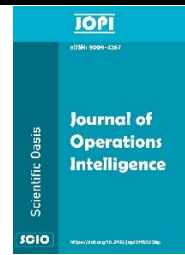




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Study on the Method of Selecting Sustainable Food Suppliers Considering Interactive Factors

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ABSTRACT

The existing sustainable supplier selection methods are not sufficient to deal with the problem of sustainable food supplier selection with the interaction of criteria under uncertainty. Therefore, this paper proposes a method of sustainable food supplier selection based on an extended decision model. First, a processing method for supplier evaluation information is constructed using the Pythagorean fuzzy set, which has the function of processing complex uncertain information. Second, to obtain the objective weights of decision experts, a Pythagorean fuzzy weighted distance measure model is constructed, and an expert information fusion method based on a weighted power mean operator is proposed to construct the group decision matrix. Then, the decision experiment and evaluation experiment methods are integrated with the traditional MARCOS method to construct a sustainable food supplier selection method considering the interaction of factors. This method can effectively deal with the complicated and uncertain problem of sustainable food supplier selection with interactive factors. Finally, the feasibility of the proposed method is verified by an example of sustainable food supplier selection. In addition, parameter sensitivity analysis and multi-method comparative analysis verify the rationality of the proposed selection method for sustainable food supplier selection.

1. Introduction

In October 2022, the Party's 20th National Congress report pointed out that the supply and demand problems of the food supply chain need to be solved urgently and should “focus on improving total factor productivity, focus on improving the resilience, and safety of the industrial chain supply chain” [1]. At the same time, it is necessary to “ensure the security of food, energy resources, and important industrial and supply chains”. It can be seen that security and resilience in the food supply chain are some of the agricultural issues that receive national attention. Subsequently, in January 2023, the Central Government issued document No.1, which made detailed

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requirements for the circulation process of the food and agricultural product supply chain more clearly, especially in the upstream links of the supply chain, proposing to “increase the supervision of food safety and agricultural product quality and safety, and improve the traceability management system”. Therefore, to ensure food security and establish a stable food supply system, we should pay attention to the selection of food suppliers to achieve the optimal selection of sustainable food suppliers [2].

In addition, under the influence of various ecological, military, and political factors such as the normalization of the novel coronavirus epidemic, global warming, flood disasters, and the Russia-Ukraine war, China’s food security is facing multiple uncertainties, which will certainly affect the stability of the sustainable food supply chain [3]. For supply chains, sustainability is the quality management of environmental, social, and economic impacts, as well as good practices throughout the life cycle of goods production and services [4]. Then, the establishment of a sustainable supply chain system can be used to optimize the rational allocation and utilization of resources throughout the product life cycle and can be used to achieve green and recyclable processes from product procurement, transportation, design, production, packaging, distribution, consumption, use, and recycling [5]. In the upstream process, sustainable suppliers can directly or indirectly become the value driver and guarantee factor of products, and the role of sustainable food suppliers in the food supply chain is more than that [6]. The sustainability of food suppliers is the cornerstone of ensuring national food security, is a magic weapon to enhance the resilience of the food supply chain, and can achieve the goal of green development and supply chain optimization and innovation [7].

Compared with the systematic study of general supplier selection methods, there is relatively little research on food supplier selection methods. In addition, the existing food supplier selection methods are rarely studied from the perspective of sustainability, especially with uncertain information from decision-makers [8]. Given the above shortcomings in the selection of sustainable food suppliers, this paper integrates the expression method of uncertain information into the multi-attribute group decision-making method to explore the selection method of sustainable food suppliers. Therefore, based on the existing research on supplier selection methods and food supplier selection methods, this paper comprehensively considers the situation of uncertainty and factor correlation and conducts a systematic study on sustainable food supplier selection methods from the aspects of the index construction of food supplier selection, analysis method construction for correlation factor, and designing optimization ranking method [9].

2. Literature review

2.1 Research on supplier selection method

Chaharsooghi and Ashrafi [10] integrated the concept of sustainable suppliers while considering traditional supplier performance evaluation criteria such as price, quality, and flexibility. A new model based on extended sustainable supplier selection is constructed according to the TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) method. Orji and Ojadi [11] combined the concepts of resilience and sustainability to investigate the impact of COVID-19 on sustainable supplier selection in Nigeria's manufacturing sector. A Fuzzy AHP (Analytic hierarchy process) method is proposed for ranking the importance of sustainable suppliers in manufacturing. Tavana et al. [12] developed a fuzzy selection model to address the problem of sustainable supplier selection in reverse logistics. First, TOPSIS and AHP methods were used to determine the weight of the criterion layer and secondary indicators, and then a consensus ranking model was used to determine the ranking results of sustainable green suppliers. Giri et al. [13] proposed a DEMATEL (Decision-making Trial and Evaluation Laboratory method based on trapezoidal Pythagoras fuzzy numbers, which can effectively deal with uncertainty by using Pythagorean fuzzy sets. At the same time, the language variable of the

ladder Pythagorean fuzzy number can be used to evaluate the standard value of the supplier scientifically.

At present, there is relatively little research on the selection methods of food suppliers in the academic circle. Wang et al. [14] developed the FAHP method and fuzzy data enveloping analysis method for supplier selection in the edible oil production industry considering sustainable factors and proposed a combination method of supplier selection combining the two methods. At the same time, green issues in edible oil production under uncertain environments are considered. Yazdani et al. [15] integrated MCDA (Multi-Criteria Decision Analysis) based on sustainability criteria, suppliers, and sub-suppliers using the SWARA (Stepwise Weighted Assessment Ratio Analysis) method and the level-based weight assessment method for estimating the weights of the supplier selection criteria. Meanwhile, the MARCOS (Measuring and Ranking of Alternatives to a Compromise) method was used to measure and sort alternative solutions, and the ordering order of suppliers at different levels was obtained. Puertas et al. [16] use a multi-criterion risk prevention tool that takes into account the socio-economic and institutional conditions of food exporters and uses the TOPSIS method to derive the ranking of suppliers based solely on aspects related to food risks.

In summary, the existing methods of selecting sustainable food suppliers lack consideration of the uncertain situation of decision-making information. In addition, the multi-attribute decision-making method is not effective in analyzing the correlation of selection factors. Therefore, this paper focuses on the selection of sustainable food suppliers under the uncertainty and factor correlation scenario.

2.2 Research status of the MARCOS method

The MARCOS method was pioneered by Stević et al. [17]. The MARCOS method can provide a more reasonable and robust method for the priority calculation of vendor selection. For example, the traditional TOPSIS priority simply depends on the sum of distance measurements from negative and positive ideal choices. This ranking principle does not reflect the relative importance of distance. However, the MARCOS method can consider both distance measurements and their relative importance. At the same time, it is possible to reflect the relationship between the reference values of the alternative, not only to deal with conflicting criteria but also to consider the relationship between the alternative and the reference point. Moreover, the MARCOS method is robust and stable in the process of alternative sorting; its computation time is short, and the operation is simpler. Therefore, the MARCOS method is a reasonable way to solve the problem of selection and ranking. At present, it has been applied by many researchers. For example, Celik and Gul [18] proposed the priority calculation framework of occupational hazard risk based on the MARCOS method. Stević et al. [17] proposed the priority calculation of continuous supplier selection. Karaaslan et al. [19] proposed the selection of renewable energy. Ali [20] proposed the selection of waste locations. Lordache et al. [21] proposed the ranking of new energy alternatives.

In view of the existing research and application of the MARCOS method, there is little research on the selection of food suppliers. Therefore, this paper integrates the concept of sustainable development into it, establishes the evaluation index system and selection method of food suppliers in connection with the MARCOS method, and provides a new research perspective for the study of green supplier selection and related issues of food supplier selection.

3. An extended MARCOS model for sustainable food supplier selection

3.1 Construction of evaluation indicators

According to the triple bottom-line principle of sustainable development, three levels of economic, social, and environmental factors need to be considered. According to the connotation of

sustainable supplier, a sustainable supplier is an enterprise or individual that supplies various necessary resources to enterprises and competitors for economic, environmental, and social sustainability, including providing raw materials, equipment, energy, services, etc. Traditional suppliers with sustainable ability can be called sustainable suppliers. On the premise of maintaining economic benefits, they should not only meet environmental protection requirements but also maintain social interests and resources for future generations. At the same time, they are willing to improve the sustainable ability of themselves and upstream and downstream supply chain node enterprises. Therefore, after reading and summarizing a large number of relevant literature, and combining the connotation of sustainable suppliers and expert opinions, this paper selects evaluation indicators for sustainable food suppliers. In this paper, the sub-influencing factor evaluation index of the downstream demand side will be constructed from the economic and practical factor layer, social relation factor layer, and ecological environment factor layer of the upstream supplier.

It can be seen from the references that the speed of receiving efficiency, quality, and suitability of economic and practical factors can affect the selection of sustainable food suppliers, as shown in Table 1.

Table 1

Economic and Practical Factors

Factor level	Sub factor	Factor reference
Economical and practical	Receiving efficiency	Lau et al. [22]
	Quality and suitability	Shi et al. [23]

Considering the evaluation indicators of sustainable suppliers from the perspective of social relations, it can be seen from the references that delivery feasibility, committed price, and suppliers' ability to take social responsibility are the evaluation sub-factors for the sustainability performance of social relations. As shown in Table 2:

Table 2

Social relationship factors

Factor level	Sub factor	Factor reference
Social relation	Deliverability	Wang et al. [14]
	Committed price	Allaoui et al. [24]
	Supplier's social responsibility ability	Banaeian et al. [25]

Since strengthening the sustainability of the ecological environment can promote the sustainability of economic utility and social relations, the sub-factor evaluation indicators of the ecological environment factor layer are divided into food planting environment, ecological practice, pollution consumption, and green health after searching references. As shown in Table 3:

Table 3

Ecological and environmental factors

Factor level	Sub factor	Factor reference
Ecological environment	Food growing environment	Banaeian et al. [26]
	Ecological practice	Govindan et al. [27]
	Pollution consumption and green health	Miranda-Ackerman et al. [28]

To sum up, this paper will build sub-factor evaluation indicators according to the economic-social-environmental factor layer and summarize the above-influencing factors to get the evaluation index system of food suppliers, which is shown in Figure.1.

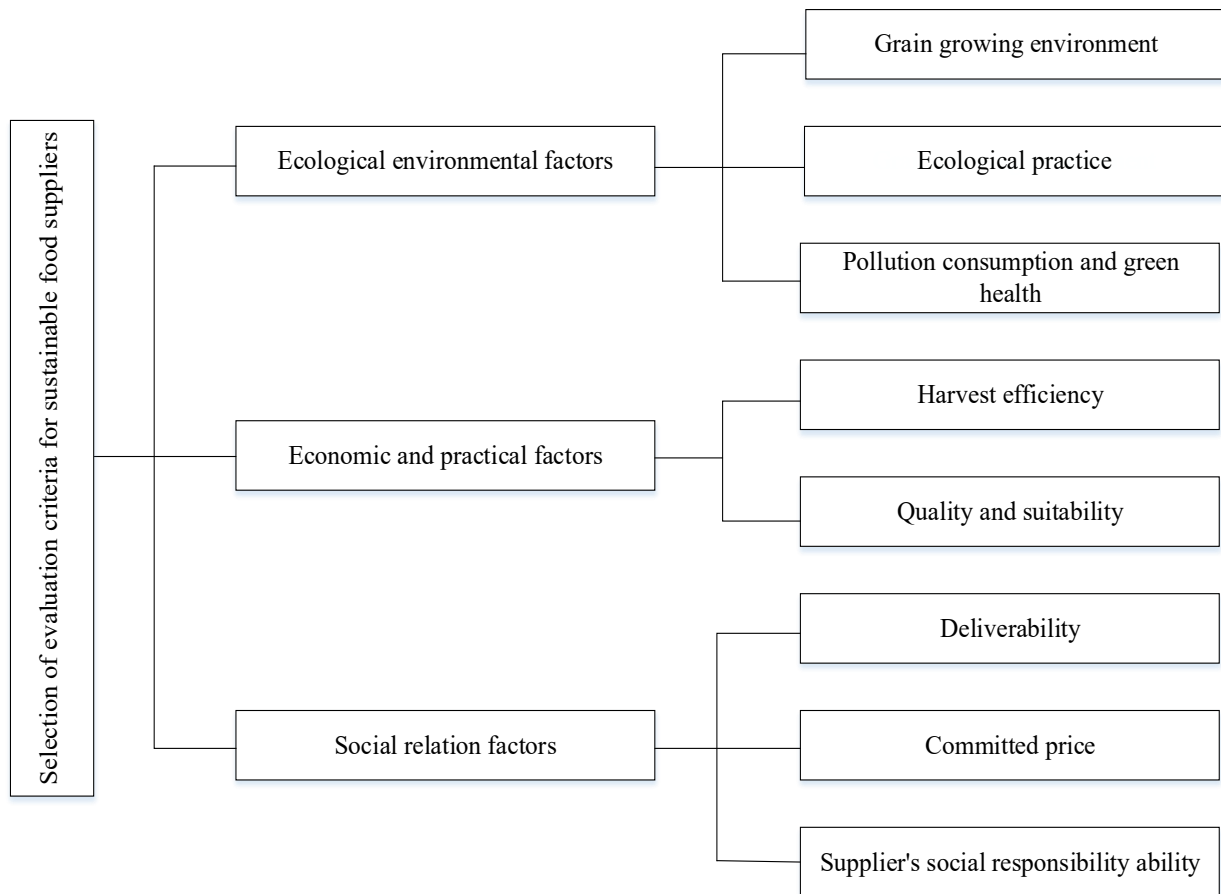


Fig. 1. Evaluation index selection system for sustainable food suppliers

3.2 Steps for calculating the priority of sustainable food suppliers

This paper studies the selection method of sustainable food suppliers considering the correlation of factors. According to the evaluation index selection system of sustainable food suppliers shown in Figure 1, the influencing factors of the sustainability of food suppliers include three-factor levels: ecological environment, economic utility, and social relations. Under the factor level, it can be divided into several specific sub-influencing factors. Each influencing factor interacts with each other, forming a complex system.

Therefore, first of all, this paper will use the expert scoring method to obtain linguistic assessment information for each sub-influencing factor index of food suppliers. Meanwhile, in order to weaken the influence of the personal preferences of experts, the initial influence matrix can be obtained by assigning weights to each expert with different importance. Secondly, the Pythagorean DEMATEL method is used. DEMATEL method is a method of system factor analysis using graph theory and matrix theory principles. This approach makes full use of expert experience and knowledge to deal with complex social problems, especially for systems where the relationships between elements are uncertain. This paper mainly constructs the optimal and the worst matrix and obtains the weighted value of each subfactor standard through the distance measure and discrete value of each subfactor. Finally, the weighted matrix is extended and sorted by the MARCOS method. The extended decision matrix is normalized by which the ideal and negative ideal solutions are constructed from the initial matrix. The extended decision synthesis matrix is established by combining the calculated weighted matrices of each sub-factor. Then, the utility degree and utility function of each supplier are calculated accordingly, and the best food-sustainable supplier can be ranked. The modeling process for sustainable food supplier priority calculation is shown in Figure 2.

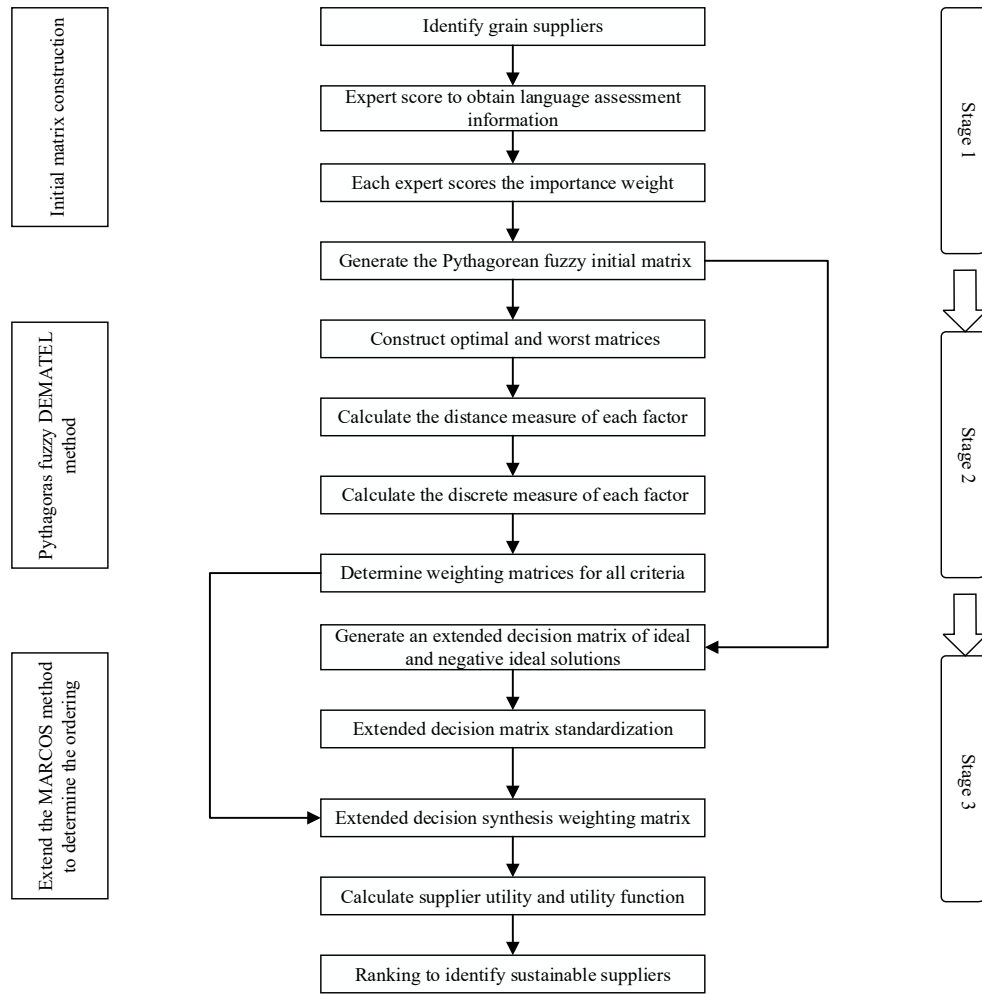


Fig.2. Establish a calculation model for the priority of sustainable food suppliers

3.3 PFS-DEMATEL-MARCOS method

Stage 1: Initial matrix construction, consider $OR_i (i = 1, 2, \dots, m)$ be the set of factors about food supply chain (For the food demand side, for example, a restaurant uses an expert $e_x (x = 1, 2, \dots, k)$ assessment method to obtain information and build an initial direct impact matrix).

Step 1. Potential suppliers were scored according to established scientific criteria $c_j (j = 1, 2, \dots, n)$ for factors influencing the selection of sustainable food suppliers.

Step 2. The language evaluation information is quantified for the original data after scoring, as shown in Table 2. At the same time, the evaluation weight $\lambda_x \left(\sum_{x=1}^k \lambda_x = 1, 0 \leq \lambda_x \leq 1 \right)$ of each expert is calculated and obtained. Finally, the fuzzy decision matrix is generated, and the PFS language rating scale is exhibited in Table 4.

$$R_{m \times n} = \begin{pmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{pmatrix} \quad (1)$$

Table 4
PFS language rating scale

Appraisal of value	PFS language rating	Linguistic variable
1	(0.5,0.2)	Very bad
2	(0.6,0.2)	Bad
3	(0.7,0.4)	Normal
4	(0.8,0.5)	Good
5	(0.9,0.3)	Very good

Stage 2: Pythagorean DEMATEL method (weighting matrix of the criteria for determining the decision matrix).

$$w = (w_1, w_2, \dots, w_r, \dots, w_t)^T \quad (2)$$

Step 3. Through Stage 1, the initial matrix $R_{m \times n}$ of the direct influence of suppliers and evaluation factors on decision-making can be obtained.

Step 4. For each known factor criterion $c_j (j = 1, 2, \dots, n)$, the corresponding optimal value matrix and the worst value matrix are calculated optimal value matrix V^+ and worst value matrix V^- :

$$V^+ = (r_1^+, r_2^+, \dots, r_n^+) \quad (3)$$

$$V^- = (r_1^-, r_2^-, \dots, r_n^-) \quad (4)$$

Where $r_j^+ = \max_{0 \leq i \leq n} \{r_{ij}\}$ is benefit criteria; $r_j^- = \min_{0 \leq i \leq n} \{r_{ij}\}$ is cost criteria.

Step 5. Distance measures d^+ and d^- can be determined from the initial matrix as follows:

$$d^+ = \sqrt{\sum_{i=1}^m (\mathcal{G}_\alpha(r_{ij}, r_j^+))^2} \quad (5)$$

$$d^- = \sqrt{\sum_{i=1}^m (\mathcal{G}_\alpha(r_{ij}, r_j^-))^2} \quad (6)$$

Where the parameter is defined as follows:

$$\mathcal{G}_\alpha = \frac{1}{2} \left(\left| (\mu_{\beta_1})^2 - (\mu_{\beta_2})^2 \right| + \left| (v_{\beta_1})^2 - (v_{\beta_2})^2 \right| + \left| (\pi_{\beta_1})^2 - (\pi_{\beta_2})^2 \right| \right) \quad (7)$$

For any fuzzy set $PFS = (\mu_\beta, v_\beta)$, the element satisfies the following condition: $0 \leq \mu_\beta, v_\beta \leq 1$ and $(\mu_{\beta_1})^2 + (v_{\beta_1})^2 \leq 1$. Then, the degree of hesitation is $\pi_\beta = \sqrt{1 - (\mu_{\beta_1})^2 - (v_{\beta_1})^2}$.

Step 6. According to the principle that the larger the ς_j value is, the greater the dispersion degree is, and the more important the j factor index is, the initial matrix dispersion metric can be calculated:

$$\varsigma_j = \frac{d^+}{d^+ + d^-} \quad (8)$$

Step 7. Based on the dispersion measure of each factor index, the weight of the factor index in the article j can be calculated as follows:

$$\omega_j = \frac{\varsigma_j}{\sum_{j=1}^n \varsigma_j} \quad (9)$$

Where $0 \leq \omega_j \leq 1$ and $\sum_{j=1}^n \omega_j = 1$.

Stage 3: According to the MARCOS method of multi-criteria decision, the weighting matrix is sorted.

Step 8. The extended matrix V^E can be obtained by adding two rows of ideal solution and negative ideal solution to the initial evaluation matrix formed in Stage 1.

$$V^E = \begin{matrix} & c_1 & c_2 & \cdots & c_n \\ \begin{matrix} OR_1 \\ OR_2 \\ \vdots \\ OR_m \\ AAI \\ AI \end{matrix} & \begin{pmatrix} \tilde{v}_{11} & \tilde{v}_{12} & \cdots & \tilde{v}_{1n} \\ \tilde{v}_{21} & \tilde{v}_{22} & \cdots & \tilde{v}_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \tilde{v}_{m1} & \tilde{v}_{m2} & \cdots & \tilde{v}_{mn} \\ \tilde{v}_{aa1} & \tilde{v}_{aa2} & \cdots & \tilde{v}_{aan} \\ \tilde{v}_{ai1} & \tilde{v}_{ai2} & \cdots & \tilde{v}_{ain} \end{pmatrix} \end{matrix} \quad (10)$$

Therefore, the ideal solution represents the optimal supplier choice, while the negative ideal solution represents the worst supplier choice, which represents each supplier to be selected. In addition, AAI and AI can be obtained by formulas (11) and (12):

$$\tilde{v}_{aaj} = \begin{cases} \min_i \tilde{v}_{ij}, & \text{if } j \in J_B \\ \max_i \tilde{v}_{ij}, & \text{if } j \in J_C \end{cases} \quad (11)$$

$$\tilde{v}_{aij} = \begin{cases} \max_i \tilde{v}_{ij}, & \text{if } j \in J_B \\ \min_i \tilde{v}_{ij}, & \text{if } j \in J_C \end{cases} \quad (12)$$

Where J_B represents the income index, J_C represents the cost index.

Step 9. To standardize the extended matrix obtained in Step 1, here are the elements in the standardized matrix:

$$\tilde{v}_{ij}^N = \begin{cases} \frac{\tilde{v}_{aij}}{\tilde{v}_{ij}}, j \in J_C \\ \frac{\tilde{v}_{ij}}{\tilde{v}_{aij}}, j \in J_B \end{cases} \quad (13)$$

Step 10. Determine the comprehensive weighting matrix $V = [V_{ij}]_{m \times n}$ and ω_i as the weighting matrix obtained in Stage 2:

$$V_{ij} = V_{ij}^N \times \omega_i \quad (14)$$

Step 11. Calculate the utility of AAI and AI in the supplier selection scheme, respectively:

$$\tilde{K}_i^- = \frac{\tilde{S}_i}{\tilde{S}_{aai}} \quad (15)$$

$$\tilde{K}_i^+ = \frac{\tilde{S}_i}{\tilde{S}_{ai}} \quad (16)$$

Where $\tilde{S}_i$ represents the sum of the elements in a row i of the comprehensive weighted matrix V ; where $\tilde{S}_{aai}$ represents the sum of the aai row of elements in the synthetic weighted matrix V ; where $\tilde{S}_{ai}$ represents the sum of the ai row of elements in the synthetic weighted matrix V :

$$\tilde{S}_i = \sum_{j=1}^n V_{ij} \quad (17)$$

Step 12. The utility function of the supplier selection scheme $f(K_i)$ is as follows:

$$f(\tilde{K}_i) = \frac{\tilde{K}_i^+ + \tilde{K}_i^-}{1 + \frac{1 - f(\tilde{K}_i^+)}{f(\tilde{K}_i^+)} + \frac{1 - f(\tilde{K}_i^-)}{f(\tilde{K}_i^-)}} \quad (18)$$

Where $f(\tilde{K}_i^+)$ and $f(\tilde{K}_i^-)$ are as follows:

$$f(\tilde{K}_i^+) = \frac{\tilde{K}_i^-}{\tilde{K}_i^+ + \tilde{K}_i^-} \quad (19)$$

$$f(\tilde{K}_i^-) = \frac{\tilde{K}_i^+}{\tilde{K}_i^+ + \tilde{K}_i^-} \quad (20)$$

Step 13. Finally, we can get the best supplier selection scheme.

4. Case study

To prove the validity of the model, this paper presents an empirical case study for the application of the model.

4.1 Calculation step

Set goals: To solve the problem of sustainable food supplier selection, an extended MARCOS method decision model is proposed. Models are used to enrich the decision-making domain to help solve the problem of supplier selection in complex environments. To demonstrate the validity of the proposed model, an empirical case study of food suppliers in the food industry is presented, and the optimal selection of food suppliers under uncertain conditions is evaluated.

The role of decision models: a real-life case study from sustainable suppliers in the food industry; An effective decision support model is established. Responsible for the evaluation of supplier performance under qualitative value.

Case examples: A demand side of the food industry needs to change suppliers recently. At the same time, to improve the core competitiveness of the enterprise and conform to the macro social environment strategy of sustainable development, the enterprise decides to choose among five suppliers, such as wholesale market, outlet store, agricultural product demonstration base, large processing enterprises, and agricultural association to find the next best food supplier. Indicators based on 8 factors identified that influence the selection of sustainable food suppliers.

Get information from expert scores. Three experts, namely practitioners with many years of experience in food procurement, SC executives of agroecology, and doctoral scholars of quality engineering, were selected respectively to evaluate the five suppliers from C_1 food growing environment, C_2 quality and suitability, C_3 receiving efficiency, C_4 ecological practices, C_5 delivery feasibility, C_6 committed price, C_7 pollution consumption and green health, and C_8 the supplier's social responsibility ability shall be scored. The language rating scale for experts e_1 , e_2 and e_3 is shown below Table 5-7.

Table 5

The language score matrix for e_1

	A_1	A_2	A_3	A_4	A_5
C_1	(0.5,0.2)	(0.6,0.2)	(0.5,0.2)	(0.5,0.2)	(0.5,0.2)
C_2	(0.6,0.2)	(0.6,0.2)	(0.7,0.4)	(0.6,0.2)	(0.5,0.2)
C_3	(0.6,0.2)	(0.5,0.2)	(0.7,0.4)	(0.5,0.2)	(0.6,0.2)
C_4	(0.5,0.2)	(0.5,0.2)	(0.5,0.2)	(0.6,0.2)	(0.6,0.2)
C_5	(0.5,0.2)	(0.6,0.2)	(0.6,0.2)	(0.6,0.2)	(0.6,0.2)
C_6	(0.6,0.2)	(0.5,0.2)	(0.6,0.2)	(0.5,0.2)	(0.8,0.2)
C_7	(0.9,0.3)	(0.6,0.2)	(0.5,0.2)	(0.6,0.2)	(0.6,0.2)
C_8	(0.8,0.5)	(0.7,0.4)	(0.6,0.2)	(0.6,0.2)	(0.5,0.2)

Table 6

The language score matrix for e_2

	A_1	A_2	A_3	A_4	A_5
C_1	(0.6,0.2)	(0.7,0.4)	(0.6,0.2)	(0.6,0.2)	(0.6,0.2)
C_2	(0.6,0.2)	(0.6,0.2)	(0.8,0.5)	(0.7,0.4)	(0.7,0.4)
C_3	(0.8,0.5)	(0.6,0.2)	(0.8,0.5)	(0.5,0.2)	(0.6,0.2)
C_4	(0.6,0.2)	(0.6,0.2)	(0.5,0.2)	(0.7,0.4)	(0.7,0.4)
C_5	(0.6,0.2)	(0.8,0.5)	(0.6,0.2)	(0.8,0.5)	(0.6,0.2)
C_6	(0.8,0.5)	(0.7,0.4)	(0.7,0.4)	(0.5,0.2)	(0.8,0.5)
C_7	(0.9,0.3)	(0.6,0.2)	(0.7,0.4)	(0.6,0.2)	(0.8,0.5)
C_8	(0.8,0.5)	(0.7,0.4)	(0.6,0.2)	(0.7,0.4)	(0.5,0.2)

Table 7

The language score matrix for e_3

	A_1	A_2	A_3	A_4	A_5
C_1	(0.6,0.2)	(0.6,0.2)	(0.5,0.2)	(0.6,0.2)	(0.5,0.2)
C_2	(0.6,0.2)	(0.7,0.4)	(0.7,0.4)	(0.7,0.4)	(0.7,0.4)
C_3	(0.8,0.5)	(0.5,0.2)	(0.8,0.5)	(0.5,0.2)	(0.6,0.2)
C_4	(0.6,0.2)	(0.6,0.2)	(0.5,0.2)	(0.7,0.4)	(0.6,0.2)
C_5	(0.6,0.2)	(0.6,0.2)	(0.6,0.2)	(0.8,0.5)	(0.6,0.2)
C_6	(0.6,0.2)	(0.6,0.2)	(0.6,0.2)	(0.5,0.2)	(0.6,0.2)
C_7	(0.9,0.3)	(0.6,0.2)	(0.5,0.2)	(0.6,0.2)	(0.7,0.4)
C_8	(0.8,0.5)	(0.7,0.4)	(0.6,0.2)	(0.7,0.4)	(0.5,0.2)

After calculating the weights of the three experts in the initial direct influence matrix through the scoring function $S_\beta = (\mu_\beta)^2 - (\nu_\beta)^2$, it is not difficult to get $\lambda_1 = 0.305$, $\lambda_2 = 0.358$ and $\lambda_3 = 0.337$ bringing the expert weights into the original data, the initial matrix (1) can be obtained as follows.

Table 8

Initial matrix

	A_1	A_2	A_3	A_4	A_5
C_1	(0.640,0.200)	(0.639,0.256)	(0.538,0.200)	(0.572,0.200)	(0.572,0.200)
C_2	(0.572,0.200)	(0.672,0.252)	(0.740,0.433)	(0.672,0.323)	(0.649,0.323)
C_3	(0.378,0.715)	(0.538,0.200)	(0.773,0.467)	(0.508,0.200)	(0.600,0.200)
C_4	(0.572,0.200)	(0.572,0.200)	(0.500,0.200)	(0.672,0.323)	(0.639,0.256)
C_5	(0.572,0.200)	(0.688,0.277)	(0.600,0.200)	(0.753,0.378)	(0.600,0.200)
C_6	(0.688,0.277)	(0.614,0.256)	(0.639,0.256)	(0.500,0.200)	(0.747,0.367)
C_7	(0.774,0.300)	(0.600,0.200)	(0.583,0.256)	(0.600,0.200)	(0.717,0.350)
C_8	(0.800,0.500)	(0.700,0.400)	(0.600,0.200)	(0.672,0.323)	(0.500,0.200)

The initial decision matrix obtained from the information obtained in the expert scores can be calculated as follows: The optimal value matrix V^+ and the worst value matrix V^- in equations (3) and (4) can be calculated respectively:

$$V^+ = \begin{pmatrix} (0.639, 0.256), & (0.672, 0.252), & (0.773, 0.467), & (0.672, 0.323) \\ (0.753, 0.358), & (0.747, 0.347), & (0.774, 0.300), & (0.800, 0.500) \end{pmatrix}$$

$$V^- = \begin{pmatrix} (0.538, 0.200), & (0.649, 0.323), & (0.507, 0.200), & (0.500, 0.200) \\ (0.572, 0.200), & (0.500, 0.200), & (0.583, 0.256), & (0.500, 0.200) \end{pmatrix}$$

According to formula (5)-(7), the distance measure d^+ and d^- can be calculated as follows in Table 9.

Table 9

Distance measurement of each factor

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
d^+	0.463	0.371	1.671	1.109	1.121	1.014	0.945	1.663
d^-	0.130	0.165	0.507	0.233	0.348	0.548	0.304	0.701

The discrete values of each factor index can be obtained from equation (8) as follows: $\varsigma_1 = 0.780$, $\varsigma_2 = 0.693$, $\varsigma_3 = 0.767$, $\varsigma_4 = 0.827$, $\varsigma_5 = 0.763$, $\varsigma_6 = 0.649$, $\varsigma_7 = 0.756$, and $\varsigma_8 = 0.703$. The weighted weights of each factor index can be obtained from equation (9) as follows: $\omega_1 = 0.131$, $\omega_2 = 0.117$, $\omega_3 = 0.129$, $\omega_4 = 0.139$, $\omega_5 = 0.128$, $\omega_6 = 0.109$, $\omega_7 = 0.127$, and $\omega_8 = 0.118$.

In this stage, the Pythagorean fuzzy MARCOS extension method is selected by the supplier. The MARCOS method of the multi-criteria decision will be used to calculate the initial matrix of information obtained from the expert scores, and the weighted matrix will be calculated using the weighted weights obtained from the aggregation of individual decision matrices. Finally, the comparative utility values will be sorted in a compromise.

According to equations (11) and (12), two lines of negative ideal solution AAI and ideal solution AI are added to the initial evaluation matrix formed by obtaining information from expert scores, and the following extended matrix similar to equation (10) can be obtained in Table 10.

Table 10

Extended matrix

	A_1	A_2	A_3	A_4	A_5	AAI	AI
C_1	(0.640, 0.200)	(0.639, 0.256)	(0.538, 0.200)	(0.572, 0.200)	(0.572, 0.200)	(0.538, 0.200)	(0.639, 0.256)
C_2	(0.572, 0.200)	(0.672, 0.252)	(0.740, 0.433)	(0.672, 0.323)	(0.649, 0.323)	(0.649, 0.323)	(0.672, 0.252)
C_3	(0.378, 0.715)	(0.538, 0.200)	(0.773, 0.467)	(0.508, 0.200)	(0.600, 0.200)	(0.507, 0.200)	(0.773, 0.467)
C_4	(0.572, 0.200)	(0.572, 0.200)	(0.500, 0.200)	(0.672, 0.323)	(0.639, 0.256)	(0.500, 0.200)	(0.672, 0.323)
C_5	(0.572, 0.200)	(0.688, 0.277)	(0.600, 0.200)	(0.753, 0.378)	(0.600, 0.200)	(0.572, 0.200)	(0.753, 0.378)
C_6	(0.688, 0.277)	(0.614, 0.256)	(0.639, 0.256)	(0.500, 0.200)	(0.747, 0.367)	(0.500, 0.200)	(0.747, 0.367)
C_7	(0.774, 0.300)	(0.600, 0.200)	(0.583, 0.256)	(0.600, 0.200)	(0.717, 0.350)	(0.583, 0.256)	(0.774, 0.300)
C_8	(0.800, 0.500)	(0.700, 0.400)	(0.600, 0.200)	(0.672, 0.323)	(0.500, 0.200)	(0.500, 0.200)	(0.800, 0.500)

After normalization and weighted deformation of the extended matrix using equations (13) and (14), the following table is shown in Table 11.

Table 11

Weighting matrix

	A_1	A_2	A_3	A_4	A_5	AAI	AI
C_1	(0.084,0.026)	(0.084,0.034)	(0.071,0.026)	(0.075,0.026)	(0.075,0.034)	(0.026,0.071)	(0.084,0.034)
C_2	(0.067,0.023)	(0.078,0.029)	(0.086,0.051)	(0.078,0.038)	(0.076,0.038)	(0.038,0.076)	(0.078,0.029)
C_3	(0.049,0.092)	(0.069,0.028)	(0.100,0.060)	(0.066,0.026)	(0.078,0.026)	(0.026,0.065)	(0.100,0.060)
C_4	(0.080,0.026)	(0.080,0.026)	(0.070,0.026)	(0.094,0.041)	(0.089,0.033)	(0.028,0.064)	(0.094,0.041)
C_5	(0.073,0.022)	(0.088,0.030)	(0.077,0.022)	(0.097,0.041)	(0.077,0.022)	(0.026,0.063)	(0.097,0.041)
C_6	(0.075,0.030)	(0.067,0.028)	(0.070,0.0280)	(0.055,0.022)	(0.082,0.040)	(0.022,0.055)	(0.082,0.040)
C_7	(0.099,0.038)	(0.076,0.025)	(0.074,0.033)	(0.076,0.025)	(0.091,0.038)	(0.033,0.074)	(0.099,0.038)
C_8	(0.095,0.059)	(0.083,0.047)	(0.071,0.024)	(0.080,0.038)	(0.059,0.024)	(0.024,0.059)	(0.095,0.059)

Through the weighting matrix, the corresponding utility of five suppliers, namely wholesale market, outlet store, agricultural product demonstration base, large processing enterprise, and agricultural association, can be obtained from equations (15)-(17), and the utility value of the final five suppliers can be obtained from utility function equations (18)-(20). The results are shown in Table 12.

Table 12

Supplier's utility and utility value

	A_1	A_2	A_3	A_4	A_5
$\tilde{K}_i^+$	0.651	0.813	0.750	0.796	0.809
$\tilde{K}_i^-$	-1.155	-1.443	-1.329	-1.441	-1.435
$f(\tilde{K}_i)$	0.377	0.471	0.434	0.460	0.468

4.2 Result Analysis

Get information from expert ratings. The original data of the personal fuzzy preference of three experts are obtained through a literature search, and the corresponding weighted values are obtained by linguistic quantification of the initial score data. The weighted value of expert 2 (SC executive of agroecology) is the largest, and it can be concluded that expert 2 should be the more objective expert among the three experts. In addition, expert 1 (a practitioner with years of experience in food procurement) and expert 3 (a doctoral scholar in quality engineering) are more subjectively influenced by their environment or work, so it can be seen that they all have certain biases in preferences that should be weakened. Therefore, important comprehensive data from this stage was obtained after the weight assignment in this paper.

Aggregation of individual decision matrix. The key is to construct the optimal value matrix and the worst value matrix by using the initial matrix of the first stage and obtain 8 distance measures and discrete values of the influence factors. For distance measures, there are cost and benefit types. When the distance is smaller, the better. Its attribute is a cost distance measure. On the contrary, when the greater the distance, the better. Its attribute is the benefit distance measure. The positive and negative distance measurements of the 8 influence factors obtained in this paper are also the same. For example, the positive distance measure and the negative distance measure of C_2 quality and suitability are both small, indicating that the cost and effect attributes of the influence factor should also have less influence on decision-making. At the same time, the positive distance measure

of C_3 receiving efficiency is the largest among all the influence factors, and the value of its negative distance measure belongs to the medium level of the whole population, which indicates that the influence factor should be considered in the pre-decision analysis. Then, after a comprehensive calculation of the calculated distance measure size and discrete value, different importance degrees and corresponding weight values of the impact factors can be obtained. According to the value size, it can be concluded that the weight values of C_4 ecological practice and C_3 receiving efficiency are higher, so they should be used as important decision-making factors in selecting sustainable food suppliers. At the same time, food suppliers should also improve and strengthen themselves according to these two influential factors.

Pythagorean fuzzy MARCOS extension method selected by the supplier. The MARCOS method was used to extend the negative ideal solution and ideal solution of the initial matrix, and the weights of the importance of different influencing factors were assigned according to the weights obtained in the second stage, to obtain the weighting matrix as shown in Table 6. After introducing utility function and utility value, it can be intuitively seen according to the value of utility value. When the demand side chooses between the five supplier wholesale markets, outlet stores, agricultural product demonstration bases, large processing enterprises, and agricultural associations. In addition, under the comprehensive score of 8 influencing factors (C_1 food growing environment, C_2 quality and suitability, C_3 receiving efficiency, C_4 ecological practice, C_5 delivery feasibility, C_6 commitment price, C_7 pollution consumption, and green health, C_8 suppliers' social responsibility ability). The final utility value obtained by suppliers is very different. For example, if the supplier 2 outlet store is closer to the ideal solution and the supplier 1 wholesale market has the lowest utility value, then the supplier 2 outlet store is more able to achieve the demand side to achieve the decision goal of sustainable food supplier under the action of eight evaluation indicators, and the supplier 5 agricultural association with the second highest utility value can also be used as an alternative. Under comprehensive evaluation, the supplier 2 outlet store is undoubtedly the best supplier.

5. Countermeasures and suggestions

Under the current development, China's food supply and demand are in a basic equilibrium state, but there are always many problems to be solved. First, when state-owned food enterprises have insufficient experience in market acquisition and poor channels, they will still face the dilemma of small actual purchase amounts, although they carry out policy purchases of food. Second, small food and oil stores funds are limited, and the time, money, and corresponding risks spent on selecting suppliers are difficult to control. Whether large, small, medium, private, or state-owned enterprises, they are all seeking a sustainable food supply chain, and sustainability undoubtedly puts strict requirements on all links of the supply chain and their connection. Combined with the results of the case and the above phenomena, two countermeasures and suggestions are put forward for realizing sustainable food supplier selection, as follows:

Self-improvement of food suppliers: To enhance their core competitiveness in the market, food suppliers should improve at least two important factors: receiving efficiency and ecological practice.

The efficiency of receiving goods is an important factor in ensuring the stable and sustainable operation of food suppliers, especially the food demand side attaches great importance to whether the food raw products can complete the order supply on time, quality and quantity. Given this point, suppliers can establish special departments to control operations, establish real-time information sharing systems with the demand side of the food supply chain, and improve the comprehensive quality of relevant responsible personnel to achieve quality services.

Ecological practice is the main theme of today's greening, recycling, and sustainability. As a food supplier, we should actively respond to the call of the national government and regard ecological practice as one of the priorities to be balanced in our economic development. For example, strict control of the systemic risks brought by excessive fertilization to the ecological environment, appropriate arrangements for the main food production area fallow, but also the management and rectification of agricultural plastic pollution.

In terms of decisions on sustainable food suppliers, outlet stores and agricultural associations should be prioritized, and wholesale markets should be placed at the bottom. The same is true from the perspective of national policies and regulations. The State Administration of Taxation has implemented preferential tax policies for the wholesale market of agricultural products in the Opinions of the Central Committee of the Communist Party of China and The State Council on Several Policies to Promote the Increase of Farmers' Income in the early years, which should be in a good trend, but there are still farmers' managers who single-handedly reduce the purchase price when engaged in purchasing and marketing activities. The phenomenon of single-handedly raising the selling price. Not only the interests of farmers are damaged, but also the price signals of local wholesale markets are distorted and the management is chaotic. The outlet store can reduce the circulation of agricultural products and reduce the circulation cost. The direct selling model makes the whole process of quality supervision easier, especially the supervision of food production, transportation, and other processes, and effectively solves the problem of poor information connection between production and marketing. Agricultural associations are departments with complete rules and regulations, supervision, and management composed of national, provincial, or local leaders, and the food suppliers provided and recommended are publicized after strict control. Many uncertainties and risks have been avoided.

6. Conclusion and prospect

6.1 Conclusion

First of all, in the process of studying the selection of sustainable food suppliers, this paper finds that there are many uncertainties, including the internal uncertainty of food supply chain nodes, the uncertainty between food supply chain nodes, and the external uncertainty of food supply chain nodes, which will highly affect the selection of sustainable food suppliers. The realization of sustainable food supplier selection is the basis of ensuring food security, so it is particularly important to establish a scientific and rigorous method of sustainable food supplier selection.

Secondly, the scoring mechanism of sustainable food supplier selection was established using the DEMATEL method. This paper analyzes the sub-influencing factors of sustainable food supplier selection through the three dimensions of food supplier's ecological environment, social relations, and economic and practical factors, and concludes that it can be divided into food planting environment, ecological practice, pollution consumption and green health related to the ecological environment, and social relations related to delivery feasibility, committed price, and supplier's social responsibility ability. What is economical and practical are 8 sub-factors such as receiving efficiency, quality, and suitability. Then, the expert scoring method is used to conduct linguistic quantitative scoring for sub-influencing factor indicators, and weighted assignment is used to weaken the subjective preference bias of each expert to obtain the initial matrix of influencing factors.

Thirdly, the MARCOS method was used to extend the initial matrix to establish the ranking results of sustainable food supplier selection. The distance measure and discrete value of each index response are obtained by using the optimal value matrix and the worst value matrix, and the different importance and weighting values of each index are obtained. Then, the initial matrix is extended, normalized, and weighted to obtain the final weighted normalized decision matrix. Finally, supplier

optimization is sorted by utility function and utility value. To sum up, the mathematical model in this paper is based on the comprehensive application of the expert scoring method, linguistic quantification method, DEMATEL method, MARCOS method, and weighting operator to achieve the selection of sustainable food suppliers. The introduction of examples also verifies the practicability and science of the research method.

Finally, through the analysis of factors affecting the selection of food suppliers, the correlation among factors and the importance of each factor are analyzed, and at the same time, they are used in the compromise ranking of supplier decision-making to improve the efficiency and accuracy of supplier selection. Based on the existing methods of selecting food suppliers, improving the relevant policies of the food supply chain, integrating the concept of sustainable development, and establishing the evaluation index system and selection method of food suppliers is an extension and improvement of the existing research indicators of supplier selection methods, supplier priority technologies, and methods. It can not only enrich the current research methods of food supplier selection but also provide a new perspective for the research of food security in China.

6.2 Future directions

In recent years, food security has been widely concerned by people from all walks of life in the world, and the food supply chain is a hot issue that scholars at home and abroad pay attention to and study. This paper focuses on the topic of food supplier selection. Although it can deal with the decision-making problem of sustainable food suppliers under uncertain situations, there are still some limitations. On the one hand, the initial data of the research is based on expert ratings, which itself has a personal preference bias. Although weighted operators have been used in the research process to mitigate the influence of this shortcoming, the establishment of a more rigorous and scientific database is one of the methods for further research on better modeling and the use of the Internet big data platform to build an information collection database. On the other hand, in the uncertain environment discussed in this paper, there is still a big problem to be solved, that is, the dynamic problem. When the evaluation or other indicators are changed dynamically, whether it is qualitative or quantitative change, the whole system data will be changed, thus affecting the supplier selection decision. Therefore, the establishment of a structure that conforms to dynamic changes is also a problem that needs to be further discussed based on this paper, and the optimization can greatly improve the accuracy and practicality of the selection of sustainable food suppliers.

Author Contributions

Conceptualization, X.H. and H.Y.; methodology, X.H. and H.Y.; writing—review and editing, Y.W. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

There is no data in this study.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The funders had worked on the writing of the manuscript.

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