Neutrosophic Systems with Applications, Vol. 19, 2024
https://doi.org/10.61356/j.nswa.2024.19320

Leveraging an Uncertainty Methodology to Appraise Risk Factors Threatening Sustainability of Food Supply Chain

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Abstract: By diminishing the risk factors associated with the food supply chain (FSC), we have recourse to strengthen the food supply chain's resilience, decrease food waste, and increase its sustainability. Prioritizing and identifying the risk factors impacting the sustainability of the food supply chain is essential for managing uncertainty and averting unfavorable consequences. This study attempts to identify and rank the most significant risks affecting the sustainability of the food supply chain under an uncertain environment. We use the α-Discounting multi-criteria decision-making (α-D MCDM) method for the main three risk factors: the risks of supply, the risks of demand, and the risks of operations. The primary causes of the challenges in assessing the food supply chain's risk elements include inaccurate assessment data, DMs' subjective preferences, and DMs' differing opinions and thoughts about the criteria. Unfortunately, earlier research fell short of fully resolving these issues. A hybrid three-phase neutrosophic MCDM method is proposed by integrating triangular neutrosophic numbers (TNNs), TNN-AHP, and TNN-CoCoSo to close this gap. In this manner, it may efficiently handle ambiguity. The application of the suggested framework is then explored using the top six food and beverage businesses in the world: Nestle (A1), PepsiCo (A2), Coca-Cola (A3), Danon (A4), Anheuser-Busch InBev SA (A5), and Mondelez International (A6). The results show the sustainability rankings from best to worst, which were established on the groups of decision-makers assessments based on the importance of the risk factors that have to be handled. To gain additional insight into the rationale and resilience of this framework, sensitivity evaluation and comparative analysis have been employed in this study.

Keywords: Food Supply Chain, Risk Factor, Sustainability, α-D MCDM, TNN-AHP, TNN-CoCoSo.

1. Introduction

The primary responsibility of the food supply chain (FSC) is to transport a variety of nourishment from farmers to end users via a network of food processors and intermediaries while maintaining high standards of quality, safety, and low food waste [1]. FSC is made up of wholesalers, retailers, warehouses, makers of food (processing facilities), and suppliers who work together to meet customer demands [2]. To ensure that customers receive safe, wholesome, and high-quality foods, it is crucial to handle each FSC stage properly. Each stage has a distinct set of issues and possibilities [3]. It is the common duty of all parties involved in the supply chain to deliver food that is safe, dependable, and of the highest caliber. Furthermore, food waste reduction and the development of sustainable national and regional economies depend on FSC [4]. As a result, sustainable FSC is critical for the development of sustainable agriculture, which is critical for guaranteeing an ongoing supply and production of food items [5]. Reduced food waste, carbon emissions, improved food quality, and increased food safety are all benefits of implementing sustainable food supply chain management methods in the food supply chain [6].

Considerations about the sustainability of the food supply chain increase with the number of procedures since supply chain stages are exposed to risk factors. Food supply chain risk factors can lead to food scarcity, poor food quality distribution, and wasted food generation, which raises sustainability issues as a result [7]. FSC confronts high uncertainty risks, which might affect food product availability and quality. One of the greatest uncertainties is the variability of meteorological conditions, which can impair farming efficiency and result in food shortages. Another cause of uncertainty is the volatility of food costs, which can affect customers' accessibility to food goods, particularly in low-income nations [8].

FSC risk valuation is crucial to prevent resource waste and aids businesses in developing resilient food security policies. Examining risks in FSCs can improve their performance in terms of sustainability, equity, and efficiency [9]. Every supply chain participant must be aware of risks both inside and outside of their networks to deliver products that are reliable and secure. In this study, the food supply chain risk factors are classified into three main groups: the risks of supply, the risks of demand, and the risks of operations.

Given the importance of the impact of the risk factors on enhancing FSC performance, this study focuses on six of the top food companies in the world and measures their sustainability performance based on the main three risk groups (the risks of supply, the risks of demand, and the risks of operations) using proposed integrated MCDM framework. Firstly, to handle n-wise comparison, the weights of the three primary risk groups in the food supply chain are evaluated using the α-discounting MCDM approach [10]. Secondly, AHP is used to calculate the relative importance of the risk factors that have an impact on the sustainability of the FSC. To deal with the ambiguity that decision-makers encounter in these evaluation situations, this phase is based on neutrosophic language variables. Thirdly, the CoCoSo approach is used to rank the top six food companies according to the weights assigned to the risk factors that have an impact on sustainability and discovered in the previous stage. This phase also is based on neutrosophic set theory to handle uncertainty in all phases of evaluation.

The main contributions of this study entail investigating the roles of risk factors in the food supply chain and how they affect sustainability; assessing the 12 risk factors of the food supply chain and the main three risk groups; and ranking the top food companies based on the impact of risk factors while taking uncertainty and consistency into serious consideration. In addition to that, risk factor weight and parameter sensitivity are employed in the sensitivity analysis to validate the suggested framework in this research.

This study is structured into a set of sections: Section 2 summarizes the research on decision-making techniques that concentrate on the sustainability of the food supply chain and associated risk factors. Section 3 is devoted to the proposed method, i.e., a hybrid three-phase decision-making approach for ranking food supply chains based on the importance of the risk factors. Section 4 presents a study case to illustrate how to use the proposed method to rank the top food companies in the world based on the risk factor effect on sustainability. Section 5 discusses a sensitivity analysis and comparative analysis to verify the results. Section 6 clarifies the conclusion future perspectives, and scopes.

2. Principles Conceptual Based Earlier Perspectives

2.1 Food Supply Chain

FSC is a network that links farmers and producers that collaborate to deliver food that is secure and safe for consumers [11]. A sustainable blockchain (BC) architecture for the halal FSC is suggested by Ali et al, in [12]. This study offers a practical solution to the issues surrounding the implementation of blockchain technology in SC for halal food. Chen et al. introduced the idea of integrated FSC management, which can improve product traceability throughout the entire chain. The benefit of smart packaging in decreasing food waste was then underlined [13]. Kittipanya-Ngam & Tan evaluated the benefits of digitalization in [14] utilizing three firms as examples. Their research looks at the strategies, problems, and opportunities that Thailand's food producers confront as they work to digitise their SCs.

Analysis of the COVID-19 scenario in 2020 by recent research and according to [15] revealed significant breakdowns, such as an increase in the proportion of people facing famine and food insecurity as the major crisis aggravated imbalances that had already hampered progress before the pandemic. Other scholars such as Aday, S., and Aday, M. S. (2019) analyze the implications of COVID-19 on the food and agricultural industries [16] to provide an overview of the recommendations needed to lessen and limit the pandemic's effects. Additionally, Barman et al. cover the macroeconomic effects of COVID-19 and the effects of lockdown on the food supply chain and agriculture [17].

2.2 Risk Management in the Food Supply Chain

Food is a perishable commodity, hence food FSCs are more complex than those for other kinds of businesses or services [18]. The volatility of food prices, food waste, the security of food, and problems with resources, have all presented ongoing concerns throughout time [19]. Food supply chain risk assessment is crucial to prevent resource waste and aids businesses in developing resilient food security policies [20]. Each component of the supply chain must be aware of risks both inside and outside of their networks to deliver reliable and secure products. In recent years, both local and global authorities have expressed concern about FSC risk management.

To better understand how knowledge management, risk management, and resilience relate to supply chain resilience in FSCs, Ali et al.'s research aims to combine these three ideas [21]. The main objective of Khan et al.'s study is to determine the risk variables associated with SCs for Halal food and to appropriately rank them to improve management [22]. Also, Zhao et al. classified the identified FSC hazards into many groups according to how reliable they were [24].

The organized literature work and the advice of specialists are shared to identify risk factors related to the FSC. The Scopus database was searched for the terms "food supply chain," "risk," and "challenges" in the related works. A thorough examination of the literature turned up 12 common risk factors in the FSC. The risk factors were categorized into three clusters based on their particular features, including the risks of supply, the risks of demand, and the risks of operations. Table 1 summarizes the 12 risk factors based on their categories.

The term "the risks of supply" describes the ambiguity surrounding the acquisition of the material along with its operations, including the failure of the supplier and the quality of the raw materials. On the other side, the risks resulting from changing market conditions and consumer demand fall under the following group, known as the risks of demand. The biggest risks in this category are those that deal with customers and how they view the good or service. The risks of operations are challenges for the supply chain to run effectively, the primary business outsources some tasks, like marketing, inventory, manufacturing, and shipping.

2.3 Risk Management in the Food Supply Chain

A decrease in food waste increases sustainability [38]. In addition to the moral concern of wasting away usable food items when people elsewhere suffer from hunger. Various techniques were offered by numerous researchers and academics to reduce food waste along the FSC. To prevent food waste, recent techniques include forecasting demand for a store shop using machine learning algorithms [39]. On a global scale, food supply chains are growing to keep up with seasonal food production and customers' rising expectations for safety, sustainability, and environmental repercussions that could have an impact on human communities and health. Since stakeholders have recently given the topic of sustainability in the FSC a lot of thought, the area of sustainable supply chain management has emerged [40].

Table 1. Food supply chain-related risks.

Risks	Risk factors	Description	References
The risks of supply	Row material cost risks	The operations of the FSCs may be impacted by the expense of obtaining fresh, high-quality raw materials	[25-27]
	Poor quality of raw material	Raw material quality and reliability issues could cause the food supply chain to fail	[28, 29]
	Shortage of raw material	Suppliers don't deliver on lead times or offer high-quality raw materials.	[20]
	Failure of raw material delivery	Failure of vendors to provide food supplies and raw materials	[30]
The risks of demand	A scarcity of marketing avenues	One of the issues of food production is getting the product in reach of consumers. Effective marketing is one of the most crucial elements for this to happen.	[31]
	Consumption attitude	The primary focus of the sustainable aims in the FSC is on sustainable consumption patterns.	[32]
	Demand volatility	Demand uncertainty and fluctuation present risk. Demand for a certain good or service is frequently accompanied by many uncertainties, which can make them unstable and difficult to forecast.	[33]
	Customer satisfaction	The most pressing problem facing the FSC is the failure to adapt to consumers' constantly shifting tastes and preferences.	[34]
The risks of operations	Operational equipment failure	The possibility of production interruption because of equipment failure is a problem for many supply chain operations.	[35]
	Lack of technological developments	Supply chain issues may occur because of sales, production, and cash flow, caused by IT system failure or a lack of technology.	[36]
	Lack of skilled human resource	Risks associated with untrained individuals managing supply chains or company processes. Lack of human resources harms how well food is produced.	[20, 37]
	Lack of capacity to produce quality products	Products that are unreliable and malfunctioning cause the company to lose reputation.	[35]

3. Study Framework

The three-phase framework is utilized in this study to evaluate the relative significance of risk factors in the FSC and how they may affect sustainability. The related works are used to recognize the risk factors for the FSC and classify them into three major groups based on their characteristics.

The first phase involves applying the α-D MCDM to weigh the major risk categories. In the next phase, the 12 FSC risk factors are assessed using the neutrosophic analytical hierarchy process (NAHP). Using the top six food and beverage companies in the world and the Combined Compromise Solution method (CoCoSo) under a neutrosophic environment, the third phase investigates how to apply the suggested framework. The adopted research framework is depicted in Figure 1.

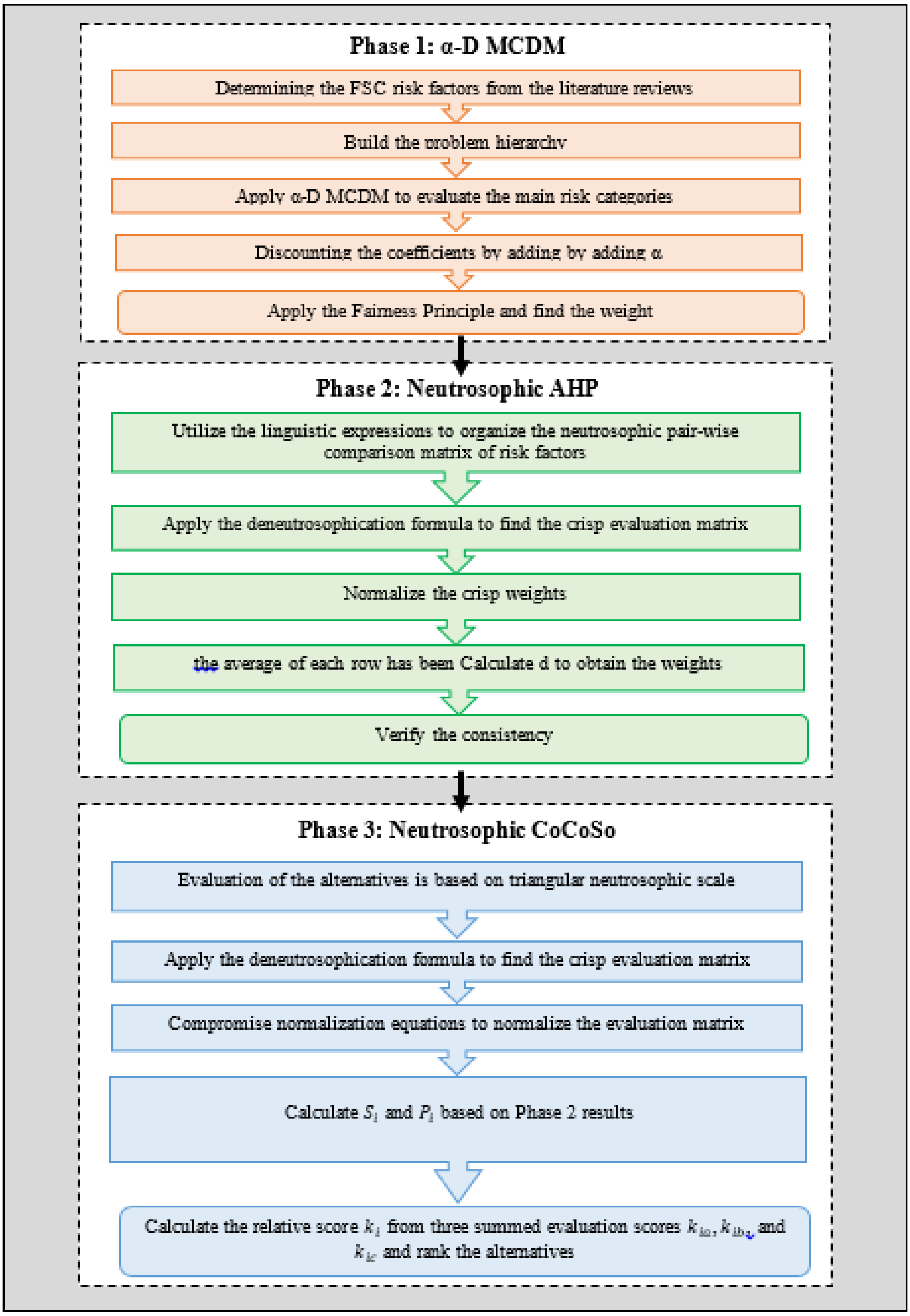

Figure 1. A MCDM framework for evaluating sustainable FSC based on risk factors.

3.1 Phase 1: α-D MCDM

Smarandache (2010) presented the α-D MCDM as an addition of AHP to address inconsistency and n-wise comparison. For pairwise comparison judgments requiring consistency, the α-D Method yields the same result as AHP when combined with the Fairness Principle. The main idea behind this strategy is to convert an inconsistent to a consistent problem by discounting the coefficients of the inconsistent problem to specified percentages [41]. For weak inconsistent decision-making issues, however, α-D provides a different result than AHP when paired with the Fairness Principle. Any set of preferences that can be converted into a set of homogeneous linear equations can be used in this method. A decision-making problem's degree of consistency is specified [42]. The phases of the α-D MCDM are as follows [43]:

- Let $C = \{C_1, C_2, C_3, \dots, C_n\}$, n≥2, be a set of criteria (in our study it is the main categories of food supply chain risks). The set of preferences is $P = \{P_1, P_2, P_3, \dots, P_m\}$, m≥1. Then, the weights of the criteria $m: C \to [0, 1]$, where $m(C_i) = x_i$,$0 < x_i < 1$ [19].
$$\sum_{i=1}^{n} m(C_i) = \sum_{i=1}^{n} x_i = 1$$
- Construct $m \times n$ linear system and its matrix:
$$\begin{Bmatrix} x_{1,1}w_1 + x_{1,2}w_2 + \dots + x_{1,n}w_n = 0 \\ \dots \\ x_{m,1}w_1 + x_{m,2}w_2 + \dots + x_{m,n}w_n = 0 \end{Bmatrix}$$
$$A = \begin{bmatrix} x_{1,1} & \dots & x_{1,n} \\ \dots & \dots & \dots \\ x_{m,1} & \dots & x_{m,n} \end{bmatrix}$$
- Determine the matrix A's determinant.
  - Det(A)=0 indicates that the issue is consistent.
  - Det(A)≠0 indicates an inconsistent issue.
  - The right side of the system must then be parameterized with α.
  - Set every parameter using the Fairness principle: $\alpha_1 = \alpha_2 = \alpha_3 = \dots = \alpha_p = \alpha > 0$.
  - After that, figure out the system's answer.
  - To get a specific outcome, multiply the secondary variables and parameter values by 1.
  - To normalize the solution, divide each result by the total of all results.
  - The α value is used to determine the initial degree of consistency and inconsistency of the decision-making problem.

Here is an example of the application of the α-D MCDM method:

- Let us construct the relevant matrix and system of equations. Let Criteria 1 (C_1)= x, Criteria 2(C_2) = y, and Criteria 3 (C_3)= z. The preference of each criteria must be formulated as a linear equation to build a system of comparisons.
$$\begin{cases} x = 2y + 3z \\ y = \dfrac{1}{2}x \\ z = \dfrac{1}{3}x \end{cases}$$
The corresponding matrix of the system is formulated as follows:
$$A = \begin{bmatrix} 1 & -2 & -3 \\ -1/2 & 1 & 0 \\ -1/3 & 0 & 1 \end{bmatrix}$$
$$\mathrm{Det}(A) = -1 \neq 0$$

Using the Fairness Principle and adding α to the right-hand side (RHS) coefficient, we will parameterize the system and solve it.

$x = 2\alpha_1 y_1 + 3\alpha_2 z$ (1)

$y = \frac{1}{2}\alpha_3 x$ (2)

$z = \frac{1}{3}\alpha_4 x$ (3)

Where $\alpha_{1,}\ \alpha_{2,}\ \alpha_{3,}\ \alpha_4 > 0$.

Then, we will solve the system:

$x = 2\alpha_1(\frac{1}{2}\alpha_3 x) + 3\alpha_2(\frac{1}{3}\alpha_4 x)$ Replacing (2) and (3) in (1)

$1 = \alpha_1\alpha_3 + \alpha_2\alpha_4$ Set 1 to the secondary variable

Let $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha$

$1 = \alpha^2 + \alpha^2$

$\alpha = \sqrt{2}/2$

$S = \begin{bmatrix} 1 & \sqrt{2}/4 & \sqrt{2}/6 \end{bmatrix}$ (4)

$W = [0.63 \quad 0.22 \quad 0.15]$

3.2 *Phase 2: Neutrosophic AHP*

Saaty's AHP is a well-known method for managing complicated problems by breaking them down into smaller problems and then combining the answers to those smaller problems. There are various steps in the AHP. To better grasp the problem, the problem hierarchy must first be organized. A desired outcome, main criteria, sub-criteria, and all possible choices make up the structure of the AHP [44]. Decision makers build pair-wise comparison matrices to find criteria weight using Saaty's scale after designing the AHP hierarchy [45]. The ultimate weight of alternatives is then established and ordered. The steps of the NAHP in details as follows:

- The four layers of the problem hierarchy are organized. The objective that the organization aims to accomplish is at the top level. The criteria, or in our study, the major risk categories, make up the second level. The risk factors that fall within each category of the level before are included in the third level. The alternatives (food and beverage companies) that need to be assessed and contrasted are included in the last level.
- Utilize the linguistic expressions from Table 2 to organize the neutrosophic comparison matrix of risk factors.

Table 2. Linguistic terms and the TNN.

Explanation	Triangular neutrosophic number (TNN)
Vey weakly important VWI	((0.1,0.2,0.45),0.2,0.6,0.5)
Weakly important WI	((0.2,0.3,0.5),0.3,0.6,0.5)
Partial important PI	((0.3,0.5,0.7),0.5,0.6,0.45)
Equally important EI	((1,1,1),0.5,0.5,0.5)
Strongly important SI	((0.7,0.8,0.9),0.8,0.1,0.2)
Very strongly important for VSI	((0.8,0.9,0.8),0.9,0.1,0.1)
Absolutely important AI	((0.9,0.9,0.9),1,0,0)

To get the crisp weights of the alternatives, use the de-neutrosopic formula in Eq. (5).

$S(a) = \frac{1}{8} \times (a_1 + a_2 + a_3) \times (2 + T - I - F)$ (5)

- Normalize the crisp weights of alternatives by dividing each column element by the appropriate sum after adding the columns.
- Calculate the average of each row to obtain the weight vector of the risk factors.
  Verify the consistency of the experts' judgment. Consistency may be checked by dividing the random index (RI) by the consistency index (CI). Following that, the result should be less than 0.1. If not, a new comparison must be made.

3.3 *Phase 3: Neutrosophic CoCoSo*

When developing mathematical and computing techniques to choose the best option among several options based on predetermined criteria, MCDM is a crucial area of operations research.

A CoCoSo method was developed by Yazdani et al. [46] that delivers a collection of aggregated solutions employing compromise approaches and aggregation strategies. Due to shifting weight distributions of criteria, the preference outcomes derived by current decision-making systems have limited dependability and stability, making it potentially unreasonable for decision-makers to choose the best alternative. CoCoSo eliminates this restriction. This method is based on a combination of the exponentially weighted product approach and the weighted sum technique, as shown in the steps below:

- To assess the alternatives in light of the relevant risk factors, the initial decision-making matrix is created. The evaluation of the alternatives is based on a triangular neutrosophic scale to ensure a more accurate evaluation using Table 3.

Table 3. Importance scale based on triangular neutrosophic numbers.

Importance scale	Triangular neutrosophic Number (TNN)
Very low influence (VLI)	((0.10, 0.30,0.35), 0.1,0.2,0.15)
Low influence (LI)	((0.3,0.4,0.10), 0.6,0.2,0.3)
Partially influence (PI)	((0.40,0.35,0.50), 0.6,0.1,0.2)
Medium important (MI)	(0.5,0.50,0.50),0.8,0.1,0.1)
High influence (HI)	((0.70,0.65,0.80),0.9,0.2,0.1)
Very high influence (VHI)	((0.90,0.85,0.90),0.7,0.2,0.2)
Absolute influence (AI)	((0.95,0.90,0.95),0.9,0.10,0.10)

- Using the de-neutrosophic formula found in Eq. (5), get a clear assessment of the alternatives.
- The compromise normalization Eqs. (6) and (7) are used to achieve the normalization of criteria values.

$$r_{ij} = \frac{x_{ij} - minx_{ij}}{maxx_{ij} - minx_{ij}} \quad \text{For beneficial criteria} \tag{6}$$

$$r_{ij} = \frac{maxx_{ij} - x_{ij}}{maxx_{ij} - minx_{ij}} \quad \text{For non-beneficial criteria} \tag{7}$$

- Eqs. (8) and (9), respectively, reflect the total of the weighted comparability sequence and an amount of the power weight of comparability sequences for each choice. as S_i and P_i. The approach of grey relational generation was used to get the S_i value.

$$S_i = \sum_{j=1}^{n}(w_j r_{ij}) \tag{8}$$

$$P_i = \sum_{j=1}^{n}(r_{ij})^{w_j} \tag{9}$$

- The CoCoSo approach ranks based on the relative score k_i, which is derived from three summed evaluation scores k_{ia}, k_{ib}, and k_{ic}, as described in the following in Eqs. (10-13):

$$k_{ia} = \frac{P_i + S_i}{\sum_{i=1}^{m}(P_i + S_i)} \tag{10}$$

$$k_{ib} = \frac{S_i}{min\ S_i} + \frac{P_i}{min\ P_i} \tag{11}$$

$$k_{ic} = \frac{\lambda(S_i) + (1-\lambda)(P_i)}{\lambda maxS_i + (1-\lambda)maxP_i} \tag{12}$$

$$k_i = (k_{ia} + k_{ib} + k_{ic})^{\frac{1}{3}} + \frac{1}{3}(k_{ia} + k_{ib} + k_{ic}) \tag{13}$$

4. Evaluation of the Influence of Risk Factors on Sustainability of Food Supply Chain Based on Constructed Framework

In this section, an alternative food supply chain is evaluated as a numerical illustration of the proposed method. To be specific, six food and beverage companies, including Nestle (A1), PepsiCo (A2), Coca-Cola (A3), Danone (A4), Anheuser-Busch InBev SA (A5), and Mondelez International (A6) are studied to select the most sustainable food supply chain according to the risk factor influence by using the proposed method in this study, and the problem hierarchy is summarized in Figure 2. The risk factors are specified based on the literature reviews as mentioned in Section 2.2 and summarized as Table 1 shows. The risk factors are categorized into three main groups based on their characteristics: the risks of supply, the risks of demand, and the risks of operations. The first phase is to evaluate the three risk categories using the α-D MCDM. The second phase is to evaluate the 12 risk factors of the food supply chain using the neutrosophic AHP to handle uncertainty in the evaluation process. The third phase is to evaluate the sustainability of the top six food and beverage companies based on the influence of the risk factors according to their performance using the neutrosophic CoCoSo method. The application steps of the proposed framework are illustrated in detail in this section.

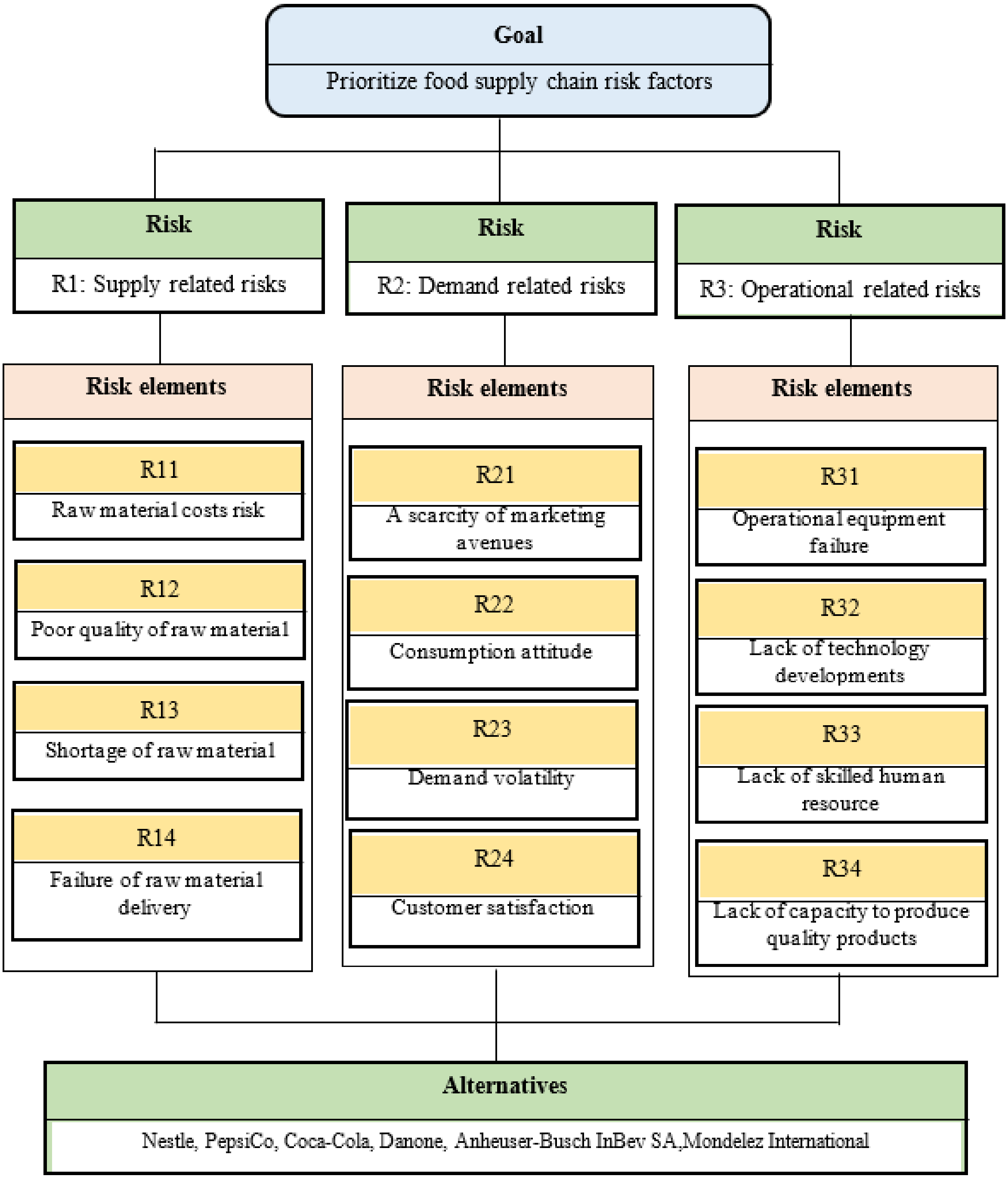

Figure 2. Food supply chain risk factors hierarchy.

4.1 Evaluation of the Main Risk Categories using α-D MCDM

This study's main goal is to rank the food supply chain according to how risk factors affect its sustainability. A hierarchy is created after the decision problem is divided. In this hierarchy, the first level denotes the main objective of the decision problem, the middle levels denote the primary risk categories that affect the food supply chain (i.e., supply-related risks, demand-related risks, and operational-related risks) and corresponding risk factors (the 12 risk elements as Figure 2 shows) that affect the FSC. The last level denotes the alternatives (i.e., the six food and beverage companies).

In terms of decision makers' selection, the diverse decision makers' preferences should be measured in ranking the food supply chain sustainability according to risk factors effect. Three groups of representative decision-makers participated in evaluating the sustainability of the six food and beverage companies. These decision-makers are academics and researchers who are interested in studying supply chain sustainability, supply chain risk management, and decision-making process. We conducted two questionnaires related to determining the main risk categories and the corresponding risk factors that affect food supply chain sustainability through which to assess the priority of food and beverage companies, the questionnaires were conducted using linguistic terminology.

In the first phase, we can see that this problem has a hierarchical structure, making AHP one of the most efficient and useful techniques. It is now unable to employ the AHP theory since the first preferences are not taken into account as a pairwise comparison, which is one of the main reasons for the theory's shortcomings. As a result, the following formula will be used to calculate the weight of these three risk categories. The three decision-makers are evaluating the main categories of food supply chain risks as follows:

- The risks of supply are as important as the risks of demand plus half as important as the risks of operations.
- The risks of demand are two times as important as the risks of supply
- The risks of operations are three times as important as the risks of supply.
- Let us construct equations and their corresponding matrix. Let the risks of supply=C_1, the risks of demand = C_2, and the risks of operations = C_3. The preference of each category must be formulated as a linear equation to build a system of comparisons.

$$\begin{cases} x = y + \frac{1}{2}z \\ y = 2x \\ z = 3x \end{cases}$$

The corresponding matrix of the system is formulated as follows: $A = \begin{bmatrix} 1 & 1 & \frac{1}{2} \\ 2 & 1 & 0 \\ 3 & 0 & 1 \end{bmatrix}$

$\text{Det}(A) = -\frac{5}{2} \neq 0$

To solve this system we will parameterize the right-hand side (RHS) coefficient by adding α and using the Fairness Principle.

$$x = \alpha_1 y_1 + \frac{1}{2}\alpha_2 z \quad (14)$$

$$y = 2\alpha_3 x \quad (15)$$

$$z = 3\alpha_4 x \quad (16)$$

where $\alpha_{1,}\ \alpha_{2,}\ \alpha_{3,}\ \alpha_4 > 0$.

Then, we will solve the system:

$x = \alpha_1(2\alpha_3 x) + \frac{1}{2}\alpha_2(3\alpha_4 x)$ Replacing (15) and (16) in (14)

$1 = 2\alpha_1\alpha_3 + \frac{3}{2}\alpha_2\alpha_4$ Set 1 to the secondary variable

Let $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha$

$1 = 2\alpha^2 + \frac{3}{2}\alpha^2$

$\alpha = \sqrt{2/7}$

$S = [1 \quad 1.069 \quad 1.6035]$

$W = [0.27 \quad 0.29 \quad 0.44]$

The result of α-D MCDM shows that economic the risk of supply weight is 0.27, the risk of demand is 0.29, and the risk of operations is 0.44 as Figure 3 shows.

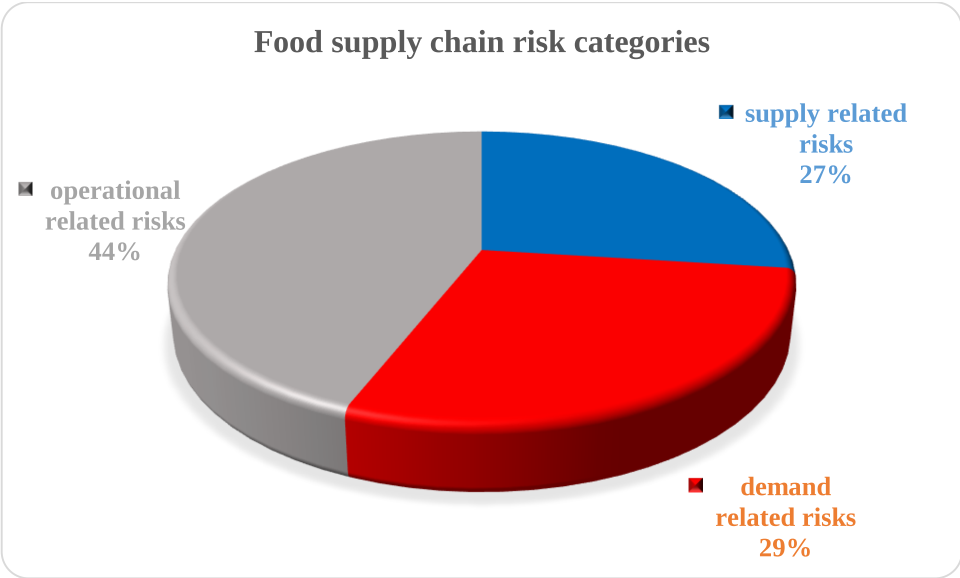

Figure 3. Evaluation of three main categories of food supply chain.

4.2 *Evaluation of the Food Supply Chain Risk Factors using Neutrosophic AHP*

In this sub-section, the second phase of the proposed method is applied to evaluate the risk factors using neutrosophic AHP.

- The questionnaire is applied to the three decision-makers and the results are applied using the linguistic terms as shown in Table 2. The pairwise evaluation is applied between the 12 risk factors for the three decision-makers as shown in Table A-1 (See Appendix).
- The pairwise comparison is applied using the corresponding neutrosophic scale, then, using Eq. (5) converted into crisp values as Table A-2 (see Appendix) shows.
- The normalized pairwise comparison is shown in Table A-3 (see Appendix).
- The weight of the risk factors by each decision maker according to neutrosophic AHP is shown in Table 4 and summarized in Figure 4.

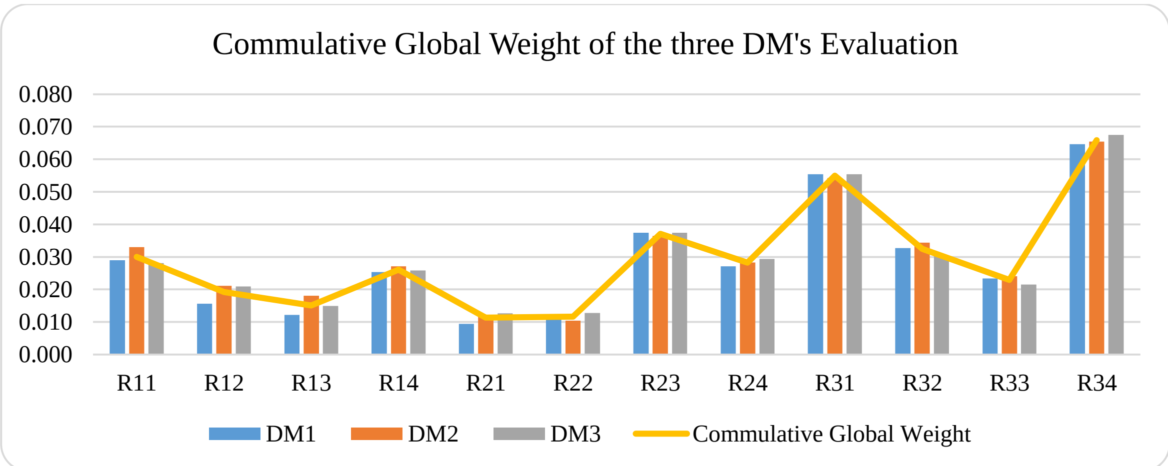

Figure 4. The result of the second phase.

Table 4. Weight and rank of the risk factor via three decision-makers using neutrosophic AHP.

	DM1		DM2		DM3		Concluding weight	
	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank
R11	0.1073	4	0.1224	4	0.1041	4	0.1113	4
R12	0.0578	8	0.0781	7	0.0777	7	0.0712	8
R13	0.0451	10	0.0671	9	0.0553	9	0.0558	9
R14	0.0940	5	0.1004	5	0.0957	6	0.0967	6
R21	0.0324	12	0.0410	11	0.0437	12	0.0390	12
R22	0.0404	11	0.0359	12	0.0439	11	0.0401	11
R23	0.1290	2	0.1255	2	0.1290	2	0.1279	2
R24	0.0934	6	0.0976	6	0.1014	5	0.0975	5
R31	0.1259	3	0.1233	3	0.1259	3	0.1250	3
R32	0.0744	7	0.0781	8	0.0690	8	0.0739	7
R33	0.0532	9	0.0547	10	0.0489	10	0.0522	10
R34	0.1469	1	0.1487	1	0.1535	1	0.1497	1

- The results of the first stage show that R34, R23, and R31 are at the top of the ranking with concluding weights 0.1497,0.1279, and 0.1250, respectively. R33, R22, and R21 are at the end of the ranking with weights of 0.0522, 0.0401, and 0.0390, respectively.

4.3 Evaluation of the Six Food and Beverage Companies using Neutrosophic CoCoSo

In this Phase, we applied the neutrosophic CoCoSo based on the weight of the FSC risk factors that result from the second phase to rank the top six food and beverage companies.

- The decision matrix is built based on the importance scale as Table 3 shows. The decision matrix is shown in Table A-4 (see Appendix).
- Build the crisp decision matrix using the score function (Eq. (5)), as Table A-5 (see Appendix) shows.
- In the normalization step, the criteria must be specified whether it is beneficial or non-beneficial criteria. Here, all criteria are beneficial while R24 is a non-beneficial criterion. The result of the normalization step is shown in Table A-6 (see Appendix) according to Eqs. (6) and (7).
- The Weighted normalized matrix is constructed using Eq. (8), as Table A-7 shows (see Appendix). The weight in this step is the result of the second stage of neutrosophic AHP.
- The power-weighted normalized matrix is constructed using Eq. (9), as Table A-8 shows (see Appendix).
- Using Eqs. (10-13) are applied to rank the top six food and beverage companies based on the risk factors of the food supply chain as Table 5 shows and summarized in Figure 5.
- The results of the neutrosophic CoCoSo show that Nestle (A1), PepseCo (A3), and Danone (A4) are at the top of the ranking. While Mondelez International (A6), Coca-Cola (A3), and Anheuser-Busch InBev SA (A5) are at the end of the ranking.

Table 5. The ranking of the top six food and beverage companies using neutrosophic CoCoSo.

	K_a	Rank	K_b	Rank	K_c	Rank	K	Rank
A1	0.2422	1	11.4095	1	1.0000	1	5.6205	1
A2	0.2403	2	10.8377	2	0.9921	2	5.3956	2
A3	0.1282	5	5.5650	5	0.5293	5	2.7970	5
A4	0.1932	3	7.7909	3	0.7975	3	3.9899	3
A5	0.0647	6	2.0000	6	0.2671	6	1.1030	6
A6	0.1314	4	5.9841	4	0.5426	4	2.9723	4

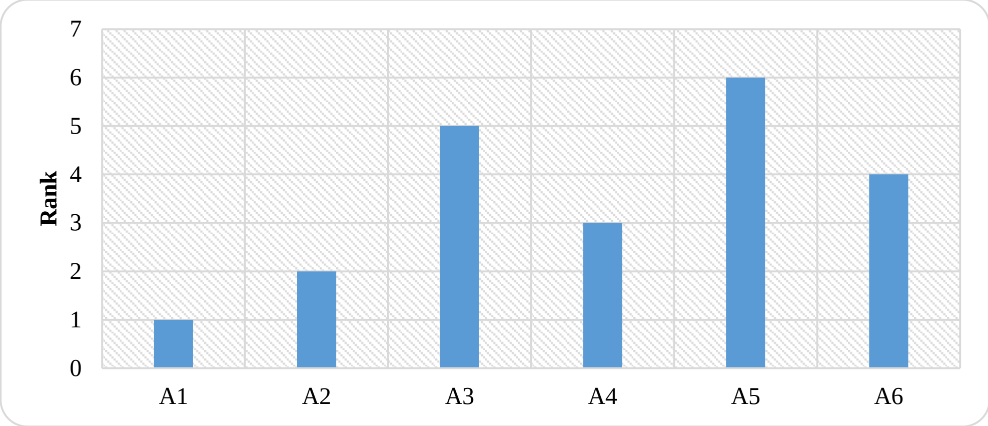

Figure 5. Ranking of the top six food and beverage companies using neutrosophic CoCoSo.

5. Result Analysis

5.1 Sensitivity Analysis

5.1.1 Sensitivity Analysis of Parameters

Since the calculation of the evaluation score k_{ic} is dependent on the values of λ parameter ($0 \leq \lambda \leq 1$), it is required to show its effect on the result of food companies' alternatives according to risk factors by varying parameter value. Thus, the nine scenarios of the possible values of λ are applied as Table 6 and Figure 6 show. As Figure 6 shows, while the value of γ changed from 0.1 to 0.9, the result is still the same as A1 ≻ A2 ≻ A4 ≻ A6≻ A3 ≻ A5, which verifies the applicability of the proposed framework in this research.

Table 6. Sensitivity analysis in the case of the parameter λ changes.

	λ values								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
A1	5.6205	5.6205	5.6205	5.6205	5.6205	5.6205	5.6205	5.6205	5.6205
A2	5.3969	5.3967	5.3964	5.3961	5.3956	5.3949	5.3937	5.3916	5.3861
A3	2.7983	2.7981	2.7978	2.7975	2.7970	2.7963	2.7952	2.7931	2.7877
A4	3.9934	3.9928	3.9921	3.9912	3.9899	3.9880	3.9849	3.9792	3.9646
A5	1.1057	1.1053	1.1047	1.1040	1.1030	1.1016	1.0992	1.0948	1.0836
A6	2.9729	2.9728	2.9726	2.9725	2.9723	2.9720	2.9715	2.9706	2.9682
	Rank								
	1	2	3	4	5	6	7	8	9
A1	1	1	1	1	1	1	1	1	1
A2	2	2	2	2	2	2	2	2	2
A3	5	5	5	5	5	5	5	5	5
A4	3	3	3	3	3	3	3	3	3
A5	6	6	6	6	6	6	6	6	6
A6	4	4	4	4	4	4	4	4	4

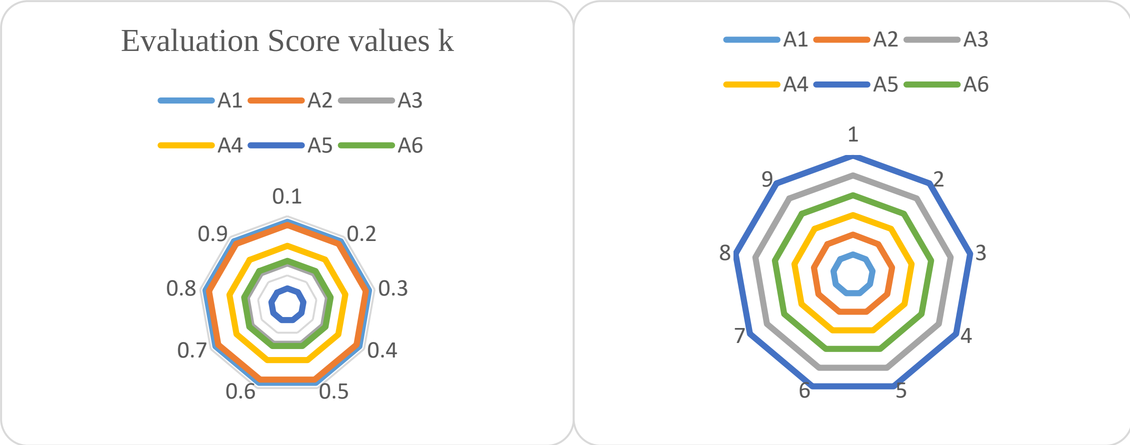

Figure 6. Sensitivity analysis of parameters.

5.1.2 Sensitivity Analysis of Risk Factors Weight

In this section, the sensitivity of the risk factor weights is studied. The weight of the risk factor is changed for 20 scenarios as Table 7 shows. Thus, the adjusted weight of each risk factor is considered, and changes in risk factors have an impact on the ranking outcomes, as seen in Figure 7.

The ranking of the alternatives A3, A4, A5, and A6 remains the same when changing the risk factors. Noteworthy, simple adjustments take place in tests 10 to 20. The ranking results of alternatives A1 and A2 change slightly when the weights of risk factors are changed in experiments 10 to 20. As a result, this proposed framework yields strong results, as shown in Figure 7. Therefore, however the risk factor weights change, either A1 or A2 remain the optimal alternatives and remain stable, and the ranking results always remain A4 ≻ A3 ≻ A6 ≻ A5 under the changing weights of risk factors, it shows that the strategy suggested in this study is efficient and reliable.

Table 7. Sensitivity analysis of risk factors weight.

		Evaluation Score						**Ranking**					
Scenario	Weight Change	A1	A2	A3	A4	A5	A6	A1	A2	A3	A4	A5	A6
1	5%	8.90	9.00	5.52	7.61	0.86	5.01	2	1	4	3	6	5
2	10%	8.90	9.00	5.52	7.61	0.86	5.01	2	1	4	3	6	5
3	15%	8.95	9.03	5.52	7.62	0.86	5.03	2	1	4	3	6	5
4	20%	9.01	9.06	5.51	7.62	0.86	5.08	2	1	4	3	6	5
5	25%	9.04	9.08	5.51	7.63	0.86	5.09	2	1	4	3	6	5
6	30%	9.06	9.09	5.51	7.63	0.86	5.11	2	1	4	3	6	5
7	35%	9.08	9.10	5.51	7.63	0.86	5.12	2	1	4	3	6	5
8	40%	9.10	9.11	5.50	7.63	0.86	5.13	2	1	4	3	6	5
9	45%	9.12	9.12	5.50	7.63	0.86	5.14	2	1	4	3	6	5
10	50%	9.13	9.13	5.50	7.63	0.86	5.15	1	2	4	3	6	5
11	55%	9.14	9.13	5.50	7.63	0.86	5.15	1	2	4	3	6	5
12	60%	9.16	9.14	5.50	7.63	0.86	5.16	1	2	4	3	6	5
13	65%	9.17	9.15	5.50	7.64	0.86	5.17	1	2	4	3	6	5
14	70%	9.18	9.15	5.50	7.64	0.86	5.17	1	2	4	3	6	5
15	75%	9.19	9.16	5.50	7.64	0.86	5.18	1	2	4	3	6	5
16	80%	9.19	9.16	5.50	7.64	0.86	5.18	1	2	4	3	6	5
17	85%	9.20	9.16	5.50	7.64	0.86	5.19	1	2	4	3	6	5
18	90%	9.21	9.17	5.49	7.64	0.86	5.19	1	2	4	3	6	5
19	95%	9.22	9.17	5.49	7.64	0.86	5.20	1	2	4	3	6	5
20	100%	9.22	9.17	5.49	7.64	0.86	5.20	1	2	4	3	6	5

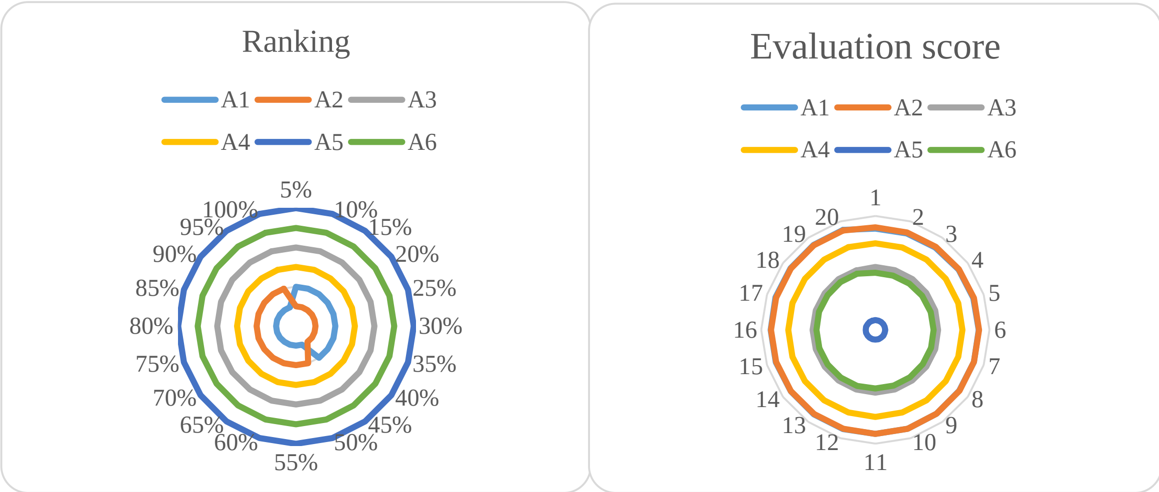

Figure 7. Sensitivity analysis of risk factor weight.

5.2 *Comparative Analysis*

In this subsection, two current methods neutrosophic simple additive weighting (SAW) [47] and neutrosophic TOPSIS [48] are introduced to conduct a comparative analysis to assess the effectiveness and reliability of the technique provided in this work. The neutrosophic TOPSIS method, which effectively addresses uncertainty in the evaluation process, intends to solve MCDM problems in an ambiguous context. Its main goal is to select the best option that is closest to or farthest from the positive ideal solution or negative ideal solution. By multiplying the weight of each criterion by its real value, adding the results, and taking into account all of the criteria, the neutrosophic SAW is also used to deal with this challenging problem. The Two methods' input data are taken from Table A-5, and the ranking results are computed and displayed in Table 8.

Table 8. Ranking results were achieved by two other existing methods.

Alternative Ranking			
	Neutrosophic CoCoSo	Neutrosophic TOPSIS	Neutrosophic SAW
A1	1	1	1
A2	2	2	2
A3	5	4	5
A4	3	3	3
A5	6	6	6
A6	4	5	4

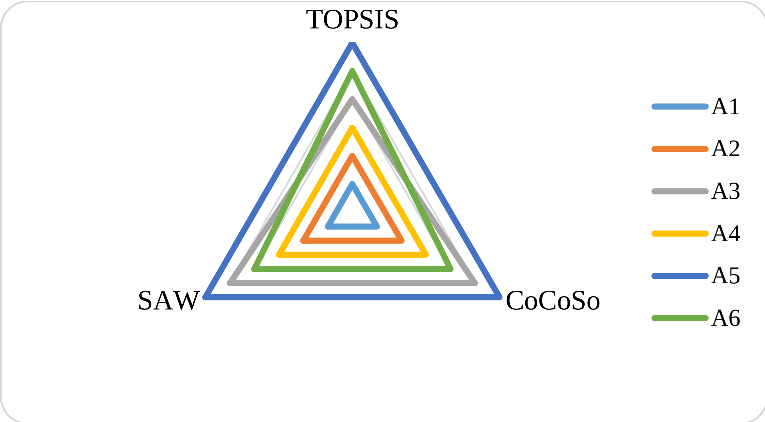

Figure 8. Comparative analysis with neutrosophic SAW and neutrosophic TOPSIS.

From Figure 8, it can be seen that the Neutrosophic SAW's ranking findings match up with those of the suggested technique with ranking A1 ≻ A2 ≻ A5 ≻ A3 ≻ A6 ≻ A4. In addition, the ranking results acquired by the neutrosophic TOPSIS are almost consistent with a slight change in the ranking of alternatives A3 and A6. As a result, it is possible to confirm the accuracy and dependability of the framework suggested in this study.

6. Conclusion

The food supply chain's many activities are exposed to a variety of risks. To reduce risks, this study proposes to determine and assign priority to the risk factors along the FSC. 12 risk factors have been determined overall utilizing systematic literature research, decision makers' feedback, and other considerations. Additionally, these elements are divided into three groups based on their characteristics: the risks of supply, the risks of demand, and the risks of operations. Six leading food and beverage firms are analyzed to understand the risk factors and how they affect the sustainability of the food supply chain.

Meanwhile, a hybrid MCDM framework was developed by combining α-D MCDM, neutrosophic AHP, and neutrosophic TOPSIS to measure the FSC risk factors and rank the top six food companies. The proposed framework's main advantage, it can effectively deal with uncertainty. The three main groups of food supply chain risks are evaluated using α-D MCDM to avoid the drawbacks of n-wise comparison of AHP to be the first stage. The results show that the the risks of operations are the most significant with a weight of 0.44 followed by the risks of demand and the risks of supply with weights of 0.29 and 0.27, respectively. In the second stage, the neutrosophic AHP was applied to evaluate the 12 risk factors of the food supply chain. The results show that R34, R23, and R31 are at the top of the ranking with concluding weights of 0.1497, 0.1279, and 0.1250, respectively. The third stage is conducted to rank the top six food and beverage companies to validate the effect of risk factors on the performance of the FSC. In this stage, the neutrosophic CoCoSo was applied to rank the six companies based on the weight that was found from the previous stage. The results show that Nestle (A_1), PepseCo (A_3), and Danone (A_4) are at the top of the ranking.

The accuracy and robustness of the framework suggested in this study were confirmed in three stages. Firstly, the influence on the ranking of food companies' alternatives according to risk factors by changing parameter values was examined. Secondly, the sensitivity of the risk factor weights was studied. Thirdly, the comparative analysis was applied with two other methods: neutrosophic SAW and neutrosophic TOPSIS. The results of the three sensitivity studies showed that the proposed framework is consistent and robust.

In future research work, the evaluation of the risk factors can be done using the other MCDM techniques, such as the Best Worst Method (BWM), Analytical Network Process (ANP), and Decision-

Making Trial and Evaluation Laboratory (DEMATEL). Moreover, more decision-makers might be asked to increase the accuracy of the outputs of decision-making. The case study or statistical work from the next research might be used to validate this study, which is based on the opinions of the decision-makers.

Acknowledgments
The author is grateful to the editorial and reviewers, as well as the correspondent author, who offered assistance in the form of advice, assessment, and checking during the study period.

Author Contributions
All authors contributed equally to this research.

Data availability
The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Funding
This research was not supported by any funding agency or institute.

Conflict of interest
The authors declare that there is no conflict of interest in the research.

Appendix

Table A-1. Assessment of risk factors via three decision makers using the linguistic terms.

DM1	R11	R12	R13	R14	R21	R22	R23	R24	R31	R32	R33	R34
R11	E1	SI	VSI	EI	VSI	VSI	PI	SI	EI	SI	SI	WI
R12	WI	E1	EI	WI	SI	SI	VWI	PI	VWI	EI	EI	VWI
R13	WI	PI	E1	WI	SI	EI	VWI	WI	VWI	WI	EI	VWI
R14	EI	SI	SI	E1	VSI	VSI	WI	EI	PI	SI	SI	WI
R21	WI	WI	WI	VWI	E1	EI	VWI	WI	VWI	WI	WI	VWI
R22	WI	PI	EI	WI	EI	E1	VWI	WI	VWI	WI	PI	VWI
R23	SI	VSI	VSI	SI	AI	VSI	E1	SI	EI	SI	VSI	PI
R24	PI	PI	SI	EI	VSI	SI	SI	E1	PI	EI	SI	WI
R31	EI	SI	VSI	SI	AI	AI	EI	SI	E1	SI	VSI	PI
R32	PI	EI	SI	PI	SI	SI	WI	EI	WI	E1	SI	WI
R33	WI	EI	EI	WI	SI	SI	VWI	WI	WI	PI	E1	VWI
R34	SI	VSI	VSI	SI	AI	AI	EI	SI	SI	VSI	VSI	E1
DM2	R11	R12	R13	R14	R21	R22	R23	R24	R31	R32	R33	R34
R11	E1	EI	SI	SI	SI	VSI	WI	SI	EI	AI	VSI	EI
R12	PI	E1	SI	PI	SI	SI	WI	AI	VWI	EI	EI	WI
R13	VWI	PI	E1	WI	EI	EI	VWI	AI	VWI	AI	EI	VWI
R14	SI	SI	SI	E1	VSI	VSI	WI	EI	PI	SI	AI	WI
R21	VWI	SI	PI	VWI	E1	EI	VWI	VWI	VWI	WI	PI	VWI
R22	VWI	WI	EI	WI	EI	E1	VWI	VWI	VWI	WI	WI	VWI
R23	EI	VSI	AI	SI	AI	VSI	E1	SI	EI	SI	VSI	PI
R24	PI	SI	SI	EI	VSI	VSI	SI	E1	WI	EI	SI	WI
R31	SI	SI	VSI	SI	AI	VSI	EI	SI	E1	SI	VSI	WI
R32	WI	EI	SI	PI	VSI	AI	WI	EI	WI	E1	SI	WI
R33	VWI	EI	EI	WI	SI	AI	VWI	WI	WI	PI	E1	VWI
R34	SI	VSI	AI	SI	AI	AI	EI	SI	SI	VSI	VSI	E1
DM3	R11	R12	R13	R14	R21	R22	R23	R24	R31	R32	R33	R34
R11	E1	AI	SI	SI	VSI	VSI	EI	WI	EI	SI	WI	WI
R12	PI	E1	EI	SI	SI	AI	VWI	SI	VWI	PI	EI	WI
R13	PI	PI	E1	SI	SI	EI	WI	WI	WI	WI	WI	VWI
R14	PI	SI	AI	E1	AI	VSI	PI	EI	PI	SI	SI	WI
R21	VWI	WI	PI	VWI	E1	EI	WI	WI	VWI	SI	WI	WI
R22	PI	PI	PI	WI	EI	E1	WI	WI	VWI	WI	EI	VWI

R23	SI	VSI	VSI	SI	AI	VSI	E1	SI	EI	SI	VSI	PI
R24	EI	PI	SI	EI	AI	SI	SI	E1	EI	EI	SI	WI
R31	EI	SI	VSI	SI	AI	AI	EI	SI	E1	SI	VSI	PI
R32	WI	EI	SI	WI	SI	SI	WI	EI	VWI	E1	SI	WI
R33	VWI	WI	EI	WI	SI	SI	VWI	WI	WI	PI	E1	WI
R34	SI	AI	VSI	SI	AI	AI	SI	SI	SI	VSI	VSI	E1

Table A-2. Crisp pairwise comparison of the risk factors via three decision-makers.

DM1	**R11**	**R12**	**R13**	**R14**	**R21**	**R22**	**R23**	**R24**	**R31**	**R32**	**R33**	**R34**
R11	0.563	0.750	0.844	0.563	0.844	0.844	0.272	0.750	0.563	0.750	0.750	0.150
R12	0.150	0.563	0.563	0.150	0.750	0.750	0.103	0.272	0.103	0.563	0.563	0.103
R13	0.150	0.272	0.563	0.150	0.750	0.563	0.103	0.150	0.103	0.150	0.563	0.103
R14	0.563	0.750	0.750	0.563	0.844	0.844	0.150	0.563	0.272	0.750	0.750	0.150
R21	0.150	0.150	0.150	0.103	0.563	0.563	0.103	0.150	0.103	0.150	0.150	0.103
R22	0.150	0.272	0.563	0.150	0.563	0.563	0.103	0.150	0.103	0.150	0.272	0.103
R23	0.750	0.844	0.844	0.750	1.013	0.844	0.563	0.750	0.563	0.750	0.844	0.272
R24	0.272	0.272	0.750	0.563	0.844	0.750	0.750	0.563	0.272	0.563	0.750	0.150
R31	0.563	0.750	0.844	0.750	1.013	1.013	0.563	0.750	0.563	0.750	0.844	0.272
R32	0.272	0.563	0.750	0.272	0.750	0.750	0.150	0.563	0.150	0.563	0.750	0.150
R33	0.150	0.563	0.563	0.150	0.750	0.750	0.103	0.150	0.150	0.272	0.563	0.103
R34	0.750	0.844	0.844	0.750	1.013	1.013	0.563	0.750	0.750	0.844	0.844	0.563
DM2	R11	R12	R13	R14	R21	R22	R23	R24	R31	R32	R33	R34
R11	0.563	0.563	0.750	0.750	0.750	0.844	0.150	0.750	0.563	1.013	0.750	0.563
R12	0.272	0.563	0.750	0.272	0.750	0.750	0.150	1.013	0.103	0.563	0.563	0.150
R13	0.103	0.272	0.563	0.150	0.563	0.563	0.103	1.013	0.103	1.013	0.563	0.103
R14	0.750	0.750	0.750	0.563	0.844	0.844	0.150	0.563	0.272	0.750	1.013	0.150
R21	0.103	0.750	0.272	0.103	0.563	0.563	0.103	0.103	0.103	0.150	0.272	0.103
R22	0.103	0.150	0.563	0.150	0.563	0.563	0.103	0.103	0.103	0.150	0.150	0.103
R23	0.563	0.844	0.844	0.750	1.013	0.844	0.563	0.750	0.563	0.750	0.844	0.272
R24	0.272	0.750	0.750	0.563	0.844	0.844	0.750	0.563	0.150	0.563	0.750	0.150
R31	0.750	0.750	0.844	0.750	1.013	0.844	0.563	0.750	0.563	0.750	0.844	0.150
R32	0.150	0.563	1.013	0.272	0.844	1.013	0.150	0.563	0.150	0.563	0.750	0.150
R33	0.103	0.563	0.563	0.150	0.750	1.013	0.103	0.150	0.150	0.272	0.563	0.103
R34	0.750	0.844	1.013	0.750	1.013	1.013	0.563	0.750	0.750	0.844	0.844	0.563
DM3	R11	R12	R13	R14	R21	R22	R23	R24	R31	R32	R33	R34
R11	0.563	1.013	0.750	0.750	0.844	0.844	0.563	0.150	0.563	0.750	0.150	0.150
R12	0.272	0.563	0.563	0.750	0.750	1.013	0.103	0.750	0.103	0.272	0.563	0.150
R13	0.272	0.272	0.563	0.750	0.750	0.563	0.150	0.150	0.150	0.150	0.150	0.103
R14	0.272	0.750	1.013	0.563	1.013	0.844	0.272	0.563	0.272	0.750	0.750	0.150
R21	0.103	0.150	0.272	0.103	0.563	0.563	0.150	0.150	0.103	0.750	0.150	0.150
R22	0.272	0.272	0.272	0.150	0.563	0.563	0.150	0.150	0.103	0.150	0.563	0.103
R23	0.750	0.844	0.844	0.750	1.013	0.844	0.563	0.750	0.563	0.750	0.844	0.272
R24	0.272	0.272	0.750	0.563	1.013	0.750	0.750	0.563	0.563	0.563	0.750	0.150
R31	0.563	0.750	0.844	0.750	1.013	1.013	0.563	0.750	0.563	0.750	0.844	0.272
R32	0.150	0.563	0.750	0.150	0.750	0.750	0.150	0.563	0.103	0.563	0.750	0.150
R33	0.103	0.150	0.563	0.150	0.750	0.750	0.103	0.150	0.150	0.272	0.563	0.150
R34	0.750	1.013	0.844	0.750	1.013	1.013	0.750	0.750	0.750	0.844	0.844	0.563

Table A-3. Normalized pairwise comparison of the risk factors.

DM1	**R11**	**R12**	**R13**	**R14**	**R21**	**R22**	**R23**	**R24**	**R31**	**R32**	**R33**	**R34**
R11	0.1255	0.1138	0.1051	0.1145	0.0870	0.0913	0.0771	0.1349	0.1523	0.1199	0.0982	0.0675
R12	0.0335	0.0853	0.0701	0.0305	0.0774	0.0811	0.0293	0.0489	0.0279	0.0900	0.0736	0.0464
R13	0.0335	0.0413	0.0701	0.0305	0.0774	0.0609	0.0293	0.0270	0.0279	0.0240	0.0736	0.0464
R14	0.1255	0.1138	0.0935	0.1145	0.0870	0.0913	0.0426	0.1012	0.0736	0.1199	0.0982	0.0675
R21	0.0335	0.0228	0.0187	0.0210	0.0580	0.0609	0.0293	0.0270	0.0279	0.0240	0.0196	0.0464
R22	0.0335	0.0413	0.0701	0.0305	0.0580	0.0609	0.0293	0.0270	0.0279	0.0240	0.0356	0.0464
R23	0.1674	0.1280	0.1051	0.1527	0.1044	0.0913	0.1596	0.1349	0.1523	0.1199	0.1104	0.1224
R24	0.0607	0.0413	0.0935	0.1145	0.0870	0.0811	0.2128	0.1012	0.0736	0.0900	0.0982	0.0675
R31	0.1255	0.1138	0.1051	0.1527	0.1044	0.1095	0.1596	0.1349	0.1523	0.1199	0.1104	0.1224
R32	0.0607	0.0853	0.0935	0.0553	0.0774	0.0811	0.0426	0.1012	0.0406	0.0900	0.0982	0.0675
R33	0.0335	0.0853	0.0701	0.0305	0.0774	0.0811	0.0293	0.0270	0.0406	0.0435	0.0736	0.0464
R34	0.1674	0.1280	0.1051	0.1527	0.1044	0.1095	0.1596	0.1349	0.2030	0.1349	0.1104	0.2532
DM2	R11	R12	R13	R14	R21	R22	R23	R24	R31	R32	R33	R34
R11	0.1255	0.0853	0.0935	0.1527	0.0774	0.0913	0.0426	0.1349	0.1523	0.1619	0.0982	0.2532
R12	0.0607	0.0853	0.0935	0.0553	0.0774	0.0811	0.0426	0.1821	0.0279	0.0900	0.0736	0.0675
R13	0.0230	0.0413	0.0701	0.0305	0.0580	0.0609	0.0293	0.1821	0.0279	0.1619	0.0736	0.0464
R14	0.1674	0.1138	0.0935	0.1145	0.0870	0.0913	0.0426	0.1012	0.0736	0.1199	0.1325	0.0675
R21	0.0230	0.1138	0.0339	0.0210	0.0580	0.0609	0.0293	0.0185	0.0279	0.0240	0.0356	0.0464
R22	0.0230	0.0228	0.0701	0.0305	0.0580	0.0609	0.0293	0.0185	0.0279	0.0240	0.0196	0.0464
R23	0.1255	0.1280	0.1051	0.1527	0.1044	0.0913	0.1596	0.1349	0.1523	0.1199	0.1104	0.1224
R24	0.0607	0.1138	0.0935	0.1145	0.0870	0.0913	0.2128	0.1012	0.0406	0.0900	0.0982	0.0675
R31	0.1674	0.1138	0.1051	0.1527	0.1044	0.0913	0.1596	0.1349	0.1523	0.1199	0.1104	0.0675
R32	0.0335	0.0853	0.1262	0.0553	0.0870	0.1095	0.0426	0.1012	0.0406	0.0900	0.0982	0.0675
R33	0.0230	0.0853	0.0701	0.0305	0.0774	0.1095	0.0293	0.0270	0.0406	0.0435	0.0736	0.0464
R34	0.1674	0.1280	0.1262	0.1527	0.1044	0.1095	0.1596	0.1349	0.2030	0.1349	0.1104	0.2532
DM3	R11	R12	R13	R14	R21	R22	R23	R24	R31	R32	R33	R34
R11	0.1255	0.1536	0.0935	0.1527	0.0870	0.0913	0.1596	0.0270	0.1523	0.1199	0.0196	0.0675
R12	0.0607	0.0853	0.0701	0.1527	0.0774	0.1095	0.0293	0.1349	0.0279	0.0435	0.0736	0.0675
R13	0.0607	0.0413	0.0701	0.1527	0.0774	0.0609	0.0426	0.0270	0.0406	0.0240	0.0196	0.0464
R14	0.0607	0.1138	0.1262	0.1145	0.1044	0.0913	0.0771	0.1012	0.0736	0.1199	0.0982	0.0675
R21	0.0230	0.0228	0.0339	0.0210	0.0580	0.0609	0.0426	0.0270	0.0279	0.1199	0.0196	0.0675
R22	0.0607	0.0413	0.0339	0.0305	0.0580	0.0609	0.0426	0.0270	0.0279	0.0240	0.0736	0.0464
R23	0.1674	0.1280	0.1051	0.1527	0.1044	0.0913	0.1596	0.1349	0.1523	0.1199	0.1104	0.1224
R24	0.0607	0.0413	0.0935	0.1145	0.1044	0.0811	0.2128	0.1012	0.1523	0.0900	0.0982	0.0675
R31	0.1255	0.1138	0.1051	0.1527	0.1044	0.1095	0.1596	0.1349	0.1523	0.1199	0.1104	0.1224
R32	0.0335	0.0853	0.0935	0.0305	0.0774	0.0811	0.0426	0.1012	0.0279	0.0900	0.0982	0.0675
R33	0.0230	0.0228	0.0701	0.0305	0.0774	0.0811	0.0293	0.0270	0.0406	0.0435	0.0736	0.0675
R34	0.1674	0.1536	0.1051	0.1527	0.1044	0.1095	0.2128	0.1349	0.2030	0.1349	0.1104	0.2532

Table A-4. Decision matrix of the top six food and beverages according to the risk factors.

	R11	**R12**	**R13**	**R14**	**R21**	**R22**	**R23**	**R24**	**R31**	**R32**	**R33**	**R34**
A1	VHI	MI	PI	HI	LI	PI	AI	HI	VHI	MI	PI	AI
A2	VHI	MI	LI	HI	LI	LI	AI	MI	VHI	MI	PI	AI
A3	HI	LI	LI	MI	VLI	VLI	VHI	MI	HI	MI	LI	VHI
A4	HI	PI	LI	HI	VLI	LI	VHI	MI	VHI	MI	LI	VHI
A5	MI	LI	LI	MI	LI	LI	HI	MI	MI	PI	LI	HI
A6	HI	MI	LI	MI	VLI	VLI	HI	MI	HI	MI	PI	HI

Table A-5. Crisp decision matrix of the top six food and beverage companies according to the risk factors.

	R11	R12	R13	R14	R21	R22	R23	R24	R31	R32	R33	R34
A1	0.7619	0.4875	0.3594	0.6988	0.2100	0.3594	0.9450	0.6988	0.7619	0.4875	0.3594	0.9450
A2	0.7619	0.4875	0.2100	0.6988	0.2100	0.2100	0.7619	0.4875	0.7619	0.4875	0.3594	0.9450
A3	0.6988	0.2100	0.2100	0.4875	0.1641	0.1641	0.7619	0.4875	0.6988	0.4875	0.2100	0.7619
A4	0.6988	0.3594	0.2100	0.6988	0.1641	0.2100	0.7619	0.4875	0.7619	0.4875	0.2100	0.7619
A5	0.4875	0.2100	0.2100	0.4875	0.2100	0.2100	0.6988	0.4875	0.4875	0.3594	0.2100	0.6988
A6	0.6988	0.4875	0.2100	0.4875	0.1641	0.1641	0.6988	0.4875	0.6988	0.4875	0.3594	0.6988
MIN	0.488	0.210	0.210	0.488	0.164	0.164	0.699	0.488	0.488	0.359	0.210	0.699
MAX	0.762	0.488	0.359	0.699	0.210	0.359	0.945	0.699	0.762	0.488	0.359	0.945

Table A-6. Normalized decision matrix.

	R11	R12	R13	R14	R21	R22	R23	R24	R31	R32	R33	R34
A1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	1.000	1.000	1.000	1.000
A2	1.000	1.000	0.000	1.000	1.000	0.235	0.256	1.000	1.000	1.000	1.000	1.000
A3	0.770	0.000	0.000	0.000	0.000	0.000	0.256	1.000	0.770	1.000	0.000	0.256
A4	0.770	0.538	0.000	1.000	0.000	0.235	0.256	1.000	1.000	1.000	0.000	0.256
A5	0.000	0.000	0.000	0.000	1.000	0.235	0.000	1.000	0.000	0.000	0.000	0.000
A6	0.770	1.000	0.000	0.000	0.000	0.000	0.000	1.000	0.770	1.000	1.000	0.000

Table A-7. Weighted normalized decision matrix.

	R11	R12	R13	R14	R21	R22	R23	R24	R31	R32	R33	R34
A1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	1.000	1.000	1.000	1.000
A2	1.000	1.000	0.000	1.000	1.000	0.235	0.256	1.000	1.000	1.000	1.000	1.000
A3	0.770	0.000	0.000	0.000	0.000	0.000	0.256	1.000	0.770	1.000	0.000	0.256
A4	0.770	0.538	0.000	1.000	0.000	0.235	0.256	1.000	1.000	1.000	0.000	0.256
A5	0.000	0.000	0.000	0.000	1.000	0.235	0.000	1.000	0.000	0.000	0.000	0.000
A6	0.770	1.000	0.000	0.000	0.000	0.000	0.000	1.000	0.770	1.000	1.000	0.000

Table A-8. Power-weighted normalized matrix.

	R11	R12	R13	R14	R21	R22	R23	R24	R31	R32	R33	R34
A1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.000	1.000	1.000	1.000	1.000
A2	1.000	1.000	0.000	1.000	1.000	0.983	0.951	1.000	1.000	1.000	1.000	1.000
A3	0.992	0.000	0.000	0.000	0.000	0.000	0.951	1.000	0.986	1.000	0.000	0.914
A4	0.992	0.988	0.000	1.000	0.000	0.983	0.951	1.000	1.000	1.000	0.000	0.914
A5	0.000	0.000	0.000	0.000	1.000	0.983	0.000	1.000	0.000	0.000	0.000	0.000
A6	0.992	1.000	0.000	0.000	0.000	0.000	0.000	1.000	0.986	1.000	1.000	0.000

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Received: 12 Jan 2024, **Revised:** 22 May 2024,

Accepted: 28 Jun 2024, **Available online:** 01 Jul 2024.