The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2024

Volume 32, Pages 257-265

IConTES 2024: International Conference on Technology, Engineering and Science

Green Supplier Selection with CoCoFISo-G

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Abstract: Green supplier selection is the process of evaluating suppliers for environmental sustainability and efficient use of resources. In recent years, there has been a growing trend to work with suppliers that meet environmental sustainability standards. Green sourcing considers criteria such as the source of a product's raw materials and its impact on the environment. In the cosmetics industry, green supplier selection is a critical step in increasing the environmental and social sustainability of products. This process ensures that green and ethical practices are considered at every stage of the supply chain. Supplier selection is a multi-criteria decision problem. This study aims to solve the supplier selection problem in the supply of perfume bottles for a cosmetics company using the CoCoFISo-G method. The CoCoFISo-G method was created by extending the CoCoFISo (Combined Compromise for Ideal Solution) method with gray numbers. The CoCoFISo method is an extension of the CoCoSo method, and the purpose of the CoCoFISo method is to find an ideal compromise solution to improve the algorithm of the CoCoSo method. In this study, the developed CoCoFISo-G method is used for green supplier selection.

Keywords: Multi-criteria decision-making, Green supplier selection, Grey values, Combined compromise solution method, Combined compromise for ideal solution

Introduction

The environmental pollution caused by the conscious or unconscious production activities of businesses, the unconscious and excessive consumption of consumers, the risk of depletion of natural resources and global warming have made societies more conscious about the environment. While this awareness of consumers puts pressure on businesses, legal regulations have been established in many countries to protect the natural environment and many environmental protocols have been signed at both national and international levels. These developments have forced businesses to produce environmentally friendly products and have led them to make additional demands from their suppliers in this direction. The concept of green supply chain has emerged. It has emerged as a result of activities aimed at reducing or eliminating the negative effects of supply chain activities on the environment and increasing their positive effects. In this paper GSCM is defined as: Green Supply Chain Management (GSCM) = Green Purchasing + Green Manufacturing / Materials Management + Green Distribution / Marketing + Reverse Logistics (Hervani et al., 2005). Green purchasing is of key importance in terms of effective and successful management of the supply chain. It expresses environmental sensitivity in the selection, evaluation and development of suppliers and also covers the measures to be taken against possible environmental problems. Studies on green supplier selection are increasing.

Hashemi et al. (2015) proposed a comprehensive green supplier selection model using both economic and environmental criteria. They used ANP and an improved GRA to weight the criteria and rank the suppliers. They determined cost, quality, technology, resource consumption, pollution production, management commitment as criteria and presented a case study in the automotive industry. In the study of Yu and Hou

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(2016) proposed a modified multiplicative analytical hierarchy process method to solve the green supplier selection problem. They determined four main criteria: product performance, supplier criteria, cooperation and development potential, and green performance. Liao et al. (2016) combined the fuzzy analytic hierarchy process (FAHP), fuzzy additive ratio assessment method (ARAS-F) and multi-segment goal programming (MSGP) methods to solve green supplier selection problems and presented a solution proposal for the green supplier selection problem. They demonstrated this integrated model with an example from a watch company. The criteria used are purchasing cost, quality service, technology capability, environmental capability and delivery performance.

In the study of Keshavarz Ghorabaee et al. (2016) a new integrated approach based on the Weighted Total Product Assessment (WASPAS) method was proposed to address multi-criteria group decision-making problems with Interval type-2 fuzzy sets (IT2FS). They used the entropy method in calculating the criteria weights. The criteria used are; environmental pollution of production, resource consumption, ecological design, environmental management system, adherence of managers to GSCM, use of green technology, use of green materials. Qin et al. (2017) developed and implemented a new TODIM method in green supplier selection in their study. They used ten criteria: green product innovation; green image, use of environmentally friendly technology, resource consumption, green competencies, environment management, quality management, total product life cycle cost, pollution production, staff environmental training. Govindan et al. (2017) proposed a hybrid approach combining the revised Simos procedure, PROMETHEE methods, algorithms to generate a group consensus ranking, and robustness analysis, and used the cost, quality, delivery, environmental impacts, technology capability as criteria. Bakeshlou et al. (2017) developed a multi-objective fuzzy linear programming model for a GSS problem, including 17 criteria, formed into 5 clusters while a hybrid fuzzy multi objective decision making (MODM) is employed to solve it. Banaeian et al. (2018) compared three popular multi-criteria decision-making methods, TOPSIS, VIKOR and GRA, in the application of supplier selection method in a fuzzy environment. Wu et al., 2019). Presented an integrated methodology for addressing MCGDM problems in discrete type-2 fuzzy environment based on best-worst method (BWM) and VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) technique. Green product innovation, environmental regime, use of green technology, product quality management, total green product cost, resource consumption, environmental pollution of production were used as a criteria. In the study conducted by Rouyendegh et al. (2020) the hybrid method, which emerged by combining Intuitive Fuzzy Set and TOPSIS, was used to select which supplier is more suitable among the alternatives.

This study aims to solve the supplier selection problem in the supply of perfume bottles for a cosmetics company using the CoCoFISo-G method. The CoCoFISo-G method was created by extending the CoCoFISo (Combined Compromise for Ideal Solution) method with gray numbers. The CoCoFISo method is an extension of the CoCoSo method, and the purpose of the CoCoFISo method is to find an ideal compromise solution to improve the algorithm of the CoCoSo method.

The CoCoSo (Combined Compromise Solution) method developed by Yazdani et al. (2019) is based on the integration of simple additive weighting (SAW) and the exponentially weighted product model (MEP). The essence of this method lies in the combination of compromise perspectives that ultimately reconcile often conflicting evaluation criteria. The CoCoSo method provides an overview of possible compromise solutions available to the decision maker (Popović, 2021).

The research by Wen et al. (2019) extends the CoCoSo method to solve the multi-expert, multi-criteria decision making (MCDM) problem in selecting third-party logistics service providers (3PLs) in a hesitant fuzzy language environment. The research presents an innovative approach to evaluate and select 3PL service providers. Stanujkic et al. (2020) evaluated the progress of European Union countries towards achieving the 2030 Sustainable Development Goals (SDGs) using CoCoSo and Shannon Entropy methods. Torkayesh et al. (2021) evaluates the social sustainability performance of seven developed countries, including the G7 countries. The study analyzes social sustainability using an integrated data-driven weighting system and the CoCoSo model. Torkayesh et al. (2021) developed an integrated multi-criteria framework for evaluating health care sectors in Eastern Europe. The methods used include BWM (Best Worst Method), LBWA (Linear Best Worst Approach), and CoCoSo (Combined Compromise Solution). This framework emphasizes that the health sector is an important element of infrastructure. In their study, Peng and Luo (2021) propose a decision model for market bubble warning of Chinese stocks. This model facilitates decision making using image fuzzy information with a unified consensus solution (CoCoSo). The authors address comparability issues by developing an innovative image fuzzy score function and calculating target weights using Renyi entropy. The goal of the study is to demonstrate the applicability of the algorithm. Deveci et al. (2021) investigated a CoCoSo method based on the Fuzzy Power Heronian function to prioritize the benefits of autonomous vehicles in real-time traffic management. Ecer (2021) proposes an integrated multi-criteria decision making (MCDM) framework for the performance evaluation of battery electric vehicles (BEVs). In the study, ten BEVs are selected as alternatives. These vehicles are then ranked based on technical attributes such as acceleration, price, battery, range, and battery using SECA, MARCOS, MAIRCA, COCOSO, ARAS, and COPRAS multi-criteria techniques. Bagal et al. (2021) aimed to investigate the effect of welding variables (such as compression time, welding time and current) on resistance spot welding of different materials. Optimization was achieved and results were evaluated using CoCoSo, EDAS and WASPAS methods, which are advanced hybrid Taguchi methods.

Yazdani et al. (2019) aimed to measure the performance of supplier selection in construction management using CoCoSo-G, an improved unified consensus solution method with gray numbers. Gabriel -Rasoanaivo et al. (2024) introduced the CoCoFISo method, which is an improved version of the CoCoSo method. The authors tested and validated this method using real case studies and compared its performance with other multi-criteria decision-making methods such as PROMETHEE, WSM, and TOPSIS2. The results show that CoCoFISo can overcome the limitations of CoCoSo and provide stable results. In this study, we extended the COCOFISo method with gray numbers and used this method, which we named COCOFISO-G, in green supplier selection.

Methods

SWARA

Different methods such as AHP, Entropy and SWARA can be used to determine criterion weights. In this study, SWARA (Step-by-Step Weight Assessment Ratio Analysis Method) was used and the method follows these steps:

Step 1: Determination of criteria (C_j, j = 1,2,3, ... n) and decision makers (DM_D, D = 1,2, ... d).

Step 2: Sort the criteria from most important to insignificant according to their own knowledge and experience.

Step 3: In this step, each decision maker, starting from the second order criterion, specifies the relational significance (s_j^d) of C_{j-1} according to the C_j criterion for decision maker d. For example, how important is the first-order criterion compared to the second-order criterion.

Step 4: A criterion (k_j^d) is calculated for each criterion in the following equation.

$$k_j^d = \begin{cases} 1 & j = 0 \\ s_j^d + 1, & j > 1 \end{cases} \tag{1}$$

Step 5: The weight coefficients (q_j^d) are calculated for each criterion using the following equation.

$$q_j^d = \begin{cases} 1 & j = 0 \\ \frac{q_{j-1}^d}{k_j}, & j > 1 \end{cases} \tag{2}$$

Step 6: The relative weight (w_j^d) values of the criteria are calculated.

$$w_j^d = \frac{q_j^d}{\sum_{j=1}^{n} q_j^d} \tag{3}$$

Step 7: In case group decision making, it is received by the geometric mean of the calculated weight value, then the relative weight values of the found weight values are calculated and the final result is reached. It is indicated by Wj.

CoCoFISo-G

The CocoFISo method was developed by Yazdani et al. due to the problems encountered in the CoCoSo method in some special cases. One of these special cases is that when a criterion has the same value for all alternatives, the normalization process cannot be calculated. The other is that when an alternative has the worst element in all criteria, it is not possible to calculate the addition step in the algorithm. In this study, this developed algorithm was extended with gray numbers. The steps of the algorithm are as follows.

1. Step: The first stage is grey decision-making matrix (GDMM) forming. In the GMCDM of the discrete optimization problem any problem to be solved is represented by the following DMM of preferences for m reasonable alternatives (rows) rated on n criteria (columns): where m – number of alternatives, n – number of criteria describing each alternative, $\otimes x_{ij}$ – grey value representing the performance value of the i alternative in terms of the j criterion.

$$\tilde{X} = \begin{bmatrix} \otimes x_{11} & \cdots & \otimes x_{1j} & \cdots & \otimes x_{1n} \\ \vdots & \ddots & \cdots & \ddots & \vdots \\ \otimes x_{i1} & \cdots & \otimes x_{ij} & \cdots & \otimes x_{in} \\ \vdots & \ddots & \ddots & \ddots & \vdots \\ \otimes x_{m1} & \cdots & \otimes x_{mj} & \cdots & \otimes x_{mn} \end{bmatrix}$$

$$i = \overline{0,m}; j = \overline{1,n}. \tag{4}$$

2. Step: Normalization of the matrix. The second stage the initial values of all the criteria are normalized-defining values $\otimes \overline{X_{ij}}$ of normalized decision-making matrix $\otimes \overline{X}$:

$$\otimes \bar{X} = \begin{bmatrix} \otimes \bar{x}_{11} & \cdots & \otimes \vec{x}_{1j} & \cdots & \otimes \bar{x}_{1n} \\ \vdots & \ddots & \cdots & \ddots & \vdots \\ \otimes \bar{x}_{i1} & \cdots & \otimes \bar{x}_{ij} & \cdots & \otimes \bar{x}_{in} \\ \vdots & \ddots & \ddots & \ddots & \vdots \\ \otimes \bar{x}_{m1} & \cdots & \otimes \bar{x}_{mj} & \cdots & \otimes \vec{x}_{mn} \end{bmatrix}$$

$$i = \overline{0,m}; j = \overline{1,n}. \tag{5}$$

The following formula is used in the normalization process:

$$\otimes \bar{x}_{ij} = \frac{\otimes x_{ij}}{\sqrt{\sum_{i=0}^{m} (\otimes x_{ij})^2}} \tag{6}$$

3. Step: The third stage is defining normalized-weighted matrix – $\otimes \bar{\bar{X}}$. Only well-founded weights should be used because weights are always subjective and influence the solution. The values of weight w_j are usually determined by the expert evaluation method.

$$\sum_{j=1}^{n} w_j = 1, \tag{7}$$

$$\otimes \bar{\bar{x}}_{ij} = \otimes \overline{x}_{ij} \times w_j, \tag{8}$$

$$\otimes \bar{\bar{X}} = \begin{bmatrix} \otimes \bar{\bar{x}}_{11} & \cdots & \otimes \bar{\bar{x}}_{1j} & \cdots & \otimes \bar{\bar{x}}_{1n} \\ \vdots & \ddots & \cdots & \ddots & \vdots \\ \otimes \bar{\bar{x}}_{i1} & \cdots & \otimes \bar{\bar{x}}_{ij} & \cdots & \otimes \bar{\bar{x}}_{in} \\ \vdots & \ddots & \ddots & \ddots & \vdots \\ \otimes \bar{\bar{x}}_{m1} & \cdots & \otimes \bar{\bar{x}}_{mj} & \cdots & \otimes \bar{\bar{x}}_{mn} \end{bmatrix}$$

$$i = \overline{0,m}; j = \overline{1,n}. \tag{9}$$

4. Step: Obtaining the total of the weighted comparability series and the total power weight of the comparability series for each alternative as $\otimes S_i$ and $\otimes P_i$, respectively.

$$\otimes S_i = \sum_{j=1}^{n} \otimes \overline{\overline{x_{ij}}} \tag{10}$$

$$\otimes P_i = \sum_{j=1}^{n} \otimes \overline{x_{ij}}^{w_j} \tag{11}$$

5. Step: Ranking of considered alternatives. For ranking purposes, method uses a relative performance score $\otimes k_i$, which is calculated based on three aggregate estimated results $\otimes k_{ia}$, $\otimes k_{ib}$ and $\otimes k_{ic}$, as follows:

$$\otimes k_{ia} = \frac{(\otimes S_i + \otimes P_i)}{\sum_{i=1}^{m}(\otimes S_i + \otimes P_i)} \tag{12}$$

$$\otimes k_{ib} = \frac{(\otimes S_i + \otimes P_i)}{1 + \left(\frac{\otimes S_i}{1+\otimes S_i}\right) + \left(\frac{\otimes P_i}{1+\otimes P_i}\right)} \tag{13}$$

$$\otimes k_{ic} = \frac{(\lambda \otimes S_i + (1-\lambda)\otimes P_i)}{(\lambda \max_i \otimes S_i + (1-\lambda)\max_i \otimes P_i)} \tag{14}$$

for $0 \leq \lambda \leq 1$.

In Eqn. (11), decision-makers chose λ (usually λ = 0.5).

$$\otimes k_i = (\otimes k_{ia} \otimes k_{ib} \otimes k_{ic})^{1/3} + \frac{(\otimes k_{ia} + \otimes k_{ib} + \otimes k_{ic})}{3} \tag{15}$$

6. Step: Calculation of K. K is the crisp value for the assumed grey number. The score obtained by Eqn. (16) is called the CoCoFISo-G score. The alternative with the highest score is the best.

$$\otimes k_i = [k^-, k^+]$$

$$Ki = k^- + ((k^+ - k^-)/2) \tag{16}$$

If the current method is developed for group decision making, the following equation can be used for the calculation of the utility degree Ki of an alternative i is given below:

$$K_i = \sqrt[D]{\prod_{d=1}^{D} K_i^d} \tag{17}$$

K_i^d : d is the decision maker d, i is the alternative i, D is the number of decision makers.

Results and Discussion

NaturaLux is one of the leading cosmetic companies in Turkey and exports 70% of its production to European Union countries and Russia. The increasing environmental awareness of its customers and the legal sanctions in these countries have led the company to green supply chain management practices. Choosing a green supplier not only contributes to the environment but is also critical to the long-term success and sustainability of businesses.

This study aims to solve the supplier selection problem in the supply of perfume bottles for NaturaLux by using the CoCoFISo-G method. For perfume bottles, suppliers were subjected to a preliminary evaluation and as a result of this preliminary evaluation, ten suppliers were included in this study. Our criteria for choosing a green supplier consist of;

- Delivery performance (C_1); covers features such as the deviation of the order from the specified date, the conformity of the ordered product to the specified conditions.
- Green product innovation(C_2); covers addressing environmental problems through product design and technical innovation.
- Green technology use(C_3); covers the use of technologies developed to protect the natural environment and resources and reduce the negative effects of human intervention.
- Cost (C_4); covers all cost items related to purchasing; product cost, logistics cost, insurance cost, etc. (The lower the cost, the higher the evaluation value.)
- Resource consumption (C_5); covers the effective and efficient consumption of natural resources, the less amount of harmful waste, and the less manufacturing waste. The lower the resource consumption, the higher the evaluation value.
- Quality Management (C_6); covers the effectiveness of the established quality management system, its reflection on the products, and the integration of quality and environmental management systems.

While determining these criteria, studies in the literature and the company's goals and objectives were taken into consideration. Our decision makers consist of the purchasing manager (DM_1), quality manager (DM_2), export manager (DM_3) and production manager (DM_4). Firstly, the weights of the criteria were calculated using the SWARA method. The criteria weight information of the decision makers was combined using the geometric mean and the data in Table 1 was obtained. After determining the criteria weights, as the first step of the CoCoFISo-G method, the initial decision matrix was created by taking the decision makers' opinions on the options based on the criteria. The evaluation scale in Table 2 was used while creating this. Table 3 shows the initial decision matrix of the purchasing manager (DM_1). As a second step, the initial decision matrices obtained were normalized (Table 4). Normalization was done using Eqn. (6).

Table 1. Criteria Weights

	Decision Makers					
Criteria	DM1	DM2	DM3	DM4	Geometric mean	Wi
C1	0,193225	0,204756	0,181536	0,184852	0,190885121	0,191104
C2	0,175659	0,16922	0,165033	0,168048	0,169445961	0,16964
C3	0,139412	0,153836	0,157174	0,145496	0,148815303	0,148986
C4	0,212548	0,186142	0,181536	0,203338	0,195488065	0,195712
C5	0,146383	0,146511	0,165033	0,152771	0,152490308	0,152665
C6	0,132773	0,139534	0,149689	0,145496	0,14172886	0,141892

Table 2. Criteria evaluation scale

Rating	Gray Number Correspondence
Very Low	(0.0,0.2)
Low	(0.2,0.4)
Medium	(0.4,0.6)
High	(0.6,0.8)
Very High	(0.8,1.0)

Table 3. Purchasing Manager's (DM_1) initial grey decision making matrix

	Resource consumption		Green product innovation		Green technology use		Cost		Delivery performance		Quality Management	
Supplier	C_1		C_2		C_3		C_4		C_5		C_6	
S_1	0,80	1,00	0,60	0,80	0,40	0,60	0,80	1,00	0,40	0,60	0,60	0,80
S_2	0,60	0,80	0,40	0,60	0,20	0,40	0,60	0,80	0,60	0,80	0,40	0,60
S_3	0,80	1,00	0,40	0,60	0,60	0,80	0,80	1,00	0,20	0,40	0,60	0,80
S_4	0,60	0,80	0,20	0,40	0,40	0,60	0,60	0,80	0,40	0,60	0,40	0,60
S_5	0,60	0,80	0,40	0,60	0,20	0,40	0,60	0,80	0,40	0,60	0,60	0,80
S_6	0,40	0,60	0,60	0,80	0,40	0,60	0,60	0,80	0,80	1,00	0,60	0,80
S_7	0,20	0,40	0,40	0,60	0,60	0,80	0,80	1,00	0,60	0,80	0,60	0,80
S_8	0,60	0,80	0,60	0,80	0,20	0,40	0,60	0,80	0,80	1,00	0,40	0,60
S_9	0,40	0,60	0,40	0,60	0,40	0,60	0,60	0,80	0,60	0,80	0,20	0,40
S_{10}	0,20	0,40	0,60	0,80	0,40	0,60	0,40	0,60	0,60	0,80	0,60	0,80

Table 4. Purchasing Manager's (DM_1) normalized decision-making matrix

	Resource consumption		Green product innovation		Green technology use		Cost		Delivery performance		Quality Management	
Supplier	C_1		C_2		C_3		C_4		C_5		C_6	
S_1	0,34	0,57	0,28	0,53	0,21	0,47	0,30	0,49	0,17	0,33	0,27	0,49
S_2	0,25	0,45	0,19	0,40	0,11	0,31	0,22	0,39	0,25	0,44	0,18	0,37
S_3	0,34	0,57	0,19	0,40	0,32	0,62	0,30	0,49	0,08	0,22	0,27	0,49
S_4	0,25	0,45	0,09	0,26	0,21	0,47	0,22	0,39	0,17	0,33	0,18	0,37
S_5	0,25	0,45	0,19	0,40	0,11	0,31	0,22	0,39	0,17	0,33	0,27	0,49
S_6	0,17	0,34	0,28	0,53	0,21	0,47	0,22	0,39	0,33	0,56	0,27	0,49
S_7	0,08	0,23	0,19	0,40	0,32	0,62	0,30	0,49	0,25	0,44	0,27	0,49
S_8	0,25	0,45	0,28	0,53	0,11	0,31	0,22	0,39	0,33	0,56	0,18	0,37
S_9	0,17	0,34	0,19	0,40	0,21	0,47	0,22	0,39	0,25	0,44	0,09	0,24
S_{10}	0,08	0,23	0,28	0,53	0,21	0,47	0,15	0,29	0,25	0,44	0,27	0,49

In the next step, the weighted normalized decision matrix (Table 5.) and normalized weighted power matrix (Table 6.) were created. These decision matrices were of course made separately for each decision maker.

Table 5. Purchasing Manager's (DM_1) weighted normalized decision matrix

Supplier	Resource consumption C_1		Green product innovation C_2		Green technology use C_3		Cost C_4		Delivery performance C_5		Quality Management C_6	
S_1	0,065	0,108	0,048	0,090	0,032	0,070	0,058	0,095	0,025	0,051	0,038	0,069
S_2	0,048	0,087	0,032	0,067	0,016	0,047	0,044	0,076	0,038	0,068	0,025	0,052
S_3	0,065	0,108	0,032	0,067	0,047	0,093	0,058	0,095	0,013	0,034	0,038	0,069
S_4	0,048	0,087	0,016	0,045	0,032	0,070	0,044	0,076	0,025	0,051	0,025	0,052
S_5	0,048	0,087	0,032	0,067	0,016	0,047	0,044	0,076	0,025	0,051	0,038	0,069
S_6	0,032	0,065	0,048	0,090	0,032	0,070	0,044	0,076	0,051	0,085	0,038	0,069
S_7	0,016	0,043	0,032	0,067	0,047	0,093	0,058	0,095	0,038	0,068	0,038	0,069
S_8	0,048	0,087	0,048	0,090	0,016	0,047	0,044	0,076	0,051	0,085	0,025	0,052
S_9	0,032	0,065	0,032	0,067	0,032	0,070	0,044	0,076	0,038	0,068	0,013	0,035
S_{10}	0,016	0,043	0,048	0,090	0,032	0,070	0,029	0,057	0,038	0,068	0,038	0,069

Table 6. Purchasing Manager's (DM_1) normalized weighted power matrix

Supplier	Resource consumption C_1		Green product innovation C_2		Green technology use C_3		Cost C_4		Delivery performance C_5		Quality Management C_6	
S_1	0,813	0,897	0,807	0,898	0,794	0,893	0,789	0,868	0,760	0,846	0,829	0,903
S_2	0,769	0,860	0,753	0,855	0,716	0,841	0,746	0,831	0,809	0,884	0,782	0,867
S_3	0,813	0,897	0,753	0,855	0,843	0,932	0,789	0,868	0,684	0,795	0,829	0,903
S_4	0,769	0,860	0,670	0,798	0,794	0,893	0,746	0,831	0,760	0,846	0,782	0,867
S_5	0,769	0,860	0,753	0,855	0,716	0,841	0,746	0,831	0,760	0,846	0,829	0,903
S_6	0,712	0,814	0,807	0,898	0,794	0,893	0,746	0,831	0,845	0,914	0,829	0,903
S_7	0,624	0,753	0,753	0,855	0,843	0,932	0,789	0,868	0,809	0,884	0,829	0,903
S_8	0,769	0,860	0,807	0,898	0,716	0,841	0,746	0,831	0,845	0,914	0,782	0,867
S_9	0,712	0,814	0,753	0,855	0,794	0,893	0,746	0,831	0,809	0,884	0,709	0,819
S_{10}	0,624	0,753	0,807	0,898	0,794	0,893	0,689	0,786	0,809	0,884	0,829	0,903

In the next step, $\otimes S_i$ and $\otimes P_i$ values were calculated by using Eqn. (10) and (11) (Table 7.).

Table 7. Purchasing Manager's (DM_1) $\otimes S_i$ and $\otimes P_i$ values

S_1	0,266	0,483	4,792	5,305
S_2	0,203	0,396	4,576	5,137
S_3	0,253	0,467	4,711	5,251
S_4	0,190	0,380	4,521	5,095
S_5	0,203	0,397	4,573	5,135
S_6	0,244	0,455	4,732	5,253
S_7	0,230	0,436	4,647	5,195
S_8	0,232	0,436	4,665	5,211
S_9	0,190	0,381	4,523	5,095
S_{10}	0,201	0,397	4,551	5,116

For ranking, a relative performance score $\otimes k_i$, was calculated using Eqn. (12), (13), (14), (15) and then The CoCoFISo-G score (K) calculated by Eqn. (16) (Table 8.)

Table 8. CoCoFISo-G Score for DM_1

Supplier	$\otimes \boldsymbol{k_{ia}}$		$\otimes \boldsymbol{k_{ib}}$		$\otimes \boldsymbol{k_{ic}}$		$\otimes \boldsymbol{k_i}$		**K**
S_1	0,0903	0,1193	2,201	2,985	0,873665311	1	1,613	2,077	1,8449
S_2	0,0853	0,1141	2,123	2,926	0,825572814	0,956016	1,542	2,016	1,7788
S_3	0,0886	0,1179	2,165	2,969	0,857529826	0,987808	1,585	2,060	1,8226
S_4	0,0841	0,1129	2,101	2,913	0,813983611	0,94589	1,524	2,001	1,7626
S_5	0,0853	0,1141	2,122	2,926	0,825175472	0,955764	1,541	2,015	1,7782
S_6	0,0888	0,1177	2,181	2,966	0,859721146	0,986127	1,593	2,057	1,8253
S_7	0,0870	0,1161	2,144	2,949	0,842434203	0,97289	1,564	2,039	1,8016
S_8	0,0874	0,1164	2,154	2,952	0,846059584	0,975506	1,571	2,043	1,8070
S_9	0,0841	0,1129	2,102	2,913	0,814216715	0,946028	1,524	2,002	1,7629
S_{10}	0,0848	0,1137	2,109	2,921	0,82085565	0,952544	1,533	2,010	1,7715

Since group decision making was used in this study, the last step was to combine the K values of the decision makers. For this, Eqn. (17) is used. The supplier with the highest CoCoFISo-G score was at the top of the ranking, which was supplier S_1.

Conclusion

Today, selecting green suppliers has become an important part of a company's sustainability and environmental efforts. Green suppliers are companies that minimize their environmental impact and adopt sustainable practices. This helps to conserve natural resources and reduce pollution. Many countries and regions have regulations and standards for environmental protection. By complying with these regulations, green suppliers help companies avoid criminal penalties and enhance their reputations. Sustainability enhances a company's brand value and reputation. Environmentally conscious consumers prefer companies that adopt sustainable practices and work with green suppliers. This increases customer loyalty and market competitiveness. Green suppliers also invest in innovative and sustainable technologies. These technologies help companies reduce their environmental impact and develop more sustainable business models.

Working with green suppliers is part of a company's corporate social responsibility. Environmentally responsible practices improve the overall well-being of society and enable companies to contribute to social responsibility projects. Adopting sustainable practices and working with green suppliers ensures long-term business success and sustainability. Environmental responsibility ensures future business success.

In this study, the CoCoFISo (Combined Compromise for Ideal Solution) method has been extended with gray numbers to create the CoCoFISo-G method. The CoCoFISo method is an extension of the CoCoSo method, and the purpose of the CoCoFISo method is to find an ideal compromise solution to improve the algorithm of the CoCoSo method. This extended method was used for green supplier selection. The supplier with the highest CoCoFISo-G score was identified as the best alternative. The method can be applied to many selection and ranking problems.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements or Notes

* This article was presented as an oral presentation at the International Conference on Technology, Engineering and Science (www.icontes.net) held in Antalya/Turkey on November 14-17, 2024.

References

Bagal, D. K., Giri, A., Pattanaik, A. K., Jeet, S., Barua, A., & Panda, S. N. (2021). MCDM optimization of characteristics in resistance spot welding for dissimilar materials utilizing advanced hybrid taguchi method-coupled CoCoSo, EDAS and WASPAS Method. *Springer Proceedings in Materials*, *9*, 475–490.

Bakeshlou, E. A., Khamseh, A. A., Asl, M. A. G., Sadeghi, J., & Abbaszadeh, M. (2017). Evaluating a green supplier selection problem using a hybrid MODM algorithm. *Journal of Intelligent Manufacturing*, *28*(4), 913–927.

Banaeian, N., Mobli, H., Fahimnia, B., Nielsen, I. E., & Omid, M. (2018). Green supplier selection using fuzzy group decision making methods. A case study from the agri-food industry. *Computers & Operations Research*, *89*, 337–347.

Deveci, M., Pamucar, D., & Gokasar, I. (2021). Fuzzy Power Heronian function based CoCoSo method for the advantage prioritization of autonomous vehicles in real-time traffic management. *Sustainable Cities and Society*, *69*, 102846.

Ecer, F. (2021). A consolidated MCDM framework for performance assessment of battery electric vehicles based on ranking strategies. *Renewable and Sustainable Energy Reviews*, *143*, 110916.

Gabriel- Rasoanaivo, R., Yazdani, M., Zaraté, P., & Fateh, A. (2024). Combined compromise for ideal solution (CoCoFISo). A multi-criteria decision-making based on the CoCoSo method algorithm. *Expert Systems with Applications*, *251*, 124079.

Govindan, K., Kadziński, M., & Sivakumar, R. (2017). Application of a novel PROMETHEE-based method for construction of a group compromise ranking to prioritization of green suppliers in food supply chain. *Omega*, *71*, 129–145.

Hashemi, S. H., Karimi, A., & Tavana, M. (2015). An integrated green supplier selection approach with analytic network process and improved grey relational analysis. *International Journal of Production Economics*, *159*, 178–191.

Hervani, A. A., Helms, M. M., & Sarkis, J. (2005). Performance measurement for green supply chain management. *Benchmarking*, *12*(4), 330–353.

Keshavarz- Ghorabaee, M., Zavadskas, E. K., Amiri, M., & Esmaeili, A. (2016). Multi-criteria evaluation of green suppliers using an extended WASPAS method with interval type-2 fuzzy sets. *Journal of Cleaner Production*, *137*, 213–229.

Liao, C. N., Fu, Y. K., & Wu, L. C. (2016). Integrated FAHP, ARAS-F and MSGP methods for green supplier evaluation and selection. *Technological and Economic Development of Economy*, *22*(5), 651–669.

Peng, X., & Luo, Z. (2021). Decision-making model for China's stock market bubble warning. the CoCoSo with picture fuzzy information. *Artificial Intelligence Review*, *54*(8), 5675–5697.

Popović, M. (2021). An Mcdm approach for personnel selection using the Cocoso method. *Journal of Process Management and New Technologies*, *9*(3–4), 78–88.

Qin, J., Liu, X., & Pedrycz, W. (2017). An extended TODIM multi-criteria group decision making method for green supplier selection in interval type-2 fuzzy environment. *European Journal of Operational Research*, *258*(2), 626–638.

Rouyendegh, B. D., Yildizbasi, A., & Ustunyer, P. (2020). Intuitionistic Fuzzy TOPSIS method for green supplier selection problem. *Soft Computing*, *24*(3), 2215–2228.

Stanujkic, D., Popovic, G., Zavadskas, E. K., Karabasevic, D., & Binkyte-Veliene, A. (2020). Assessment of progress towards achieving sustainable development goals of the agenda 2030 by using the CoCoSo and the shannon entropy methods. the case of the EU Countries. *Sustainability 2020*, *12*(14), 5717.

Torkayesh, A. E., Ecer, F., Pamucar, D., & Karamasa, C. (2021). Comparative assessment of social sustainability performance. Integrated data-driven weighting system and CoCoSo model. *Sustainable Cities and Society*, *71*, 102975.

Torkayesh, A. E., Pamucar, D., Ecer, F., & Chatterjee, P. (2021). An integrated BWM-LBWA-CoCoSo framework for evaluation of healthcare sectors in Eastern Europe. *Socio-Economic Planning Sciences*, *78*, 101052.

Wen, Z., Liao, H., Kazimieras Zavadskas, E., & Al-Barakati, A. (2019). Selection third-party logistics service providers in supply chain finance by a hesitant fuzzy linguistic combined compromise solution method. *Economic Research-Ekonomska Istraživanja*, *32*(1), 4033–4058.

Wu, Q., Zhou, L., Chen, Y., & Chen, H. (2019). An integrated approach to green supplier selection based on the interval type-2 fuzzy best-worst and extended VIKOR methods. *Information Sciences*, *502*, 394–417.

Yazdani, M., Wen, Z., Liao, H., Banaitis, A., & Turskis, Z. (2019). A grey combined compromise solution (Cocoso-g) method for supplier selection in construction management. *Journal of Civil Engineering and Management*, *25*(8), 858–874.

Yazdani, M., Zarate, P., Zavadskas, E. K., & Turskis, Z. (2019). A combined compromise solution (CoCoSo) method for multi-criteria decision-making problems. *Management Decision*, *57*(9), 2501–2519.

Yu, Q., & Hou, F. (2016). An approach for green supplier selection in the automobile manufacturing industry. *Kybernetes*, *45*(4), 571–588.

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To cite this article:

Sen, H. & Toksoy, M.S. (2024). Green supplier selection with CoCoFISo-G. *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 32,* 257-265.