, which makes the decision more reasonable [85]. The MCDM problem's neutrosophic set approach helps to overcome the drawbacks of integrating qualitative measurement and subjective assessment. To describe the selection problem and do a sensitivity analysis, this paper proposes a VIKOR model based on single-valued neutrosophic set to lessen the impact of individual preference and experience on the final results of evaluation, to solve the issue of excessive personal regret brought on by factor correlation, and put forward the notion of "relative distance" to increase evaluation accuracy. The method proposed in this paper provides a solution closer to ideal and a balance between minimal individual regret and maximum group utility, and also considers the flawed information provided by managers to help decision-makers communicate

evaluation information more accurately and effectively. Moreover, this method has lower complexity.

3 Basic concept

3.1 VIKOR

The core idea of the VIKOR method is to determine the positive and negative solutions, calculate the variables, and sort the schemes. The smaller the value, the better the evaluation object [85]. For the purpose of calculating programs, the following formulas are used:

$$S_i = \sum_{j=1}^{n} w_j \frac{f_{ij}^+ - f_{ij}}{f_{ij}^+ - f_{ij}^-}$$

$$R_i = \max_j \left\{ w_j \frac{f_{ij}^+ - f_{ij}}{f_{ij}^+ - f_{ij}^-} \right\}$$

$$Q_i = v \left(\frac{S_i - S^-}{S^+ - S^-} \right) + (1 - v) \left(\frac{R_i - R^-}{R^+ - R^-} \right) \tag{1}$$

Among them, S_i represents the overall utility value and R_i represents the individual regret value. f_{ij}^+ is the positive rational solution, f_{ij}^- is the negative rational solution, and Q_i represents the ratio of benefits that the scheme A_i can produce.

$S^+ = \max S_i, S^- = \min S_i, R^+ = \max R_i, R^- = \min R_i$. v is the adjustment coefficient of "group utility" and "individual regret," $v<0.5$ means more attention to individual regret and $v>0.5$ means more attention to group satisfaction; v usually equals 0.5.

By using linear weighting and only taking into account the difference between each scheme under each index and the optimal term under that index, the conventional VIKOR technique subtracts two values when computing the distance. The acquired solution will raise the calculated value of the group utility, comparable to a covert increase of the group utility coefficient v, leading to a reasonably considerable divergence in the estimated distance. The individual regret value in Formula (1) is to select the most significant value. The classic VIKOR approach will boost the personal regret value and exaggerate the particular regret when the assessment indicators are related.

On the basis of this, the conventional VIKOR approach has to be improved. Three parameters are taken into account in the theory of neutrosophic sets: the degree of truth, the degree of uncertainty, and the degree of distortion. This can assist decision-makers in providing more accurate and thorough opinions as well as addressing issues that the VIKOR is unable to address.

3.2 Single-valued neutrosophic sets

Definition 1. [76] (SVNS): Let X be the given collection, the single-valued neutrosophic A is defined in the collection X; it consists of three functions $(T_A(x), I_A(x), F_A(x))$ of a finite subset of X to the unit interval [0,1]. A can be expressed as $A = \{\langle x, T_A(x), I_A(x), F_A(x) \rangle x \in X\}$. Here, $T_A(x), I_A(x), F_A(x)$ are three sets of finite discrete values that belong to [0,1], representing the degree of truth, the degree of uncertainty, and the degree of distortion, respectively.

In particular, $a = \langle t,i,f \rangle$ is called a single-valued neutrosophic number, and $0 \le t, i, f \le 1, 0 \le t^+ + i^+ + f^+ \le 3, t \in T_A(x), i \in I_A(x), f \in F_A(x)$.

Definition 2. [76]: $A = \langle T_A(x), I_A(x), F_A(x) \rangle$ is set to the single-valued neutrosophic set.
Hence, the complementary set of A is $A^C = \langle 1 - T_A(x), 1 - I_A(x), 1 - F_A(x) \rangle$

Definition 3. [86]: For the single-valued neutrosophic number $A = \langle T_A(x), I_A(x), F_A(x) \rangle$,
its scorecard function S_A, exact function α_A, and definite function C_A are respectively defined
as follows:

$$S_A = \frac{T_A + 1 - I_A + 1 - F_A}{3}$$

$$\alpha_A = T_A - F_A$$

$$C_A = T_A \tag{2}$$

Definition 4. [86]: For two single-valued neutrosophic numbers A and B:
If $S_A > S_B$, then $A > B$;
If $S_A = S_B, \alpha_A > \alpha_B$, then $A > B$;
If $S_A = S_B, \alpha_A = \alpha_B, C_A > C_B$, then $A > B$;
The following formula is used to calculate the distance between single-valued neutrosophic
sets:

$$A = \{T_A(x), I_A(x), F_A(x) | x_i \in X\}, B = \{T_B(x), I_B(x), F_B(x) | x_i \in X\},$$

Then, the weighted measurement distance formula between the two single-valued neutro-
sophic set is expressed as [87]:

$$d_\lambda(A, B) = \left[\sum_{j=1}^{n} W_j (\sum_{i=1}^{4} \beta_i \phi_i(x_j))^\lambda \right]^{\frac{1}{\lambda}} \tag{3}$$

Among, $\lambda > 0, \beta_i \in [0, 1], \sum_{i=1}^{4} \beta_i = 1, W_j \in [0, 1]$ and $\sum_{j=1}^{n} W_j = 1,$

$$\phi_1\left(x_j\right) = \frac{|T_A(x_i) - T_B(x_i)|}{3} + \frac{|I_A(x_i) - I_B(x_i)|}{3} + \frac{|F_A(x_i) - F_B(x_i)|}{3}$$

$$\phi_2\left(x_j\right) = \max\left\{ \frac{2 + T_A(x_i) - I_A(x_i) - F_A(x_i)}{3}, \frac{2 + T_B(x_i) - I_B(x_i) - F_B(x_i)}{3} \right\}$$

$$-\min\left\{ \frac{2 + T_A(x_i) - I_A(x_i) - F_A(x_i)}{3}, \frac{2 + T_B(x_i) - I_B(x_i) - F_B(x_i)}{3} \right\}$$

$$\phi_3\left(x_j\right) = \frac{|T_A(x_i) - T_B(x_i) + I_B(x_i) - I_A(x_i)|}{2}$$

$$\phi_4\left(x_j\right) = \frac{|T_A(x_i) - T_B(x_i) + F_B(x_i) - F_A(x_i)|}{2}$$

4 Model construction

Since numerous indicators and evaluation topics are involved in evaluating sustainable suppliers, it is vital to weigh both precise and ambiguous information concurrently [88]. This leads to establishing the three-phased proposed model for sustainable supplier selection in an uncertain environment:

- Building the sustainable supplier evaluation index system

- Obtaining the sustainable supplier evaluation index criteria weights

- Ranking potential sustainable suppliers

4.1 Construction of index system

In the conventional assessment procedure, we must first choose the best evaluation criteria before evaluating the alternatives and selecting the supplier. The creation of appropriate measures is a significant obstacle in supplier selection. These criteria are often seen to include three areas: the economy (money supply and capital), society (social issues), and the environment (pollution).As a result, sustainable providers should consider sustainability of the economy, society, and environment. Economic sustainability aims to maximize profits with the least amount of capital invested [89]; environmental sustainability concentrates on environmental issues [56] like pollution, resource reuse, and resource consumption; it also pays attention to resource utilization efficiency and waste generation; and social sustainability concentrates on employee equity and social responsibility. To produce unbiased and fair evaluation results, the sustainable supplier evaluation method must adhere to rational and scientific standards. The index system is made in accordance with the principles of hierarchy and systematization, independence, authenticity, and comparability, as well as the combination of qualitative and quantitative principles, and the evaluation system is built in accordance with practice. See Table 1.

4.2 Comprehensive weight method

4.2.1 Calculating subjective weight by AHP. AHP is a weighing technique that has quickly evolved for usage in real-world applications [124]. Following are the steps for utilizing the AHP approach to determine the weight of the criteria:

Step 1. Create a decision hierarchy using the requirements and options.

Step 2. Create the matrix for comparisons. As paired comparisons, each standard is evaluated versus various other criteria. All comparison matrices should be finished in accordance with the Saaty scale (Table 2), as follows [125]:

$$
A = \begin{pmatrix}
1 & \frac{c_1}{c_2} & \cdots & \frac{c_1}{c_n} \\
\frac{c_2}{c_1} & 1 & \cdots & \frac{c_2}{c_n} \\
\vdots & \vdots & 1 & \vdots \\
\frac{c_n}{c_1} & \frac{c_n}{c_2} & \cdots & 1
\end{pmatrix}
$$

Table 1. Sustainable supplier evaluation index system.

Dimension	Index layer	Detailed indicators
Economy B_1	Cost [13,90–95] C_1	Product Price [12,56,92,96–101], Product costs [74,101–104], Ordering Costs [74,101–104], Transportation Costs [74,88,97–101,103–107] Carbon tax [96]
	Innovation Capability C_2	Innovativeness [13,74,93,101,108,109], Technical Capabilities [12,74,90,91,94,95,97,99,110,111], Patents [102]
	Quality [13,32,56,90–95,97] C_3	Product Qualification Rate [94,98,102,112], Product Safety [56,100], Product Quality Improvement [92,98,113], Defect rate [74,103,112], Rejection rate [97,99,101,114], Quality Management System [98,100,101,104,115–117]
	Service Capability [91,94,98,118] C_4	Delivery Period [32,56,97,106,109], On-time delivery [74,86,90,92,97,100,103,107,109,112,113,116,117,119], After-sales service level [32,104,106,116,117,119], Order Completion Rate [103], Flexibility [12,56,86,90–92,96,110,114,115], Logistics [107,116], Responsiveness [99,104,107,119]
	Long-term cooperation [116] C_5	Finance [90,94–96,100,104,109,110,112,115,116], Culture [90], Enterprise size [102], Relationships [90,99,100,109,110,115,118], Performance History [86], Credibility [74,100], Supply capacity [92,117,118], Production facilities [74,94,100,109,112,116], Risks [32,90,104,112], Public Relations Capability
Society B_2	Environmental Management System [92,97,107,115] C_6	Environmental Management System [74,89–91,94,96,99,100,110,114,118,120], Eco-design [13,56,74,95,97,99,102,114,120], environmental certification [74,99,100,102,109], environmental costs [89,110], employee environmental training [98,100,109,120]
	Reduce pollution [99] C_7	Greenhouse gas emissions [90,109,121], Pollution Control [13,89,90,94,96,97,100,107,109–111,114,115,118], Resource consumption [12,74,90,91,98–100,103,107,108,110,111,115], Green Logistics [96,113], Reuse/recycling [74,90,91,99,107,109], Harmful substances [56,98,107,109,115], Waste Management [97–99,104,107,110]
	Green Image [90,92,94,98,100,114,120] C_8	Green Production [98,104,113,120], Green Packaging [74,99,100,104,110,114], Environmentally friendly materials [74,92,99,120], Green Products [94,96,97,111,114,115], Green Technology Capability [96,99,100,107–110,115],
Environment B_3	Social Responsibility [56,90,94,96,100,121] C_9	Impact of local establishment [74,90,94,97,110,115,118,122], Social Welfare [12,90,98], Employment Opportunities [90,99,102], Ethical issues and legal compliance [56,74,100,107,109,110,114,123], Product Liability [93,109],
	Employment Practices [93,122] C_{10}	Employee Rights and Benefits [74,89–92,99,104,110,111,113,115,121,122], Work safety and labor health [13,74,89,90,92–97,99–102,105–107,113–115,118,121], Working Environment (Human rights, discrimination, forced labor) [93,98,99,106,109,113,118], Employee turnover rate [74,98], Stakeholder Power [74,89–91,94,98,99,102,104,107,109–111,114,115,118,122], Information Disclosure [91,96,98,104,107,110,114,122], Staff Training [89,95,97,99,104,107,110,115,118]

Table 2. Scale given by reference [126] for pairwise comparison.

Preference/ordinal scale	Intensity of importance
1	Equal
3	Moderate
5	Strong
7	Very strong
9	Extreme
2,4,6,8	Intermediate weights between 1.3.5.7,9
Reciprocals	Inverse (opposite) comparison

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Step 3. Different weights can be applied to the sub-criteria and factors based on the various input data, and the correct weights can be derived. The results of the criterion were determined by creating a cumulative pairwise comparison matrix using the AHP software.

Step 4. Check the comparability matrices for consistency. The consistency ratio (CR), which is determined by dividing the consistency index (CI) by the random index (RI), determines the surface of the comparison matrix [125]. RI is influenced by matrix order (n). RI is calculated using Table 3. Where n stands for the number of criteria and is the matrix's primary eigenvalue. AHP software's reported incompatibility rate is assessed. A valid conclusion can be made if the inconsistency rate is 0.1 or less and the matrix is consistent.

4.2.2 Calculating objective weight by entropy. Let the neutrosophic sets be $A = \{x, T_A(x), I_A(x), F_A(x)|x_i \in X\}$ and the domain be $X = \{x_1, x_2, \cdots x_m\}$, then calculate the entropy $E_{(A)}$ of each single-valued neutrosophic set in the evaluation matrix. Determine the factor weight as Eq (4) [126].

$$E_{(A)} = 1 - \frac{1}{n}\sum_{x_i \in x}\left(T_A(x_i) + F_A(x_i) \cdot |I_A(x_i) - I_{A^C}(x_i)|\right)$$

$$o\omega_{c_j} = \frac{1 - \frac{1}{m}\sum_{i=1}^{m}E_{(A)}}{\sum_{j=1}^{n}\left(1 - \frac{1}{m}\sum_{i=1}^{m}E_{(A)}\right)}(i = 1, 2, \cdots, m; j = 1, 2, \cdots n) \tag{4}$$

Among, $E_{(A)}$ is the entropy of the neutrosophic set A, $o\omega_{c_j}$ is the subjective weight of the index.

4.2.3 Obtaining the combination weight. The comprehensive weight of indicators (c_j) can be expressed by Eq in order to increase judgment accuracy and get beyond the limitations of the independent subjective weighting approach and the independent objective weighting method. (5) [38,127].

$$\omega_{c_j} = \alpha \times s\omega_{c_j}(1 - \alpha) \times o\omega_{c_j}(j = 1, 2, \cdots, n) \tag{5}$$

Table 3. Presents a random index from reference [125].

n	2	3	4	5	6	7	8	9	10
RI	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

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Whereas ω_{c_j} is the comprehensive weight, $o\omega_{c_j}$ is the objective weight, $s\omega_{c_j}$ is the subjective weight obtained by the AHP method, and α is weight coefficient, $0 \leq \alpha \leq 1$. Here we take $\alpha = 0.5$.

4.3 VIKOR method based on single valued neutrosophic set

One must consider both the distance between A and B and the spread between A and B and C while extending the single-valued neutrosophic sets to VIKOR. To ensure that the distance between each scheme and the positive ideal solution is minimized and the distance between each project and the perfect negative solution is always the greatest, the weighted relative distance between each answer and the positive and negative ideal solutions is divided by the weighted distance between the positive and negative perfect solutions to determine the "relative distance."

The following formulas are used:

$$\Delta d_{ij} = d_{ij}^+ - d_{ij}^-$$

$$d_{ij}^+ = d(O_{ij}, O_{ij}^+) = d(O_{ij}^+, O_{ij})$$

$$d_{ij}^- = d(O_{ij}, O_{ij}^-) = d(O_{ij}^-, O_{ij}) \tag{6}$$

Here, Δd_{ij} is a relative distance, and the smaller Δd_{ij} is, the better the scheme is. On the contrary, the larger Δd_{ij} is, the worse the scheme is, $i = 1,2,\cdots,m, j = 1,2,\cdots,n$.

In a single valued neutrosophic sets environment, this study assumes that there are m alternative schemes, and that the alternative set is $A = \{A_1, A_2 \cdots, A_n\}$, and n indicators are selected to evaluate each scheme. The index set is $C = \{C_1, C_2 \cdots, C_n\}$, and the n attribute values of scheme A_i are represented by $O = \{O_{i1}, O_{i2}, \cdots, O_{in}\}$, where O_{ij} is the value of the scheme A_i under the C_j index, expressed in the form of the a single valued neutrosophic number, that is:

$O_{ij} = \langle T_{A_i}(c_j), I_{A_i}(c_j), F_{A_i}(c_j) \rangle$, where $i = 1,2,\cdots,m, j = 1,2,\cdots,n$, the weight of each index is determined using the entropy weight method.

According to definitions 3 and 4, the positive ideal solution O_{ij}^+ and negative ideal solution O_{ij}^- of m alternatives are determined, and the weighted distance Δd_{ij}^* between them is calculated by Formula (3), $i = 1,2,\cdots,m, j = 1,2,\cdots,n$.

Using Formula (3) to calculate the weighted distance d_{ij}^+ of each scheme and positive ideal solution O_{ij}^+, $i = 1,2,\cdots,m, j = 1,2,\cdots,n$.

Using Formula (3) to calculate the weighted distance d_{ij}^- of each scheme and negative scenario solution O_{ij}^-, $i = 1,2,\cdots,m, j = 1,2,\cdots,n$.

Δd_{ij} is calculated according to Formula (6).

According to the formula, S_i, R_i and Q_i are calculated. The decision-making mechanism coefficient v in the formula takes the median value, order $v = 0.5$, which means that the maximum group utility should be pursued and the individual regret should be minimized at the same time.

The calculation formulas of S_i, R_i and Q_i of the scheme are as follows:

$$S_i = \sum_{j=1}^{n} W_j \frac{\Delta d_{ij}}{\Delta d_{ij}^*}$$

$$R_i = \max_j \langle W_j \frac{\Delta d_{ij}}{\Delta d_{ij}^*} \rangle$$

$$Q_i = v \left(\frac{S_i - S^-}{S^+ - S^-} \right) + (1 - v) \left(\frac{R_i - R^-}{R^+ - R^-} \right) \tag{7}$$

Among them, S_i represents the overall utility value, and R_i represents the individual regret value. Δd_{ij} represents the relative distance between each scheme and the positive and negative ideal solutions, $\Delta d_{ij}^* = d(O_{ij}^+, O_{ij}^-)$ represents the relative distance between positive and negative ideal solutions, and Q_i represents the benefit ratio that can be generated by scheme A_i,

$S^+ = \max S_i$, $S^- = \min S_i$, $R^+ = \max R_i$, $R^- = \min R_i$, $i = 1,2,\cdots,m$, $j = 1,2,\cdots,n$, v denotes the decision-making mechanism coefficient, which is equivalent to a weight. When $v \in [0,0.5]$, it is more focused on the pursuit of the group effect; when $v \in [0.5,1]$, it means more attention should be paid to individual regret.

The compromise solution in the VIKOR approach is established based on two decision conditions.

Condition 1: Describe it as an acceptable minimal requirement, i.e.

$$Q^2 - Q^1 \geq DQ$$

$$DQ = \frac{1}{M - 1} \tag{8}$$

Ranking from small to large according to the Q_i, symbol description in Formula (8) is that:

Q^1: the Q value of scheme A_1 which is ranked first,

Q^2: the Q value of scheme A_2 which is ranked after A_1,

M: The total number of options available.

Only when $Q^2 - Q^1 \geq \frac{1}{M-1}$ can it be said that option A_1, which ranks first, has an obvious advantage over alternative option A_2.

If there is more than one sort result, A_1 need to be changed with $A_2, A_3, \cdots, A_n$, one-to-one calculations should be done to determine if they meet the first condition.

Condition 2: It is called the acceptable decision reliability in the decision process.

After sorting by Q value, S_{A_1} must be less than S_{A_2} at the same time, or R_{A_1} must also be less than R_{A_2}.

As with condition 1, if more than one result occurs, A_1 need to be changed with $A_2, A_3, \cdots, A_n$, one by one to see if they meet the second condition.

The VIKOR compromise solution is shown in Table 4.

4.4 Supplier evaluation system

Fig 1 presents the suggested integrated methodology, and it is theoretically explained in the steps that follow.

Table 4. VIKOR compromise solution.

Judgment Criterion		Result	Optimal Compromise Solution
The relationship between A_1 and A_2 schemes satisfies both condition 1 and condition 2.		To determine that scheme A_1 is a reliable and optimal scheme to choose from.	A_1
The value of the relationship Between A_1 and A_2 satisfies one of the conditions	It only satisfies condition 1, it does not satisfy condition 2	At the same time, both schemes A_1 and A_2 are found to be optimal.	A_1 or A_2
	It only satisfies condition 2, it does not satisfy condition 1	At the same time, identify those schemes $A_2, A_3, \cdots, A_J$ that do not meet condition 1, is the best scheme.	$A_2, A_3, \cdots, A_J$

Note: A_1 and A_2 are the alternatives of the first and second positions after the C values are sorted from small to large; A_J is the maximum J value determined by $Q^j - Q^1 < DQ$.

5 Numerical study

Due to the need for strategic development, an enterprise K determines that strengthening sustainable supply chain management requires a long-term, stable sustainable supplier. After enterprise inspection, there are four alternative suppliers A_1, A_2, A_3, and A_4 to meet the requirements of the enterprise. It is necessary to evaluate these to select those that fit the long-term development of enterprise K.

5.1. The weight calculation

Step 1. Calculating the subjective weight of the indications utilizing the methods in Section 4.2.1. To obtain the final weight of the index, the pairwise comparison matrix utilized the conventional Saaty's scale (from Table 2). The results are shown in Tables 5–8.
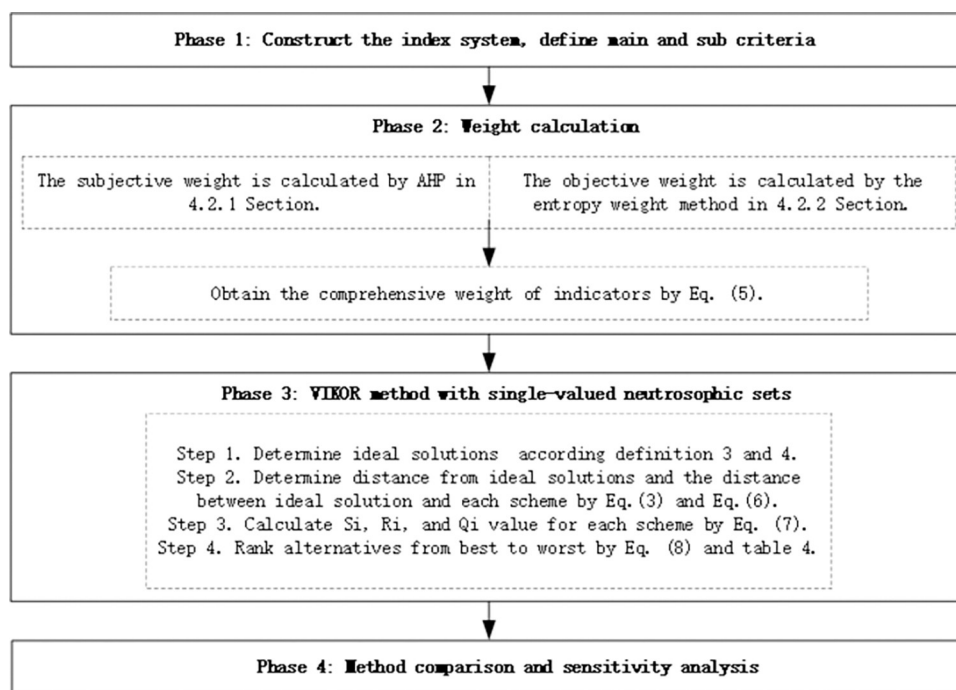

Fig 1. The proposed methodology.

Table 5. Comparison matrix and weights of criteria B_1.

Criteria	c_1	c_2	c_3	c_4	c_5	Weights	CR
c_1	1	2	2	3	3	0.3614	
c_2	1/2	1	1/3	1/3	3	0.1233	0.0927435
c_3	1/2	3	1	2	2	0.2526	
c_4	1/3	3	1/2	1	2	0.1765	
c_5	1/3	1/3	1/2	1/2	1	0.0862	

The final subjective weight of each indicator is: $s\omega_{c_1} = 0.2018$, $s\omega_{c_2} = 0.0689$, $s\omega_{c_3} = 0.141$, $s\omega_{c_4} = 0.0986$, $s\omega_{c_5} = 0.0481$, $s\omega_{c_6} = 0.0797$, $s\omega_{c_7} = 0.1897$, $s\omega_{c_8} = 0.0502$, $s\omega_{c_9} = 0.0305$, $s\omega_{c_{10}} = 0.0915$.

Step 2. Calculating the objective weight of indicators. For sustainable suppliers, A_1, A_2, A_3, or A_4 are chosen, the candidate suppliers are evaluated and selected using the 10 indicators above, $c_1 \sim c_{10}$. Indicator values of each scheme A_i under each index c_j are expressed as single valued neutrosophic sets, $O_{ij} = \langle T_{A_i}(c_j), I_{A_i}(c_j), F_{A_i}(c_j) \rangle$. Among them, $i = 1, 2, \cdots, m$, $j = 1, 2, \cdots, n$, the data obtained are reported in Table 9.

The objective weight of each indicator is determined according to Formula (4), and the objective weight of each indicator is: $o\omega_{c_1} = 0.1481$, $o\omega_{c_2} = 0.125$, $o\omega_{c_3} = 0.1296$, $o\omega_{c_4} = 0.1074$, $o\omega_{c_5} = 0.0537$, $o\omega_{c_6} = 0.1083$, $o\omega_{c_7} = 0.1481$, $o\omega_{c_8} = 0.0435$, $o\omega_{c_9} = 0.0667$, $o\omega_{c_{10}} = 0.0694$.

Step 3. Obtaining the combination weight by Eq (5), and the combination weight of each indicator is: $\omega_{c_1} = 0.175$, $\omega_{c_2} = 0.097$, $\omega_{c_3} = 0.1353$, $\omega_{c_4} = 0.103$, $\omega_{c_5} = 0.0509$, $\omega_{c_6} = 0.094$, $\omega_{c_7} = 0.1689$, $\omega_{c_8} = 0.0469$, $\omega_{c_9} = 0.0486$, $\omega_{c_{10}} = 0.0805$.

5.2. Evaluation and Selection Method of VIKOR with SVNS

The positive ideal solution O_{ij}^+ and the negative ideal solution O_{ij}^- of the four sustainable suppliers are determined according to definitions 3 and 4, respectively.

$$O_{ij}^+ = \left\langle \begin{matrix} (0.9, 0.1, 0.2), (0.9, 0.1, 0.1), (0.8, 0.1, 0.3), (0.7, 0.2, 0.3), (0.6, 0.3, 0.4) \\ (0.8, 0.2, 0.2), (0.8, 0.1, 0.1), (0.6, 0.3, 0.4), (0.6, 0.3, 0.4), (0.5, 0.2, 0.3) \end{matrix} \right\rangle$$

$$O_{ij}^- = \left\langle \begin{matrix} (0.8, 0.1, 0.2), (0.8, 0.2, 0.2), (0.7, 0.2, 0.3), (0.6, 0.3, 0.4), (0.5, 0.4, 0.4) \\ (0.8, 0.2, 0.3), (0.9, 0.2, 0.3), (0.5, 0.4, 0.5), (0.5, 0.3, 0.5), (0.6, 0.3, 0.4) \end{matrix} \right\rangle$$

The weighted distance of positive and negative ideal solutions under each index is calculated according to Formula (3), in which the weight of each index w_{c_i} has been calculated using the entropy weight method. At this point, $\lambda = 2$, $\beta = {}^1/_4$, and the distance are then obtained as follow.

$\Delta d_1^* = 0.017429$, $\Delta d_2^* = 0.031137$, $\Delta d_3^* = 0.026056$, $\Delta d_4^* = 0.032094$, $\Delta d_5^* = 0.015981$

Table 6. Comparison matrix and weights of criteria B_2.

Criteria	c_6	c_7	c_8	Weights	CR
c_6	1	1/3	2	0.2493	
c_7	3	1	3	0.59336	0.0515592
c_8	1/2	1/3	1	0.1571	

Table 7. Comparison matrix and weights of criteria B_3.

Criteria	c_9	c_{10}	Weights	CR
c_9	1	1/3	0.25	0
c_{10}	3	1	0.75	

$\Delta d_6^* = 0.08943$, $\Delta d_7^* = 0.025688$, $\Delta d_8^* = 0.021647$, $\Delta d_9^* = 0.015613$, $\Delta d_{10}^* = 0.09456$

The comprehensive distance between positive and negative ideal solutions is $d_\lambda(O_{ij}^+, O_{ij}^-) = 0.069132$ The same method determines d_{ij}^+ and d_{ij}^-. The results are shown in Tables 10 and 11.

On the basis of Tables 10 and 11, Formula (6) is used to calculate Δd_{ij}, and the results are reported in Table 12.

According to Formula (7), S_i, R_i and Q_i, the decision-making coefficient is calculated, that is, $v = 0.5$, the mean value of the decision-making coefficient v in used is to maximize the utility of the group and minimize the regret of the individual. The results are reported in Table 13.

According to the results of Table 13, the compromise solution and the optimal scheme are determined. From Table 13, it can be concluded that scheme A_1 ranks first and scheme A_2 ranks second. Next, it is necessary to verify whether conditions 1 and 2 are met. Calculated by Formula (8): $Q^2 - Q^1 = 0.528218 > DQ = \frac{1}{3}$, condition 1 is satisfied. At the same, $S_1 < S_2$ and $R_1 < R_2$ can be seen from S_i and R_i values at the same time, so it also satisfies condition 2. That is, the top-ranked option A_1 satisfies both requirements of the VIKOR judgment simultaneously and is, therefore, the best sustainable provider to select following the evaluation and ranking of the VIKOR evaluation model in the context of single-valued neutrosophic sets.

5.3 Sensitivity analysis

In the actual selection process of the sustainable supplier, affected by the external environment, the company's decision-makers constantly adjust their decision-making intention, and parameter adjustment will lead to changes in the ranking of alternatives. Therefore, the decision result must have certain robustness. There are two critical parameters; the first is the coefficient of combination weighting of Eq (5), this parameter determines the proportion of emotional weight and objective weight; the second is the coefficient of Eq (7), this parameter determines the balance of the group satisfaction and individual regret.

This paper utilized set $\alpha = (0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1)$ respectively, then analyze how weight adjustments can impact the rankings on our model, which can be seen in Table 14. From the Table 14, alternative suppliers A_1 is always the best. As a result, the ideal outcome is quite stable.

Next, this paper initially set $v = (0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1)$ respectively, then analyze how weight adjustments can directly affect the rankings on our model, which can be seen in Table 15. From Table 15, alternative suppliers A_1 and A_2 are the best when v takes values of 0.8 and 0.9, and alternative suppliers A_1 is the best when v takes other values, but the best option is always alternative suppliers A_1. Therefore, the optimal result is relatively stable.

Table 8. Comparison matrix and weights of criteria dimension.

Criteria	B_1	B_2	B_3	Weights	CR
B_1	1	2	4	0.5584	
B_2	1/2	1	3	0.3196	0.0175911
B_3	1/4	1/3	1	0.122	

Table 9. Data for suppliers under each index in a SVNS environment.

Plan / Index	A_1	A_2	A_3	A_4
c_1	<0.9,0.1,0.2>	<0.8,0.1,0.2>	<0.8,0.1,0.1>	<0.8,0.1,0.2>
c_2	<0.9,0.1,0.1>	<0.9,0.2,0.2>	<0.8,0.2,0.2>	<0.7,0.1,0.1>
c_3	<0.8,0.2,0.3>	<0.8,0.1,0.3>	<0.7,0.2,0.3>	<0.8,0.2,0.3>
c_4	<0.7,0.2,0.4>	<0.7,0.2,0.3>	<0.6,0.3,0.4>	<0,7,0.2,0.4>
c_5	<0.5,0.4,0.4>	<0.6,0.4,0.5>	<0.5,0.3,0.4>	<0.6,0.3,0.4>
c_6	<0.7,0.2,0.1>	<0.8,0.2,0.2>	<0.8,0.2,0.3>	<0.8,0.2,0.2>
c_7	<0.8,0.1,0.2>	<0.8,0.1,0.1>	<0.9,0.1,0.3>	<0.9,0.2,0.3>
c_8	<0.5,0.4,0.4>	<0.6,0.3,0.4>	<0.5,0.4,0.3>	<0.5,0.4,0.5>
c_9	<0.4,0.3,0.3>	<0.5,0.3,0.4>	<0.6,0.3,0.4>	<0.5,0.3,0.5>
c_{10}	<0.6,0.3,0.4>	<0.7,0.4,0.4>	<0.5,0.2,0.3>	<0.6,0.3,0.4>

In conclusion, the ideal result is quite consistent. The decision model suggested in this work can make sure that the decisions made have strong robustness, and alternative providers are the best sustainable suppliers A_1.

5.4 Comparison with other methods

The following strategies are utilized for comparative analysis as there are numerous ways to research this area [128–132].

5.4.1 Comparison between the improved and traditional VIKOR methods. The results of the traditional VIKOR approach [128] are presented in Table 16.

From Table 16, it can be seen that scheme A_1 ranks first and scheme A_2 ranks second. Next, whether the two schemes satisfy two conditions needs to be verified. Calculated by Formula (8): $Q^2 - Q^1 = 0.4721 > DQ = \frac{1}{3}$; condition 1 is satisfied. However $S_1 > S_2$, so condition 2 is not satisfied. Therefore, the traditional VIKOR method is used to sort the evaluation, and the compromise solution is as follows: A_1 and A_2.

In conclusion, although though the findings of the improved VIKOR method are essentially the same as those of the conventional VIKOR method, there is only one scheme that is the improved VIKOR method's ideal solution, and that is A_1.

Table 10. The weighted distance between each scheme and the ideal solution under each index d_{ij}^+.

Plan / Index	A_1	A_2	A_3	A_4
c_1	0.000000	0.017429	0.012200	0.017429
c_2	0.000000	0.018163	0.031137	0.025947
c_3	0.010729	0.000000	0.026056	0.010729
c_4	0.009361	0.000000	0.032094	0.009361
c_5	0.015981	0.013161	0.009401	0.000000
c_6	0.008943	0.000000	0.008943	0.000000
c_7	0.011988	0.000000	0.023975	0.025688
c_8	0.015333	0.000000	0.012627	0.021647
c_9	0.015613	0.009184	0.000000	0.015613
c_{10}	0.009456	0.017730	0.000000	0.009456
Total	0.035356682	0.03472135	0.061073098	0.051394557

Table 11. The weighted distance between each scheme and the ideal solution under each index d_{ij}^-.

Plan Index	A_1	A_2	A_3	A_4
c_1	0.017429	0.000000	0.012200	0.000000
c_2	0.031137	0.012974	0.000000	0.010379
c_3	0.015327	0.026056	0.000000	0.015327
c_4	0.022733	0.032094	0.000000	0.022733
c_5	0.000000	0.006580	0.006580	0.015981
c_6	0.017886	0.008943	0.000000	0.008943
c_7	0.013700	0.025688	0.011988	0.000000
c_8	0.006314	0.021647	0.012627	0.000000
c_9	0.012858	0.006429	0.015613	0.000000
c_{10}	0.000000	0.008274	0.009456	0.000000
Total	0.052323945	0.056910428	0.02878332	0.034566212

Although the compromise solutions A_1 and A_2 are obtained using the traditional VIKOR method, it does not present a clear choice, A_1 and A_2 are acceptable. The enhanced approach produces more precise results.

5.4.2 Comparison with TOPSIS method. The method of reference [129] is used to calculate, and the results are shown in Table 17.

Supplier A_1 is the ideal provider, as shown in Table 17, which is in line with the findings of the paper construction model. However, the comprehensive distance between A_1 and A_2 that was found using the TOPSIS technique is quite modest, and the level of discrimination is only mildly present. In comparison, the VIKOR method's evaluation is significant. The TOPSIS method's guiding concept is separating the selected scheme from the positive and negative ideal solutions. The best option is not always the one closest to the ideal point based solely on distance measurements, and there is a reverse order problem brought on by the expansion or contraction of the design in actual use. This problem can be solved using the VIKOR approach. It is an ideal solution-based ranking compromise strategy. In this study, the multi-attribute decision-making problem is solved using the VIKOR approach based on neutro-sophic sets to find a satisfying resolution. Instead of using the optimal solution, it opts for the ideal compromise.

5.4.3 Comparison with weighted ensemble operator method. The method of reference [130] is used to calculate, and the results are shown in Table 18.

Table 12. Relative weighted distance between each scheme and positive and negative ideal solutions.

Plan Index	A_1	A_2	A_3	A_4
c_1	-0.017429	0.017429	0.000000	0.017429
c_2	-0.031137	0.005189	0.031137	0.015568
c_3	-0.004598	-0.026056	0.026056	-0.004598
c_4	-0.013373	-0.032094	0.032094	-0.013373
c_5	0.015981	0.006580	0.002820	-0.015981
c_6	-0.008943	-0.008943	0.008943	-0.008943
c_7	-0.001713	-0.025688	0.011988	0.025688
c_8	0.009020	-0.021647	0.000000	0.021647
c_9	0.002755	0.002755	-0.015613	0.015613
c_{10}	0.009456	0.009456	-0.009456	0.009456

Table 13. Results of VIKOR method in a SVNS environment.

Plan	S_i	R_i	Q_i
A_1	-0.284167	0.080601	0
A_2	-0.24627	0.175249	0.528218
A_3	0.387335	0.135556	0.790309
A_4	0.359005	0.175249	0.978905
Rank	$A_1>A_2>A_4>A_3$	$A_1>A_3>A_2>A_3$	$A_1>A_2>A_3>A_4$

In the evaluation framework, the weighted operator is frequently applied and extended to single-valued neutrosophic sets. The accuracy of this strategy is confirmed by the ranking results' consistency with the model's output. The simple negative ideal solution distance is replaced by the relative distance in the model developed in this work instead. The candidate chosen by this method comes the closest to the ideal solution, and the findings are more accurate and reliable.

5.5 Discussion

This study suggests a sustainable supplier selection model and uses the MCDM method to put it into effect. Choosing the right MCDM techniques and supplier selection criteria are two fundamental concerns that assist businesses in managing product procurement and enhancing the entire supply chain. Considering the importance of human judgment and information provided by raw data, combining the consequences of AHP and target entropy to determine the criteria weight has proved to be one of the most effective methods.

Group and individual decision-making have always been critical issues and challenges in sustainable supplier selection; combining the advantages of both group and personal decision-making is wise. The method proposed in this paper provides a solution closer to ideal and a balance between minimal individual regret and maximum group utility. It is challenging for experts to accurately assess suppliers in practice since the environment for choosing sustainable suppliers is complex and unpredictable. The method suggested in this research considers the flawed information provided by managers, and decision-makers can try their best to communicate their evaluation information more precisely and efficiently by using SVNS, which

Table 14. The compromise measures calculated by α at different values.

α	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Q_{A_1}	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Q_{A_2}	0.5287	0.5285	0.5284	0.5282	0.5281	0.5279	0.5277	0.5276	0.5269	0.5261	0.5254
Q_{A_3}	0.8824	0.8611	0.8414	0.8231	0.8061	0.7902	0.7753	0.7614	0.7391	0.7159	0.6935
Q_{A_4}	0.9276	0.9369	0.9464	0.9562	0.9663	0.9766	0.9872	0.9982	1.0000	1.0000	1.0000
S_{A_1}	-0.3059	-0.3017	-0.2974	-0.2931	-0.2888	-0.2845	-0.2802	-0.2760	-0.2717	-0.2674	-0.2631
S_{A_2}	-0.2647	-0.2547	-0.2247	-0.1747	-0.1047	-0.0147	0.0953	0.2253	0.3753	0.5453	0.7353
S_{A_3}	0.4129	0.4079	0.4029	0.3980	0.3930	0.3880	0.3831	0.3781	0.3731	0.3682	0.3632
S_{A_4}	0.3088	0.3183	0.3279	0.3374	0.3470	0.3566	0.3661	0.3757	0.3853	0.3948	0.4044
R_{A_1}	0.0694	0.0717	0.0739	0.0761	0.0783	0.0805	0.0827	0.0849	0.0871	0.0893	0.0915
R_{A_2}	0.1481	0.1581	0.1881	0.2381	0.3081	0.3981	0.5081	0.6381	0.7881	0.9581	1.1481
R_{A_3}	0.1296	0.1308	0.1319	0.1330	0.1342	0.1353	0.1365	0.1376	0.1387	0.1399	0.1410
R_{A_4}	0.1481	0.1535	0.1589	0.1642	0.1696	0.1750	0.1803	0.1857	0.1911	0.1964	0.2018

Table 15. The compromise measures calculated by v at different values.

v	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Q_{A_1}	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Q_{A_2}	1.0000	0.9056	0.8112	0.7167	0.6223	0.5279	0.4335	0.3391	0.2447	0.1502	0.0558
Q_{A_3}	0.5803	0.6223	0.6643	0.7062	0.7482	0.7902	0.8321	0.8741	0.9161	0.9580	1.0000
Q_{A_4}	1.0000	0.9953	0.9906	0.9860	0.9813	0.9766	0.9719	0.9672	0.9626	0.9579	0.9532

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offers an efficient method for choosing sustainable suppliers. Moreover, this method has lower complexity and is easier to apply to decision-making problems, saving decision-makers' time and energy. The case study reviewed shows the model's effectiveness, and relevant supply chain practitioners can make plans based on the results of supplier evaluation. Therefore, the results of this case can provide a reference for the development of a sustainable supply chain, which can save costs and reduce the negative impact brought by external factors.

Additionally, businesses are more likely to work with suppliers concerned about environmental issues due to external factors like policy and the environment. Therefore, while choosing suppliers, it is essential to be clear about the specifics of environmental management (such as pollution avoidance, resource consumption, discharge of harmful substances and wastes, etc.). Suppliers can take on social responsibility, check the legality of their production process, and confirm that primary and sub suppliers have signed environmental contracts to prevent potential environmental issues brought on by lower-level suppliers by signing legal agreements with them.

6 Conclusion

One of the modern businesses' most significant challenges is sustainable supply chain management. Supplier selection is a crucial topic in engineering and management since an enterprise's

Table 16. Results and type of traditional VIKOR method.

Plan	S_i	R_i	Q_i
A_1	0.470796583	0.092823978	0.027880
A_2	0.453336601	0.175249442	0.500000
A_3	0.766468911	0.15791948	0.894875
A_4	0.687600923	0.175249442	0.874066
Rank	$A_2>A_1>A_4>A_3$	$A_1>A_3>A_2>A_4$	$A_1>A_2>A_4>A_3$

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Table 17. Results and ranking based on TOPSIS method.

Plan	A_1	A_2	A_3	A_4
Comprehensive distance	0.694782	0.639802	0.295253	0.282053
Sort	$A_1>A_2>A_3>A_4$			

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Table 18. Score function and ranking.

Plan	A_1	A_2	A_3	A_4
Score	0.6784	0.6630	0.5957	0.6134
Rank	$A_1>A_2>A_4>A_3$			

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supply chain comprises several suppliers, and those suppliers' qualifications impact the total benefit of the supply chain. To attain the objective of sustainable development, the corporation should prioritize social and environmental responsibility and maximize economic rewards.

The result of the study addressed the goals and objectives mentioned in the paper's introduction. The first part of this study evaluates the literature on sustainable suppliers, quantifies and makes readily accessible a framework of environmental, social, and economic performance indicators, and analyses and formulates the selection criteria for sustainable suppliers. The total weight created by combining subjective and objective weights is used to indicate the importance of indicators, improving the ranking results' effectiveness by taking into account the value of human judgment and the information provided by raw data. Additionally, the supplier selection issue is an MCDM issue.

Due to the constraints of the decision maker's subjective cognition and the objective complexity of the actual decision-making problem, the decision-makers frequently communicate the assessment value of the scheme using fuzzy information. This study employs the notion of neutrosophic sets, SVNS to quantify ambiguous and inconsistent data, and the VIKOR method to analyze it. This study extends the VIKOR method using SVNS. The metric for SVNS distance substitutes the immediate difference of the original VIKOR method and introduces the idea of "relative distance," which makes the data processing more logical and scientific. This approach enhances the character of evaluation results by reducing the impact of individual preferences and experiences on the final evaluation results and the issue of particular excessive regret brought on by factor correlation. It also increases the consistency of the evaluation's findings. Finally, the effectiveness and flexibility of the suggested method are confirmed through case analysis, sensitivity analysis, and comparative analysis of various forms. This method can effectively capture the competition among sustainable suppliers, offer more options for decision support systems, and better meet the needs of various practical problems.

The approach presented in this paper is very adaptable to sectors that support supply chain sustainability. Managers can use it to choose suitable suppliers to suit those sectors' needs. In contrast to earlier studies, the index system developed in this study is more thorough based on the fundamental principles, and the suggested model is more appropriate for uncertain scenarios and nearer to human cognition. This model not only effectively manages information fuzziness and uncertainty but also maintains the accuracy of evaluation data. To assist decision-makers in expressing their ideas more convincingly and realistically in additional multi-attribute decision-making challenges, the developed SVNS model can be applied.

The study does have certain restrictions. Future research should consider the decision-making mechanism coefficient and any potential interactions and relationships between standards, as these elements have not been fully explored in the current study. Additionally, fuzzy and neutrosophic sets cannot fully capture fundamental uncertainty; therefore, future research will focus on combining multi-granularity language data with support vector machines, fuzzy sets, and neutrosophic sets to create a model known as the Multi-Criteria Decision Making (MCDM).

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