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A New Hybrid Triple Bottom Line Metrics and Fuzzy MCDM Model: Sustainable Supplier Selection in the Food-Processing Industry

Nguyen Van Thanh [1] and Nguyen Thi Kim Lan [2,*]

[1] Faculty of Commerce, Van Lang University, Ho Chi Minh City 70000, Vietnam; thanh.nguyenvan@vlu.edu.vn
[2] International Education Institute, Van Lang University, Ho Chi Minh City 70000, Vietnam
* Correspondence: lan.ntk@vlu.edu.vn

Abstract: Vietnam's food processing and production industries in the past have managed to receive many achievements, contributing heavily to the growth of the country's economic growth, especially the production index. Even with an increase of 7% per year over the past five years, the industry currently also faces problems and struggles that require business managers to rewrite legal documents and redevelop the business environment as well as the production conditions in order to compete better and use the available resources. Xanthan gum (a food additive and a thickener) is one of the most used ingredients in the food-processing industry. Xanthan gum is utilized in a number of variety of products such as canned products, ice cream, meats, breads, candies, drinks, milk products, and many others. Therefore, in order to improve competitiveness, the stage of selecting raw-material suppliers is a complicated task. The purpose of this study was to develop a new composite model using Triple Bottom Line Metrics, the Fuzzy Analytical Hierarchy Process (FAHP) method, and the Combined Compromise Solution (CoCoSo) algorithm for the selection of suppliers. The application process was accomplished for the Xanthan-gum (β-glucopyranose $(C_{35}H_{49}O_{29})n$) supplier selection in a food processing industry. In this study, the model building, solution, and application processes of the proposed integrated model for the supplier selection in the food-processing industry are presented.

Keywords: fuzzy theory; FAHP; CoCoSo; MCDM; chemistry; supplier selection model; food-processing industry

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1. Introduction

In recent years, Vietnam's food-processing industry has been on a strong growth trend, gradually supplying more competitive products, dominating the domestic market, and increasing exports. Statistics from the Vietnam Ministry of Industry and Trade show that Vietnam's annual food consumption value is estimated at about 15% of GDP. In the last 5 years, consumption of processed foods and beverages has increased by an average annual rate of 9.68% and 6.66%, respectively [1]. Seizing this opportunity, many businesses have expanded their investment and increased production in the food-processing sector.

The food-processing industry is one of the industry groups selected by the Vietnamese Government to prioritize sustainable development. To develop a sustainable food-processing industry, there needs to be a methodical investment in production, ensuring the source of good quality raw materials, meeting the requirements of food hygiene and safety and other environmental factors [2].

In order to pursue sustainability management, companies utilize stable decision-making tools in order to support their change process, including the development of sustainable materials, products, and procedures [3]. For choosing the best suppliers in a supplier selection process, the integration of social, ethical, and environmental evaluation is key for sourcing decisions. Constructing the strong bond with suppliers is the final goal that all businesses want to achieve. Changing and evaluating performance on environmental, social, and ethical issues is vital to developing such relationships [4].

A Multicriteria Decision-Making (MCDM) model is based on the theory that fuzzy sets are a strong tool for calculating complex supplier selection problems including multiple standards (qualitative and quantitative) with multiple options [5]. Qualitative standards often have unclear characteristics, making it hard to distinguish accuracy and resulting in the difficulty to achieve the suitability of the evaluation according to the standards and the delivery decision. The MCDM method will quantify these criteria and calculate the total score of these alternatives. There have been many studies on the application of MCDM in the sustainable-supplier-selection processes. A number of methods are commonly used today and include The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), AHP, the analytic network process (ANP), CoCoSo, etc. [6].

In this study, the authors developed a new composite model using Triple Bottom Line Metrics, the Fuzzy Analytical Hierarchy Process (FAHP) method, and the Combined Compromise Solution (CoCoSo) Algorithm for the selection of suppliers in the food-processing industry. The supplier selection criteria were identified by the Triple Bottom Line (TPL) model (environmental, economic, and social factors) and literature reviews. In addition, the FAHP method was utilized to identify the weight of all criteria in the second stage. The CoCoSo is an MCDM method, which is utilized for ranking the suppliers list in the result stage.

One of the tools that can assist businesses in evaluating and selecting sustainable suppliers is the Triple Bottom Line (TBL). The TPL is an accounting framework that incorporates three dimensions of performance: social, environmental, and financial (Figure 1) [7]. TBL reporting can be an important tool to support sustainability goals.

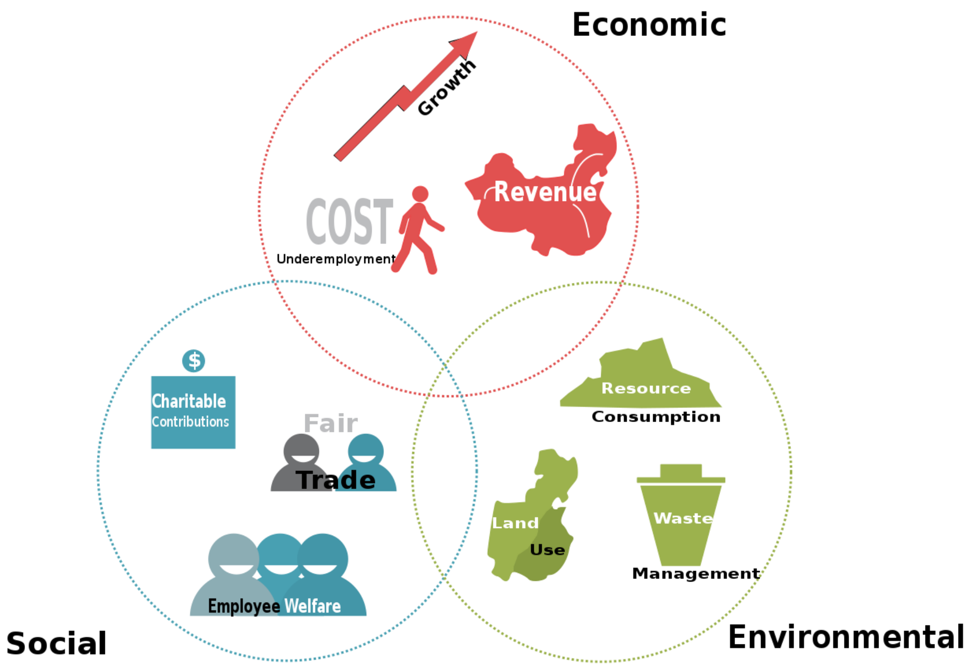

Figure 1. Graphic describing the three types of bottom lines.

In recent decades, due to the rapid consumption of natural resources and the need for environmental protection, sustainability in supply chain management has emerged as an increasingly important issue. Therefore, in this study, supplier selection was performed in order to achieve sustainability, taking into account all aspects: economic, social, and environmental criteria. For this purpose, a combined TPL–FAHP–CoCoSo approach was used for selecting the optimal Xanthan-gum (β-glucopyranose $(C_{35}H_{49}O_{29})n$) supplier. The research goal of this study can be described as following:

- Developing a new composite model for supplier selection for a sustainable food-processing supply chain.
- Achieving sustainable goals, the author used the Triple Bottom Line (TPL) for defining criteria that affect the decision-making process. Then, a Fuzzy Analytical Hierarchy Process (FAHP) method and the Combined Compromise Solution (CoCoSo) model was used to select an optimal supplier (Xanthan gum (β-glucopyranose ($C_{35}H_{49}O_{29}$)n) supplier).
- Evaluating the fuzzy multi-criteria decision model for a case study.

2. Literature Review

The supplier evaluation and the selection processes is a typical multicriteria decision problem, and a more complex variation of it is the sustainable supplier selection that should consider many qualitative and quantitative factors. There are many approaches that have been applied to address this decision process, some of which are based on MCDM/multi-criteria decision analysis (MCDA) methods, applied individually, or combined with other MCDM/MCDA methods, and/or other different techniques [8].

Mirko Stojčić et al. [9] showed that sustainability is one of the main challenges of the recent decades. In this study, the authors reviewed many MCDM models that are applied in the sustainability engineering sector. Bojan Matić et al. [10] presented a new hybrid MCDM model for evaluating and selecting sustainable suppliers in the supply chain for a construction company. In this study, the authors applied four MCDM models including rough simple additive weighting (SAW), rough weighted aggregated sum product assessment (WASPAS), rough additive ratio assessment (ARAS), and rough multi-attributive border approximation area comparison (MABAC). SemihÖnüt et al. [11] developed a new MCDM model for supplier evaluation in telecommunication company. This MCDM model was developed based on the analytic network process (ANP) and the technique for order performance by similarity to ideal solution (TOPSIS) methods.

S. Nallusamy et al. [12] proposed a MCDM model based on the Analytical Hierarchy Process (AHP), Fuzzy Logic (FL), and Artificial Neural Networks (ANN) for selection of suppliers in manufacturing industries. Morteza Yazdani [13] found the right supplier based on a fuzzy Multi-Criteria Decision Making (MCDM) process. In this study, the author applied the AHP and the TOPSIS model for ranking potential suppliers. Joseph Sarkis and Dileep G. Dhavale [14] proposed a triple-bottom-line approach using a Bayesian framework for supplier selection for sustainable operations. The author considered a TBL model approach and considered business operations as well as environmental impacts and social responsibilities of the suppliers while they evaluated and selected optimal suppliers in their search.

Kannan Govindan et al. [15] presented an effective model for supplier-selection operations in supply chains by triple-bottom-line metrics, the fuzzy theory, and the multicriteria approach. Ioannis E. Nikolaou et al. [16] proposed a new framework of performance indicators for measuring reverse logistics social responsibility performance based on the TPL approach. Maedeh Rezaeisaray et al. [17] merged three decision-making techniques including decision-making trial and evaluation (DEMATEL), the fuzzy analytic network process (FANP), and the data envelopment analysis (DEA) model into a hybrid MCDM model for outsourcing supplier selection in pipe and fittings manufacturing. Alireza Fallahpour et al. [18] presented a fuzzy decision-making model for the sustainable resilient supplier-selection problem. In this research, they used fuzzy DEMATEL, the fuzzy Best Worst Method, the fuzzy ANP, and the fuzzy inference system. For showing the applicability of this hybrid decision-making model, an industrial case of palm oil in Malaysia was presented. He-Yau Kang et al. [19] used a fuzzy analytic network process model to evaluate various aspects of suppliers in IC packaging company selection. Hengameh Hadian et al. [20] integrated VIKOR-AHP-BOCR (Benefits, Opportunities, Costs, and Risks) to select the best providers of galvanized steel sheets for Iran Khodro (IKCO), which is the largest Iranian automaker. Wang et al. [21] introduced a MCDM model for N-hexane solvent (C_6H_{14}) supplier evaluation and selection for vegetable-oil production. In this study, the authors used fuzzy ANP and the TOPSIS model for the supplier-selection process. Wang et al. [22] applied FAHP and Green DEA for sustainable supplier selection in the SMEs food-processing industry.

Vladimir R. Milovanović et al. [23] discusses the selection of the most optimal supplier using the example of an unmanned aircraft when the decision-maker has data of a qualitative nature. In this study, the authors used intuitive fuzzy numbers (IF ELECTRE) to rank some potential suppliers. Hamed Fazlollahtabar and Navid Kazemitash [24] represented the relation between Information Systems (IS) and Green Supplier Selection (GSS) as two vital components of firms in a novel way, which has not been done before.

Zeeshan Ali et al. [25] proposed a novel complex interval-valued Pythagorean fuzzy setting with application in green supplier chain management. Marko Radovanovic [26] proposed a MCDM model based on the fuzzy AHP method and the VIKOR method in selection of the most efficient procedure for rectification of the optical sight of the long-range rifle. Tapas Biswas et al. [27] presented an integrated criteria importance through inter-criteria correlation (CRITIC)—Combined Compromise Solution (CoCoSo) method for selection of commercially available alternative passenger vehicles in the automotive environment. Aleksandra Bączkiewicz et al. [28] provided a reliable recommendation to the consumer in the form of a compromise ranking constructed from the five MCDM methods: the hybrid model TOPSIS-COMET, COCOSO, EDAS, MAIRCA, and MABAC. Each of the methods used contributes significantly to the final compromise ranking built with the Copeland strategy. Wojciech Sałabun et al. [29] have benchmarked Multi-Criteria Decision Analysis (MCDA) methods. To achieve that, a set of feasible MCDA methods was identified. Based on reference literature guidelines, a simulation experiment was planned. Wang and Hongjun [30] studied interval-valued fuzzy and Muirhead Mean algorithms. We deduced new algorithms named as the Hesitant Interval-Valued Fuzzy Muirhead Mean (HIVFMM) and the Hesitant Interval-Valued Fuzzy Muirhead Mean (HIVFWMM) with Muirhead Mean algorithms based on the Hesitant Interval-Valued Fuzzy Set (HIVFS). Then, we combined them both and gave the proof process of properties and theorems, a mathematic model applying to MADM.

Pamučar Dragan S. and Savin Lazar M. [31] proposed the Best Worst Method (BWM) and the Compressed Proportional Assessment (COPRAS) models for the selection of the optimal off-road vehicle for the needs of the Serbian Armed Forces (SAF). Elmina Durmić et al. [32] combined FUCOM—Rough SAW for sustainable supplier selection. Fatih Ecera and Dragan Pamucarb [33] proposed a new FMCDM model for sustainability supplier selection (SSS). In this research, a real-world example of a home-appliance manufacturer in Serbia is discussed. Madjid Tavana et al. [34] proposed a fuzzy group BWM and CoCoSo for supplier selection in reverse supply chains. Morteza Yazdani et al. [35] presented a two-phase sustainable multitier supplier selection model for food supply chains based on an integrated decision analysis under multi-criteria perspectives considering sustainability criteria, suppliers, and sub-suppliers. Seyed Amirali Hoseini et al. [36] proposed a hybrid fuzzy best worst method, and a fuzzy inference system model was developed for sustainable supplier selection. Morteza Yazdani et al. [37] proposed a combined compromise solution (CoCoSo) method for multi-criteria decision-making problems. The purpose of this study was to discuss the advantage of a combinatory methodology; the study also suggested that the comparison with the results of previously developed methods is in high agreement.

As a literature review, MCDM is a branch of operational research dealing with finding optimal results in complex scenarios including various indicators and conflicting objectives and criteria. This popular tool in the sustainable-supplier-selection field is receiving attention due to the flexibility it provides for decision-makers in finalizing decisions while considering all the criteria, but there are very few studies using the MCDM based on fuzzy sets to develop a decision-making tool in the food-processing industry. Thus, the author proposed a fuzzy MCDM model for sustainable supplier selection in this research.

3. Methodology

Supplier selection is a multi-criteria problem that includes both tangible and intangible factors. In this research, the authors developed a new composite model using Triple Bottom Line Metrics, the Fuzzy Analytical Hierarchy Process (FAHP) method, and the Combined Compromise Solution (CoCoSo) Algorithm for the selection of suppliers in the food-processing industry. There are three step in the decision-making process (Figure 2) as follows:

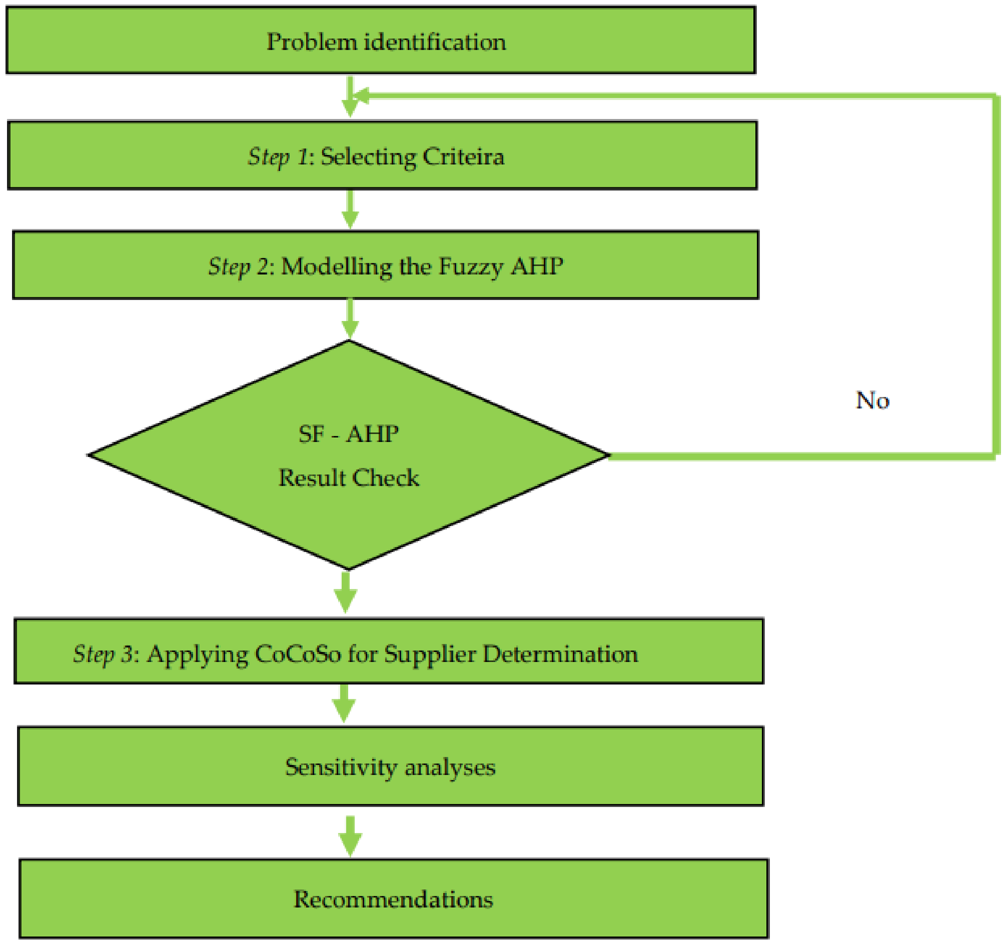

Figure 2. Research process.

Step 1: All important criteria affecting the decision process are defined based on Triple Bottom Line and the literature review.

Step 2: The Fuzzy Analytical Hierarchy Process (FAHP) is employed to determine the important weights of criteria under fuzzy environment conditions.

Step 3: The CoCoSo model is an MCDM technique that applies an integrated simple additive methodology with an exponentially weighted product model. The CoCoSo approach is used to evaluate and rank the potential sustainable suppliers.

3.1. Fuzzy Analytical Hierarchy Process (FAHP) Method

3.1.1. Theoretical Fuzziness

The triangular fuzzy number (TFN) is defined $(k,\ h,\ g)$, where $k,\ h$, and g $(k\ \leq h\ \leq\ g)$ are parameters that determine the least likely value, the most promising value, and the greatest conceivable value in TFN. TFN are seen in Figure 3 and may be characterized as follows:

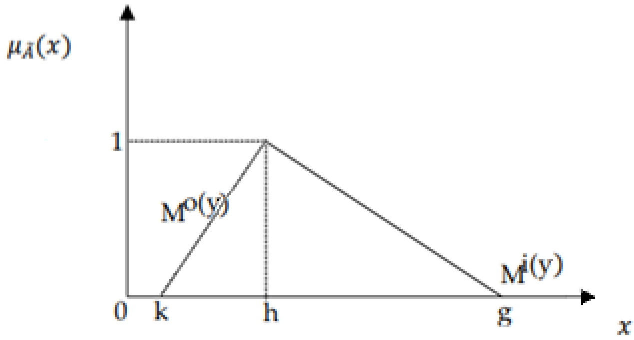

Figure 3. Triangular fuzzy number.

The following is an example of a fuzzy number:

$$\widetilde{M} = (M^{o(y)}, M^{i(y)}) = [k + (h-k)y,\ g + (h-g)y], y\ \in [0,1] \quad (1)$$

The left and right sides of a fuzzy number are represented by $o(y)$ and $i(y)$, respectively. The fundamental computations shown below utilize two positive TFN, $(k_1,\ h_1,\ g_1)$ and $(k_2,\ h_2,\ g_2)$.

$$\begin{array}{c}(k_1,\ h_1,\ g_1) + (k_2,\ h_2,\ g_2) = (k_1 + k_2,\ h_1 + h_2, g_1 + g_2)\\ (k_1,\ h_1,\ g_1) - (k_2,\ h_2,\ g_2) = (k_1 - k_2,\ h_1 - h_2, g_1 - g_2)\\ (k_1,\ h_1,\ g_1) \times (k_2,\ h_2,\ g_2) = (k_1 \times k_2,\ h_1 \times h_2, g_1 \times g_2)\\ \frac{(k_1,\ h_1,\ g_1)}{(k_2,\ h_2,\ g_2)} = (k_1/k_2,\ h_1/h_2, g_1/g_2)\end{array} \quad (2)$$

3.1.2. Fuzzy Analytical Hierarchy Process (FAHP)

The Fuzzy Analytical Hierarchy Process (FAHP) is the fuzzy extension of the AHP methodology that would assist its limitation in opinionated with unclear decision-making environments. Let $X = \{x_1,\ x_2, \ldots .x_n\}$ be the set of objects and $K = \{k_1,\ k_2, \ldots .k_n\}$ be the final ranking set. According to Chang [38,39], in the extent analysis method, each alternative is counted for, and an extended analysis of its goals are analyzed. Therefore, the l extended analysis values for each alternative can be determined. These values are defined as:

$$L^1_{k_i}, L^2_{k_i}, \ldots, L^m_{k_i}, \quad i = 1, 2, \ldots, n \quad (3)$$

where $L^j_k (j = 1, 2, \ldots ., m)$ are the TFNs

The fuzzified extent number of the ith object is calculated as:

$$S_i = \sum_{j=1}^{m} L^j_{k_i} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} L^j_{k_i}\right]^{-1} \quad (4)$$

The possibility that $L_1 \geq\ L_2$ is calculated as:

$$V(L_1 \geq L_2) = sup_{y \geq x}\left[min\left(\mu_{L_1}(x),\right), \left(\mu_{L_2}(y)\right)\right] \quad (5)$$

where the pair (x, y) are shown with $x \geq y$ and $\mu_{L_1}(x) = \mu_{L_2}(y)$, then we finally have $V(L_1 \geq L_2) = 1$.

Since L_1 and L_2 are convex fuzzy numbers, we have:

$$V(L_1 \geq L_2) = 1,\ if\ l_1 \geq l_2 \quad (6)$$

and

$$V(L_2 \geq L_1) = hgt(L_1 \frown L_2) = \mu_{L_1}(d) \quad (7)$$

where d is the ordinate of the highest crossing point D of μ_{L_1} and μ_{L_2}.

With $L_1 = (o_1, p_1, q_1)$ and $L_2 = (o_2, p_2, q_2)$, the ordinate of point D is calculated by (7):

$$V(L_2 \geq L_1) = hgt(L_1 \frown L_2) = \frac{l_1 - q_2}{(p_2 - q_2) - (p_1 - o_1)} \quad (8)$$

In order to compare L_1 and L_2, we need to calculate the values of $V(L_1 \geq L_2)$ and $V(L_2 \geq L_1)$.

The possibility for a convex fuzzy number to be higher than the k convex fuzzy numbers $L_i(i = 1, 2, \ldots k)$ is calculated as:

$$\begin{aligned} V(L \geq L_1, L_2, \ldots, L_k) = V[(L \geq L_1)\ and\ (L \geq L_2)] \\ and,\ (L \geq L_k) = min\ V\ (L \geq L_i),\ i = 1, 2, \ldots,\ k \end{aligned} \quad (9)$$

Assume that:

$$d'(B_i) = minV(S_i \geq S_k), \quad (10)$$

For k = 1, 2, ... n and k#i, the weight vector is calculated as:

$$W' = \left(d'(B_1), d'(B_2), \ldots d'(B_n)\right)^T, \quad (11)$$

where B_i are n elements.

The normalized weight vectors are defined as

$$W = (d(B_1), d(B_2), \ldots., d(B_n))^T \quad (12)$$

where W is a defuzzified number.

3.2. Combined Compromise Solution (CoCoSo)

CoCoSo is an MCDM technique that applies an integrated simple additive methodology with an exponentially weighted product model [37]:

Stage 1: Creating the first decision-making matrix:

$$x_{ij} = \begin{bmatrix} x_{11} & x_{12} & \ldots & x_{1n} \\ x_{21} & x_{22} & \ldots & x_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ x_{m1} & x_{m2} & & x_{mn} \end{bmatrix} \quad (13)$$

with $i = 1, 2, \ldots,\ m;\ j = 1, 2, \ldots, n$, where m represents the number of alternatives, and n represents the number of criteria.

Stage 2: Normalizing the values of the criteria

In terms of the benefit criteria:

$$r_{ij} = \frac{x_{ij}\ -\ \underset{i}{min} x_{ij}}{\underset{i}{max} x_{ij} - \underset{i}{min} x_{ij}} \quad (14)$$

In terms of the cost criteria:

$$r_{ij} = \frac{\underset{i}{max} x_{ij} - x_{ij}}{\underset{i}{max} x_{ij} - \underset{i}{min} x_{ij}} \quad (15)$$

Stage 3: Total the weighted comparability sequence (S_i) and the sum of the weighted comparability sequences (P_i) for each alternative, as well as the total power weight of comparability sequences for each alternative:

$$S_i = \sum_{j=1}^{n} (w_j r_{ij}) \quad (16)$$

The grey relational generation technique is used to compute this S_i value:

$$P_i = \sum_{j=1}^{n} \left({r_{ij}}^{w_j} \right) \quad (17)$$

Stage 4: Determining the relative weights of each alternative.

Calculate the overall mean for the summation of the WSM and WPM values:

$$k_{ia} = \frac{P_i + S_i}{\sum_{i=1}^{m} (P_i + S_i)'} \quad (18)$$

Calculate the total of the relative WSM and WPM scores in comparison to the best alternative:

$$k_{ib} = \frac{S_i}{\min\limits_i Si} + \frac{P_i}{\min\limits_i P_i} \quad (19)$$

Determine the weighted average of the WSM and WPM values:

$$k_{ic} = \frac{\lambda(S_i) + (1-\lambda)P_i}{\lambda \max\limits_i S_i + (1-\lambda)\max\limits_i P_i} \quad (20)$$

where λ is a coefficient (usually λ = 0.5) that is chosen by the decision-makers.

Stage 5: Defining the ultimate alternative rating k_i

$$k_i = (k_{ia}k_{ib}k_{ic})^{\frac{1}{3}} + \frac{1}{3}(k_{ia} + k_{ib} + k_{ic}) \quad (21)$$

4. Case Study

With Vietnam's expected turnover for agriculture, forestry, and fishery products to be 200% of the current turnover by 2030, the food-production sector has great attraction for investments [40]. However, there are still many difficulties for the food-processing industry when there are clear shortcomings in the supply chain of raw materials and a shortage in the goods flow resulting in the accumulation in warehouses [41].

As an initiative to minimize food manufacturing's environmental impact in the future, businesses are trying to innovate different methods in order to embrace the potential challenges [42].

In order to reveal the potentiality of the proposed model, a sustainable-supplier-selection case study for Xanthan-gum (β-glucopyranose ($C_{35}H_{49}O_{29}$)n) supplier selection in the food-processing industry was considered. Xanthan gum is actually a very familiar additive in food technology, with international code E415, and is used in the following applications: as a binding agent for sauces, including salad dressings; to create gel for beverage products; bakery technology; ice cream; and gluten-free flour-based foods (vermicelli, pho, rice flour cakes, etc.).

In this study, a Multicriteria Decision-Making (MCDM) model using Triple Bottom Line Metrics, a Fuzzy Hierarchy Network Process (FAHP) method, and the Combined Compromise Solution (CoCoSo) Algorithm was used for the selection of Xanthan-gum suppliers. In the decision process, the authors identified all criteria based on the Triple Bottom Line (TBL) model (economic, environmental, and social aspects) and the literature reviews.

All criteria were used for assessment of sustainable suppliers as defined by 15 experts; the literature review and the initial decision-making matrix were defined by experts. Some information about the criteria is shown in Figure 4.

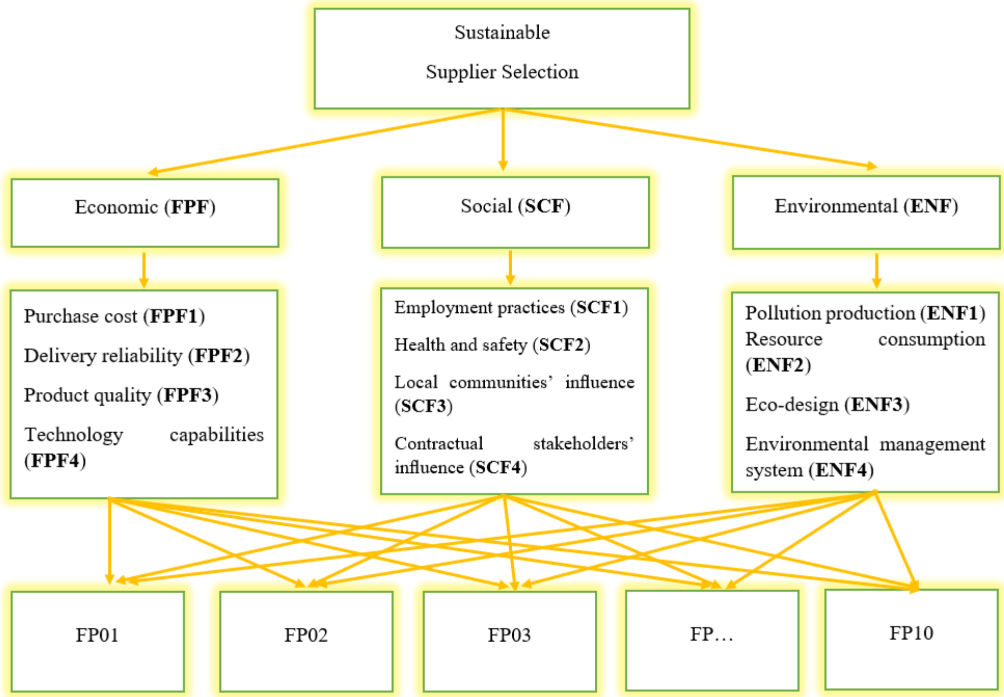

Figure 4. Structure of FAHP model.

In the first stage, the Fuzzy Analytic Hierarchy Process (FAHP) method was applied for identifying the weight of 12 criteria. AHP allows a certain degree of inconsistency that may occur during the pairwise comparisons of criteria and other decision elements. This approach, however, cannot capture the uncertainty of the preference ratings for scoring the criteria. Combining fuzzy logic with AHP overcomes this problem of AHP by allowing the decision-makers to give their assessments in terms of a range of values in the fuzzy scale instead of the AHP scale. The weight of all criteria is shown in Table 1.

Table 1. The weight of criteria.

Criteria	Fuzzy Geometric Mean of Each Row			Fuzzy Weights			BNP	Normalization
FPF1	0.7826	1.0928	1.5255	0.0471	0.0895	0.1704	0.102	0.0905
FPF2	0.7423	1.0208	1.3842	0.0447	0.0836	0.1546	0.094	0.0834
FPF3	1.0156	1.4132	1.8999	0.0612	0.1157	0.2122	0.130	0.1147
FPF4	0.7778	1.0613	1.4265	0.0469	0.0869	0.1593	0.098	0.0864
SCF1	0.9556	1.3108	1.7732	0.0576	0.1073	0.1981	0.121	0.1069
SCF2	0.6177	0.8340	1.1373	0.0372	0.0683	0.1270	0.078	0.0685
SCF3	0.5958	0.8236	1.1620	0.0359	0.0674	0.1298	0.078	0.0687
SCF4	0.7313	0.9981	1.3208	0.0440	0.0817	0.1475	0.091	0.0805
ENF1	0.7376	0.9978	1.3213	0.0444	0.0817	0.1476	0.091	0.0807
ENF2	0.6489	0.8768	1.2198	0.0391	0.0718	0.1363	0.082	0.0728
ENF3	0.5461	0.7051	0.9682	0.0329	0.0577	0.1081	0.066	0.0586
ENF4	0.8013	1.0781	1.4638	0.0483	0.0883	0.1635	0.100	0.0884

CoCoSo is an MCDM technique that applies an integrated simple additive methodology with an exponentially weighted product model. In this stage, the CoCoSo model was used for ranking 10 potential suppliers.

From the weighted comparability sequence and S_i (Table 2) and the exponentially weighted comparability sequence and P_i (Table 3), the final results are shown in Table 4.

Table 2. Weighted comparability sequence and S_i.

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
FPF1	0.04523	0.04523	0.00000	0.04523	0.00000	0.09047	0.09047	0.04523	0.00000	0.00000
FPF2	0.08336	0.04168	0.00000	0.04168	0.00000	0.08336	0.00000	0.04168	0.08336	0.04168
FPF3	0.00000	0.05733	0.00000	0.05733	0.05733	0.00000	0.05733	0.00000	0.11465	0.05733
FPF4	0.08636	0.00000	0.04318	0.04318	0.00000	0.08636	0.00000	0.08636	0.04318	0.00000
SCF1	0.10695	0.05347	0.00000	0.05347	0.00000	0.00000	0.05347	0.10695	0.05347	0.00000
SCF2	0.06852	0.03426	0.03426	0.06852	0.03426	0.03426	0.03426	0.00000	0.03426	0.06852
SCF3	0.06869	0.00000	0.06869	0.00000	0.06869	0.00000	0.06869	0.00000	0.00000	0.00000
SCF4	0.08054	0.04027	0.08054	0.00000	0.04027	0.04027	0.08054	0.04027	0.04027	0.08054
ENF1	0.04033	0.04033	0.00000	0.08065	0.04033	0.04033	0.08065	0.08065	0.04033	0.08065
ENF2	0.07282	0.05462	0.07282	0.05462	0.05462	0.01821	0.05462	0.00000	0.07282	0.05462
ENF3	0.05857	0.04393	0.04393	0.02929	0.01464	0.02929	0.01464	0.02929	0.00000	0.04393
ENF4	0.08842	0.05894	0.02947	0.05894	0.02947	0.05894	0.05894	0.00000	0.02947	0.05894

Table 3. Exponentially weighted comparability sequence and P_i.

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
FPF1	0.93922	0.93922	0.00000	0.93922	0.00000	1.00000	1.00000	0.93922	0.00000	0.00000
FPF2	1.00000	0.94386	0.00000	0.94386	0.00000	1.00000	0.00000	0.94386	1.00000	0.94386
FPF3	0.00000	0.92360	0.00000	0.92360	0.92360	0.00000	0.92360	0.00000	1.00000	0.92360
FPF4	1.00000	0.00000	0.94189	0.94189	0.00000	1.00000	0.00000	1.00000	0.94189	0.00000
SCF1	1.00000	0.92855	0.00000	0.92855	0.00000	0.00000	0.92855	1.00000	0.92855	0.00000
SCF2	1.00000	0.95362	0.95362	1.00000	0.95362	0.95362	0.95362	0.00000	0.95362	1.00000
SCF3	1.00000	0.00000	1.00000	0.00000	1.00000	0.00000	1.00000	0.00000	0.00000	0.00000
SCF4	1.00000	0.94571	1.00000	0.00000	0.94571	0.94571	1.00000	0.94571	0.94571	1.00000
ENF1	0.94563	0.94563	0.00000	1.00000	0.94563	0.94563	1.00000	1.00000	0.94563	1.00000
ENF2	1.00000	0.97927	1.00000	0.97927	0.97927	0.90398	0.97927	0.00000	1.00000	0.97927
ENF3	1.00000	0.98329	0.98329	0.96021	0.92201	0.96021	0.92201	0.96021	0.00000	0.98329
ENF4	1.00000	0.96479	0.90743	0.96479	0.90743	0.96479	0.96479	0.00000	0.90743	0.96479

Table 4. Final aggregation and ranking.

Alternatives	Ka	Ranking	Kb	Ranking	Kc	Ranking	K
A1	0.1285	1	3.9590	1	1.0000	1	2.4942
A2	0.1098	4	2.7852	4	0.8539	4	1.8887
A3	0.0788	10	2.0980	10	0.6127	10	1.3959
A4	0.1113	3	2.9811	3	0.8656	3	1.9790
A5	0.0871	8	2.1166	9	0.6775	8	1.4602
A6	0.1007	5	2.6960	6	0.7835	5	1.7904
A7	0.1129	2	3.1732	2	0.8785	2	2.0685
A8	0.0794	9	2.2679	8	0.6179	9	1.4694
A9	0.1005	6	2.7778	5	0.7818	6	1.8220
A10	0.0911	7	2.5803	7	0.7087	7	1.6769

Supplier evaluation and selection is the process of appraising and evaluating potential existing and potential suppliers by quantifying, helping to choose the right supplier to ensure the business's production, business without interruption, and a move towards driving continuous improvement. Supplier selection is very important for every business, especially those with long supply chains that depend on many suppliers. The authors developed a new composite model using Triple Bottom Line Metrics, the Fuzzy Analytical Hierarchy Process (FAHP) method, and the Combined Compromise Solution (CoCoSo) Algorithm for the selection of suppliers in the food-processing industry. As a result from Table 4, A01 is the optimal supplier. This approach was demonstrated with a real-world case study involving six main evaluation criteria that the company determined to choose the most-appropriate supplier.

5. Sensitivity Analysis

It is shown that besides Equation (21) being the general method for the results of the coefficient λ, a fixed value in the range of 0.1, 0.2, 0.3, ..., 1.0 can be used. Therefore, in the first part of the sensitivity analysis, a modification in the coefficient λ was conducted. The ranking performance of CoCoSo for varying λ values is exhibited in Table 5.

Table 5. Rankings of robots for varying λ values.

	λ = 0.1	λ = 0.2	λ = 0.3	λ = 0.4	λ = 0.5	λ = 0.6	λ = 0.7	λ = 0.8	λ = 0.9	λ = 1
A1	2.4952	2.3842	2.4002	2.5042	2.3972	2.4350	2.5142	2.4768	2.4979	2.4904
A2	1.8987	1.8971	1.8950	1.8923	1.8887	1.8836	1.8757	1.8621	1.8329	1.7251
A3	1.4014	1.4005	1.3994	1.3979	1.3959	1.3930	1.3887	1.3811	1.3651	1.3065
A4	1.9866	1.9854	1.9838	1.9818	1.9790	1.9751	1.9692	1.9590	1.9371	1.8575
A5	1.4697	1.4682	1.4662	1.4637	1.4602	1.4554	1.4479	1.4351	1.4074	1.3038
A6	1.7973	1.7961	1.7947	1.7929	1.7904	1.7868	1.7814	1.7721	1.7522	1.6797
A7	2.0737	2.0728	2.0718	2.0704	2.0685	2.0658	2.0617	2.0547	2.0397	1.9858
A8	1.4724	1.4719	1.4713	1.4705	1.4694	1.4678	1.4654	1.4613	1.4525	1.4212
A9	1.8274	1.8266	1.8254	1.8240	1.8220	1.8193	1.8150	1.8077	1.7921	1.7359
A10	1.6808	1.6802	1.6794	1.6783	1.6769	1.6750	1.6719	1.6667	1.6557	1.6159

Table 5 show the relative calculated values of the options according to the value of the coefficient λ. Note that the values of the coefficient λ do not affect the change in the rank of the alternative. The research successfully created a hybrid MCDM model, using FAHP and CoCoSo, to determine the supplier evaluation and selection procedure in the food-processing industry.

6. Conclusions

In the domestic market, Vietnam, with a population of nearly 94 million people and with more than half of them of working age, is also a great opportunity for processed-food consumption. Currently, food and beverages account for the highest proportion in the monthly consumption structure of the Vietnamese with about 35%. Vietnam's annual food-consumption value also accounts for about 15% of GDP and will increase as income levels improve in the future.

Therefore, in order to survive and develop, businesses constantly improve their production processes towards the goal of sustainable development, especially in the selection of raw material suppliers. Supplier selection is a multi-criteria decision, and the decision-maker must evaluate many qualitative and quantitative criteria, which may conflict with each other, with the aim of selecting the optimal supplier. In this research, the authors developed a new composite model for supplier selection for a sustainable food-processing supply chain. The authors also evaluated the proposed fuzzy multi-criteria decision model for a case study. Given the results from Table 4, the ranking list of the robot alternatives was achieved as A1–A7–A4–A2–A6–A9–A10–A5–A8–A3 for a λ value of 0.5; thus, supplier 1 (A1) is the optimal supplier.

The contribution of this study includes modeling the sustainable supplier selection decision problem in the food-processing industry under fuzzy environment. The most significant contributions and successes in this study can be described as follows:

- ➢ The proposed FMCDM model is the first Xanthan-gum (β-glucopyranose $(C_{35}H_{49}O_{29})n$) supplier evaluation and selection model in Vietnam by interviewing experts and reviewing the literature.
- ➢ Second, this is the first study to provide a case study on evaluating suppliers for the food-processing industry utilizing the model proposed by the combination of FAHP and CoCoSo models.
- ➢ The proposed model can also address different complex problems in supplier selection in other industries.

There are also some limitations in this study. Because Saaty's AHP produces rank reversal, a new procedure was proposed based on a simple algebraic system of equations, called "Alpha-Discounting Method for Multi-Criteria Decision Making" [43], which will be considered for multi-criteria decision-making in a future study.

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References

1. Sức Hút Của Ngành Công Nghiệp Chế Biến Thực Phẩm Việt Nam. Available online: https://thanguy.com/tin-thi-truong-4/ (accessed on 18 October 2021).
2. Làm gì để Phát Triển Bền Vững Công Nghiệp Chế Biến Thực Phẩm? Available online: https://dantocmiennui.vn/lam-gi-de-phat-trien-ben-vung-cong-nghiep-che-bien-thuc-pham/180544.html (accessed on 18 October 2021).
3. Beske-Janssen, P.; Johnson, M.P.; Schaltegger, S. 20 years of performance measurement in sustainable supply chain management—What has been achieved? *Supply Chain. Manag. Int. J.* **2015**, *20*, 664–680. [CrossRef]
4. What Is Sustainable Sourcing? Available online: https://ecovadis.com/glossary/sustainable-sourcing/#:~{}:text=Sustainable%20sourcing%20is%20the%20integration,the%20process%20of%20selecting%20suppliers.&text=The%20ultimate%20goal%20of%20sustainable,long%2Dterm%20relationships%20with%20suppliers (accessed on 18 October 2021).
5. Zadeh, L.A. Fuzzy sets. *Inf. Control* **1965**, *8*, 338–353. [CrossRef]
6. Đạt, L.Q.; Phượng, B.H.; Thu, N.T.P.; Anh, T.T.L. Xây dựng mô hình ra quyết định đa tiêu chuẩn tích hợp để lựa chọn và phân nhóm nhà cung cấp xanh. *Tạp Chí Khoa Học Đhqghn Kinh Tế Và Kinh Doanh Tập* **2017**, *33*, 43–54.
7. Slaper, T.F.; Hall, T.J. The triple bottom line: What is it and how does it work. *Indiana Bus. Rev.* **2011**, *86*, 4–8.
8. Schramm, V.B.; Cabral, L.P.B.; Schramm, F. Approaches for supporting sustainable supplier selection—A literature review. *J. Clean. Prod.* **2020**, *273*, 123089. [CrossRef]
9. Stojčić, M.; Zavadskas, E.K.; Pamučar, D.; Stević, Ž.; Mardani, A. Application of MCDM methods in sustainability engineering: A literature review 2008–2018. *Symmetry* **2019**, *11*, 350. [CrossRef]
10. Matić, B.; Jovanović, S.; Das, D.K.; Zavadskas, E.K.; Stević, Ž.; Sremac, S.; Marinković, M. A new hybrid MCDM model: Sustainable supplier selection in a construction company. *Symmetry* **2019**, *11*, 353. [CrossRef]
11. Önüt, S.; Kara, S.S.; Işik, E. Long term supplier selection using a combined fuzzy MCDM approach: A case study for a telecommunication company. *Expert Syst. Appl.* **2009**, *36*, 3887–3895. [CrossRef]
12. Nallusamy, S.; Sri Lakshmana Kumar, D.; Balakannan, K.; Chakraborty, P.S. MCDM tools application for selection of suppliers in manufacturing industries using AHP, Fuzzy Logic and ANN. *Int. J. Eng. Res. Afr.* **2016**, *19*, 130–137. [CrossRef]
13. Yazdani, M. An integrated MCDM approach to green supplier selection. *Int. J. Ind. Eng. Comput.* **2014**, *5*, 443–458. [CrossRef]
14. Sarkis, J.; Dhavale, D.G. Supplier selection for sustainable operations: A triple-bottom-line approach using a Bayesian framework. *Int. J. Prod. Econ.* **2015**, *166*, 177–191. [CrossRef]
15. Govindan, K.; Khodaverdi, R.; Jafarian, A. A fuzzy multi criteria approach for measuring sustainability performance of a supplier based on triple bottom line approach. *J. Clean. Prod.* **2013**, *47*, 345–354. [CrossRef]
16. Nikolaou, I.E.; Evangelinos, K.I.; Allan, S. A reverse logistics social responsibility evaluation framework based on the triple bottom line approach. *J. Clean. Prod.* **2013**, *56*, 173–184. [CrossRef]
17. Rezaeisaray, M.; Ebrahimnejad, S.; Khalili-Damghani, K. A novel hybrid MCDM approach for outsourcing supplier selection: A case study in pipe and fittings manufacturing. *J. Model. Manag.* **2016**, *11*, 536–559. [CrossRef]
18. Fallahpour, A.; Nayeri, S.; Sheikhalishahi, M.; Wong, K.Y.; Tian, G.; Fathollahi-Fard, A.M. A hyper-hybrid fuzzy decision-making framework for the sustainable-resilient supplier selection problem: A case study of Malaysian Palm oil industry. *Environ. Sci. Pollut. Res.* **2021**, 1–21. [CrossRef] [PubMed]
19. Kang, H.Y.; Lee, A.H.; Yang, C.Y. A fuzzy ANP model for supplier selection as applied to IC packaging. *J. Intell. Manuf.* **2012**, *23*, 1477–1488. [CrossRef]
20. Hadian, H.; Chahardoli, S.; Golmohammadi, A.M.; Mostafaeipour, A. A practical framework for supplier selection decisions with an application to the automotive sector. *Int. J. Prod. Res.* **2020**, *58*, 2997–3014. [CrossRef]

21. Wang, C.N.; Tsai, H.T.; Nguyen, V.T.; Nguyen, V.T.; Huang, Y.F. A hybrid fuzzy analytic hierarchy process and the technique for order of preference by similarity to ideal solution supplier evaluation and selection in the food processing industry. *Symmetry* **2020**, *12*, 211. [CrossRef]
22. Wang, C.-N.; Nguyen, V.T.; Thai, H.T.N.; Tran, N.N.; Tran, T.L.A. Sustainable Supplier Selection Process in Edible Oil Production by a Hybrid Fuzzy Analytical Hierarchy Process and Green Data Envelopment Analysis for the SMEs Food Processing Industry. *Mathematics* **2018**, *6*, 302. [CrossRef]
23. Milovanović, V.R.; Aleksić, A.V.; Sokolović, V.S.; Milenkov, M.A. Uncertainty modeling using intuitionistic fuzzy numbers. *Vojnotehnički Glasnik/Mil. Tech. Cour.* **2021**, *69*, 905–929. [CrossRef]
24. Fazlollahtabar, H.; Kazemitash, N. Green supplier selection based on the information system performance evaluation using the integrated best-worst method. *Facta Univ. Ser. Mech. Eng.* **2021**, *19*, 345–360. [CrossRef]
25. Ali, Z.; Mahmood, T.; Ullah, K.; Khan, Q. Einstein Geometric Aggregation Operators using a Novel Complex Interval-valued Pythagorean Fuzzy Setting with Application in Green Supplier Chain Management. *Rep. Mech. Eng.* **2021**, *2*, 105–134. [CrossRef]
26. Radovanovic, M.; Ranđelović, A.; Jokić, Ž. Application of hybrid model fuzzy AHP-VIKOR in selection of the most efficient procedure for rectification of the optical sight of the long-range rifle. *Decis. Mak. Appl. Manag. Eng.* **2020**, *3*, 131–148. [CrossRef]
27. Biswas, T.; Chatterjee, P.; Choudhuri, B. Selection of commercially available alternative passenger vehicle in automotive environment. *Oper. Res. Eng. Sci. Theory Appl.* **2020**, *3*, 16–27. [CrossRef]
28. Bączkiewicz, A.; Kizielewicz, B.; Shekhovtsov, A.; Wątróbski, J.; Sałabun, W. Methodical Aspects of MCDM Based E-Commerce Recommender System. *J. Theor. Appl. Electron. Commer. Res.* **2021**, *16*, 2192–2229. [CrossRef]
29. Sałabun, W.; Wątróbski, J.; Shekhovtsov, A. Are mcda methods benchmarkable? A comparative study of topsis, vikor, copras, and promethee ii methods. *Symmetry* **2020**, *12*, 1549. [CrossRef]
30. Wang, H. Models for MADM with hesitant interval-valued fuzzy information under uncertain environment. *Int. J. Knowl.-Based Intell. Eng. Syst.* **2021**, *25*, 315–322. [CrossRef]
31. Pamučar, D.S.; Savin, L.M. Multiple-criteria model for optimal off-road vehicle selection for passenger transportation: BWM-COPRAS model. *Vojnoteh. Glas.* **2020**, *68*, 28–64. [CrossRef]
32. Durmić, E.; Stević, Ž.; Chatterjee, P.; Vasiljević, M.; Tomašević, M. Sustainable supplier selection using combined FUCOM–Rough SAW model. *Rep. Mech. Eng.* **2020**, *1*, 34–43. [CrossRef]
33. Ecer, F.; Pamucar, D. Sustainable supplier selection: A novel integrated fuzzy best worst method (F-BWM) and fuzzy CoCoSo with Bonferroni (CoCoSo'B) multi-criteria model. *J. Clean. Prod.* **2020**, *266*, 121981. [CrossRef]
34. Tavana, M.; Shaabani, A.; Di Caprio, D.; Bonyani, A. An integrated group fuzzy best-worst method and combined compromise solution with Bonferroni functions for supplier selection in reverse supply chains. *Clean. Logist. Supply Chain.* **2021**, *2*, 100009. [CrossRef]
35. Yazdani, M.; Pamucar, D.; Chatterjee, P.; Torkayesh, A.E. A multi-tier sustainable food supplier selection model under uncertainty. *Oper. Manag. Res.* **2021**, 1–30. [CrossRef]
36. Hoseini, S.A.; Fallahpour, A.; Wong, K.Y.; Mahdiyar, A.; Saberi, M.; Durdyev, S. Sustainable Supplier Selection in Construction Industry through Hybrid Fuzzy-Based Approaches. *Sustainability* **2021**, *13*, 1413. [CrossRef]
37. Gogus, O.; Boucher, T.O. Strong transitivity, rationality and weak monotonicity in fuzzy pairwise comparisons. *Fuzzy Sets Syst.* **1998**, *94*, 133–144. [CrossRef]
38. Chang, D.-Y. Applications of the extent analysis method on fuzzy AHP. *Eur. J. Oper. Res.* **1996**, *95*, 649–655. [CrossRef]
39. Yazdani, M.; Zarate, P.; Zavadskas, E.K.; Turskis, Z. A combined compromise solution (CoCoSo) method for multi-criteria decision-making problems. *Manag. Decis.* **2019**, *57*, 2501–2519. [CrossRef]
40. Công nghiệp thực phẩm Việt Nam có tiềm năng lớn trong thu hút đầu tư. Available online: https://tapchitaichinh.vn/nghien-cuu-trao-doi/cong-nghiep-thuc-pham-viet-nam-co-tiem-nang-lon-trong-thu-hut-dau-tu-315296.html (accessed on 18 October 2021).
41. Thách Thức và cơ hội cho ngành chế biến thực phẩm ở Việt Nam năm. 2021. Available online: https://fbsp.ftu.edu.vn/thach-thuc-va-co-hoi-cho-nganh-che-bien-thuc-pham-o-viet-nam-nam-2021/ (accessed on 18 October 2021).
42. 4 Ways to Make Food Processing More Sustainable. Available online: https://certification.bureauveritas.com/magazine/4-ways-make-food-processing-more-sustainable (accessed on 18 October 2021).
43. Smarandache, F. α-Discounting Method for Multi-Criteria Decision Making. 2016. Available online: https://digitalrepository.unm.edu/math_fsp/243/ (accessed on 18 October 2021).