

Performance evaluation of green suppliers using the integrated Fuzzy DEMATEL-AHP-VIKOR Multi criteria decision making techniques

Jerin Joseph¹, Rajeshwar S Kadadevaramath², B. Latha Shankar³, Shiou-Yu Chen⁴,
Akarsha Kadadevaramath⁵

¹Research Scholar, Industrial Engineering & Management, Siddaganga Institute of Technology, Tumkur
Visvesvaraya Technological University, Belgaum, Karnataka, India

²Dean Academics, Amruta Institute of Engineering and Management Sciences, Bidadi, Karnataka, India,

³Asso. Professor, Industrial Engineering & Management, Siddaganga Institute of Technology, Tumkur, Karnataka, India

⁴Professor, National Taiwan Ocean University, Keelung City, Taiwan

⁵Mechanical Engineer, Intel India Pvt. Ltd, Bangalore, Karnataka, India

Corresponding author: jerinjosephjj@gmail.com

Email: jerinjosephjj@gmail.com

Abstract: Green Supply Chain Management (GSCM) strives to decrease, if not eliminate, supply chain operations' negative environmental effects. Multi-criteria decision-making (MCDM) strategies should be utilized to evaluate suppliers' GSCM performance because GSCM includes multi-dimensional methods. To address complex and confounding multi-attribute questions in a fuzzy environment, it is essential to devise fuzzy group decision making techniques. The present work introduces a methodology for evaluating the performance of firms in Green Supply Chain Management (GSCM) with regards to green design, green image, green transformation, green logistics, and green management system. This approach relies on integrated fuzzy MCDM techniques. The fuzzy DEMATEL approach is used to calculate the cause and effect correlation between GSCM dimensions. Based on this association, the fuzzy AHP technique is utilized to generate the weights of the relevant criterion. Finally, the fuzzy VIKOR technique is used to evaluate and rank the GSCM performance of alternative suppliers or organizations using the weights obtained from the fuzzy AHP method.

Keywords: Supplier selection; Green; MCDM; Supply chain; Fuzzy.

1. Introduction

SCM and logistics are significant components of today's most critical operations since they are still necessary tools for firms to remain competitive. As local and global awareness of environmental concerns grows, as well as increasing pressures on businesses to reduce their negative environmental effects, many organizations have begun to embrace and apply green practices to improve their environmental performance and minimize their adverse environmental effects. It is becoming increasingly common for businesses to unify their supply chains in order to lower their operational expenses and enhance their level of service to customers. The GSCM initiative aims to lessen the adverse impacts that the supply chain has on the environment. Technology advancement is also tied to GSCM methods. Green activities benefit the environment and the manufacturing sector, whereas GSCM procedures improve technical innovation in businesses. Reduced or eliminated environmental impacts from supply chain activities is the primary objective of GSCM. Many factors need that businesses enhance their GSCM operations. These factors encompass, but are not limited to, the introduction of new environmental regulations and the passionate stances taken by businesses in relation to environmental policies. As a result of the fact that GSCM necessitates the use of multi-dimensional approaches, MCDM methodologies ought to be executed in the process of assessing the GSCM performance of businesses.

In order to produce a solution that demands consensus, MCDM is a method that combines alternative performance over various kinds of qualitative and quantitative criteria that are in conflict with one another. As opposed to promoting the best answer, the aim of MCDM is to provide decision-makers with assistance in picking a group of possibilities that have been shortlisted or a single option that satisfies their needs and is consistent with their unique preferences. There are already several competing goals in supply chain strategy, and the increasing weight of environmental concerns has added green criteria to the list.

In 1965, Zadeh presented the fuzzy theory, which has been shown to be a successful technique for MCDM throughout the course of the past few decades, particularly in the supply chain. Fuzzy set theory is a development of classical set theory that enables the resolution of numerous issues that are associated with managing data that is both imprecise and ambiguous (Büyüközkan & Çifçi, 2012a). It provides numerous advantages. According to Kannan, De Sousa, and others (2014), fuzzy logic takes into account both the growth of accessible knowledge and the presence of insufficient information. It permits input that is not precise. In this way, a small number of rules can be used to solve issues that are extremely complicated. Developing fuzzy systems can be difficult at times, which is one of the disadvantages of using them. Before they can be utilised in the actual world, they may, in many instances, be required to undergo a great deal of simulation. It is possible to take use of the availability of imprecise input in order to solve many of the decision-making challenges that arise in the supply chain. These applications favour an approach that is open to ambiguity and can be evaluated multiple times before being used in the real world to ensure its effectiveness.

The powerful tool DEMATEL allows for the creation and analysis of structural models with complex causal linkages. As to Govindan and Chaudhuri (2016), one method that excels at analyzing interdependencies and linkages without being constrained by sample size is the Decision-Making Trial and Evaluation Laboratory (DEMATEL). For this reason, it is suitable for a limited number of respondents or, on occasion, groups of respondents (for instance, project teams). Since its inception in 1973 for the purpose of conducting research on social issues, it has evolved into a well-established technique for conducting multi-criteria analysis in the field of economics. Its primary advantage is that it makes it possible to determine the fundamental causes that are responsible for a particular problem by analyzing the interactions and relationships that exist between the criteria that are set for the particular problem.

Constructing a hierarchical relevant network system, can improve knowledge of challenges, and groups of interconnected components, and propose a possible solution (Uygun & Dede, 2016). Morteza Yazdani (2017) states that due to the cause-and-effect nature of DEMATEL, there are instances where soft approaches like fuzzy sets theory, Complex Proportional Assessment (COPRAS), and Quality function deployment are required. Moreover, Büyüközkan&ıfçi (2012)a and Uygun & Dede (2016) found that GSCM processes benefit from pairwise comparison methods like AHP and ANP.

The Analytic Hierarchy Process (AHP) approach was first presented by Saaty in the early 1970s. According to Saaty (1980), the technique makes it easier to find the relative significance of various characteristics and the order in which a group of choices should be considered in circumstances where a large number of criteria are available. Meade and Sarkis (1998) argue that the notable advantage of the AHP approach lies in its capability to efficiently handle different criteria and conduct both qualitative and quantitative data analysis. Due to its user-friendliness and interpretability, the application of AHP is extensive in GSCM-related supplier selection and evaluation. AHP is commonly utilized in GSCM supplier selection and analysis because of its ease of use and interpretability. According to Ireneusz Miciua (2018) and G. Karunakumar (2018), the majority of the time, AHP is directly applied in GSCM operations by supply alternative options. Nevertheless, in a significant number of literary works, it is used in conjunction with other methodologies, like ELECTRE III (Ali Alazzawi, 2020), VIKOR (Ashwani Kumar, 2019), PROMETHEE (Tsui & Wen, 2015), TOPSIS (Rajnish Kumar, 2018; Hsiu Mei, 2016; Yazdani, 2014; White, Wang & Li, 2015), and ARAS (Yan Kai-Fu, 2019; Jolanta Tamošaitienė, 2017). These methods are used to finish the decision-making process.

Opricovic (2004) was the one who first presented the concept of VIKOR, which aims on analysing and choosing from a number of different choices, locating solutions that are a compromise for situations that involve competing criteria, and providing assistance to decision-makers in the process of making a final decision (Hsu and colleagues, 2013). The VIKOR technique is a recent development in comparison to other fundamental approaches of multi-channel data management (MCDM). For supplier selection, the VIKOR approach was used in conjunction with the Fuzzy Best Worst Best method (Devika Kannan,

2020; Qun Wu 2019). MCDM strategies like the Analytical Network Process (ANP) were fused with VIKOR in order to facilitate the selection of environmentally responsible suppliers (Sahaj Valipour, 2017; Akman, 2015). There are a number of benefits that VIKOR offers in comparison to other MCDM techniques. The main goal of VIKOR is to handle matters related to supplier evaluation and selection. Hybrid multi criteria decision-making methods grounded on fuzzy environments have been utilized due to the dearth of literature on the supplier selection problem. The present study is structured into four clearly delineated sections. The initial part comprises an introduction and literature reviews as pertinent to the topic. Next level, included the proposed approach in the MCDM methods section. The suggested method is then illustrated with an example in the third section. The final part is the conclusion section.

2. Proposed MCDM approach

This research proposes a novel methodology for analyzing the overall GSCM performance of organizations depending on fuzzy DEMATEL, fuzzy ANP, and fuzzy TOPSIS techniques. The dimensions and associated variables that affect GSCM performance are established first and foremost through research and conversation with academic and industry specialists. This research use the fuzzy DEMATEL method to assess the level of correlation among the dimensions. The approach described by Lin and Wu (2004) and Wu (2008) is a very efficient tool for collecting ideas from a group and discovering the link between the causes of complicated issues that crop up in uncertain settings. To evaluate the weights of the criteria associated with the dimensions using this interrelationship network, the fuzzy Analytic Hierarchy Process (AHP) methodology is a viable way. Finally, based on their GSCM capacity, the fuzzy VIKOR technique helps to evaluate and rank alternative organizations.

A representation of the fundamental stages of the GSCM evaluation approach is shown in Figure 1. The technique begins with determining the GSCM evaluation dimensions and associated criteria. After that, the Fuzzy DEMATEL technique is utilized to find correlations between the dimensions. The Fuzzy AHP technique, which is based on the primary interactions, is used for calculating the local weights of each criterion. After that, the suppliers are investigated using preset GSCM criteria in order to get evaluation inputs for the Fuzzy VIKOR technique. Suppliers are given a score based on their GSCM operations in this last technique.

2.1. Fuzzy DEMATEL Technique

Battelle Geneva Institute established the technique in order to address complicated issues by employing interactive man model approaches and measuring qualitative and factor-related characteristics of social concerns (Gabus & Fontela, 1972). The methodology was designed in order to solve complex challenges. Before translating the elements into the system's explicit structural mode, it assesses their relative importance and strength. According to Lin and Wu (2004, 2008), the fuzzy DEMATEL technique was established with the purpose of collecting the opinions of a group and determining the link between causes and effects of difficult circumstances that occur in settings that are fuzzy. How the algorithm works is as follows:

Step 1: Design the fuzzy linguistic scale and establish the evaluation criteria.

Sets of dimensions and criteria that are related to them are established in order to conduct the analysis of GSCM. When making decisions as a group, the fuzzy linguistic scale helps to mitigate the effects of subjective human judgment. This is due to the fact that evaluation criteria are characterized by the presence of a causal relationship and typically consist of a number of complex characteristics. There are five language expressions that are used to indicate the various degrees of influence. These terms are "No," "Low," "Medium," "High," and "Very high." The positive triangular fuzzy numbers that correlate to these terms are displayed in tableau 3.

Step 2: Make a fuzzy direct-relation matrix.

The initial step in determining the model of the relationships between the n criteria is to build a matrix with dimensions of n by n . You can use fuzzy numbers to measure how each row of this matrix affects each column's elements. It is helpful to compute the mathematical mean of all the expert-generated thoughts in order to develop the direct relation matrix y .

$$y1 = [0 \cdots \tilde{y}_{n1} \quad \ddots \quad \tilde{y}_{1n} \cdots 0]$$

Step 3: It is necessary to normalise the fuzzy direct-relation matrix which can be calculated by,

$$\tilde{x}_{pq} = \frac{\tilde{y}_{pq}}{r} = \left(\frac{l_{pq}}{r}, \frac{m_{pq}}{r}, \frac{u_{pq}}{r} \right), \text{ where}$$

$$r = \left\{ \sum_{p=1}^n \cdot u_{pq}, \sum_{q=1}^n \cdot u_{pq} \right\} \quad p, q \in \{1, 2, 3, \dots, n\}$$

Step 4: Calculating the total-relation matrix's fuzziness.

In step 3, use the following formula to generate the fuzzy total-relation matrix:

$$\tilde{T} = (\tilde{x}^1 \oplus \tilde{x}^2 \oplus \dots \oplus \tilde{x}^k)$$

Step 5: Defuzzify into crisp values

It is possible to ascertain the precise value of the total-relation matrix by utilizing the CFCS approach, which was initially presented by Opricovic and Tzeng. The steps would be as follows:

$$l_{pq1}^n = \frac{(l_{pq1}^t - l_{pq}^t)}{\Delta_{min}^{max}}$$

$$m_{pq1}^n = \frac{(m_{pq}^t - \min l_{pq}^t)}{\Delta_{min}^{max}}$$

$$u_{pq1}^n = \frac{(u_{pq}^t - \min l_{pq}^t)}{\Delta_{min}^{max}}$$

The top and lower boundaries of normalised values are calculated as follows:

$$l_{pq}^s = \frac{m_{pq}^n}{(1 + m_{pq}^n - l_{pq}^n)}$$

$$u_{pq}^s = \frac{u_{pq}^n}{(1 + u_{pq}^n - l_{pq}^n)}$$

The CFCS approach results in crisp values. The following formula is utilized to obtain the total normalised crisp values:

$$x_{pq1} = \frac{[l_{pq}^s(1 - l_{pq}^s) + u_{pq}^s \times u_{pq}^s]}{[1 - l_{pq}^s + u_{pq}^s]}$$

Step 6: Estimate the value of the threshold

It is required for the threshold value to be present before the construction of the internal relations matrix can begin. A network relationship map is formed by ignoring incomplete relationship. Matrix T values that are higher than the threshold value are the only ones that are taken into consideration when determining the NRM for each relationship. For the purpose of determining the relative relationship threshold, it is necessary to compute the mean of the outcomes of matrix T. Following the discovery of the threshold intensity, all of the values in matrix T that are lower than the threshold are assigned a value of zero.

Step 7: Generate a causal relationship diagram that visually represents the ultimate outcome.

After that, remember to add up all the numbers in each row and column of T in the fourth step. The formula below can be used to determine the sum of rows O and columns L:

$$O = \sum_{j=1}^n T_{pq} \quad L = \sum_{i=1}^n T_{pq}$$

2.2. Fuzzy AHP Method

Saaty's technique is incorporated into Fuzzy AHP, a decision-making system (Saaty, 2000). In the 1970s, fuzzy set theory was utilized to build the Analytic Hierarchy Process (AHP) (Zimmermann, 2010). Fuzzy integers are generated using this method by means of a membership function, which is a countable real number between zero and one. Its relevance in dealing with the supplier selection

dilemma has been demonstrated by several research studies (Kannan et al.). For each of the three criteria in this study, this technique is used to assign substantial weights to each sub-criterion. The linguistic elements that were utilized to weight the criterion are listed in Table 11. The language rating "very strong (VM)" is an example of a numerical evaluation (2.5, 3, 3.5). In accordance with the recommendations provided by their specialists, the decision-makers are required to assign a priority to each of the sub-criteria that are included in each of the three sets of criteria.

2.3. Fuzzy VIKOR Method

In order to rank options in a fuzzy environment, the FUZZY VIKOR approach, which was created by Opricovic (2007), has been utilized. The following is the method for employing the fuzzy VIKOR algorithm in this investigation:

Step 1: Make a matrix of options.

Step 2: Create a list of the best and worst possible outcomes.

The following is a list of the solutions that are both positive and negative ideals.

If the criterion is positive, the optimum solution is positive, if the criterion is negative, the optimum answer is positive as well as a negative ideal solution can be derived from the following relationships:

$$\tilde{f}_q^* = \text{Max}_{p=1,2,\dots,n} (f_{pq}) \text{ (Positive)}, \quad \tilde{f}_q^{\circ} = \text{Min}_{p=1,2,\dots,n} (f_{pq}) \text{ (negative)}$$

Step 3: Evaluate the decision matrix that has been normalised.

Create a normalized choice matrix based on both ideal solutions using the following link:

$$d_{pq} = (f_q \ominus f_{pq}) / (r_q^* - l_q) \text{ Positively the best option}$$

$$d_{pq} = (f_{pq} \ominus f_q) / (r_q^* - l_q) \text{ Unfavorable optimum solution}$$

$$\text{Where } f_q^* = (l_p^*, m_q^m, m_q^*) \quad f_q^{\circ} = (l_p^{\circ}, m_p^{\circ}, m_q^{\circ})$$

Step 4: Compute the values O_p and L_p :

Prior to being converted back to a normalized matrix, the normalized matrix is transformed into a Weighted normalized decision matrix. The values O_p and L_p can be calculated as

$$\text{follows: If } L_p = (L_p^l, L_p^m, L_p^r) \quad \text{and} \quad O_p = (o_p^l, o_p^m, o_p^r)$$

$$o_p = \sum_{q=1}^j (w_q \otimes y_{pq}) \quad L_p = \max (w_q \otimes y_{pq})$$

Step 5: VIKOR index (Q) Calculation

For the purpose of determining the value of Q, the following formula can be utilized.

$$\text{If } Q_p = (Q_p^l, Q_p^m, Q_p^r)$$

$$Q_p = v \frac{(O_p \ominus O^*)}{O^r - O^l} \oplus (1 - v) \frac{(L_p \ominus L^*)}{L^r - L^l}$$

$$\text{Where, } O^* = \min_p O_p \quad L^* = \max_p L_p \quad L^r = \max_p L_p^r \quad L^l = \min_p L_p^l$$

A value of 0.5 is assigned to the variable v, which denotes the highest level of group usefulness. To transform the fuzzy numbers O, L, and Q into unambiguous numerical values.

$$\text{Crisp}(A) = \frac{2m + l + r}{4}$$

If $A = (l, m, r)$ A denotes fuzzy number.

Step 6: Compromise solution is proposed

To make a decision, the L, O, and Q values for the alternatives, ordered in descending order, are used. There are two situations in which a decision must be made, and a series of compromise solutions can be offered as a result of these two elements.

3. Case study and Discussion

A case study is undertaken to assess four particular suppliers based on predefined green dimensions and associated criteria. This is done in order to test the performance evaluation technique that has been provided for GSCM. Hence, the suggested methodology, which combines fuzzy DEMATEL, fuzzy AHP, and fuzzy VIKOR techniques, is employed to evaluate and rank the different organizations. Prior to implementing the fuzzy DEMATEL approach, experts from both academic and industrial domains must ascertain the degree to which each dimension impacts the others. There is no difference between the pairwise comparison matrix that was developed by experts and the direct relationship matrix that is displayed in Table 2. Table 3, which may be found on the internet, illustrates the fuzzy scale that was utilized in the model. It is possible to generate the normalized fuzzy direct-relation matrix as well as the fuzzy total relation matrix by making use of the equations that are shown in a schematic format in Tables 4 and 5, respectively. The CFCS method developed by Opricovic and Tzeng made it possible to provide an accurate computation of the total-relation matrix. Table 6 provides an explanation of the equations that reflect the upper and lower limits of normalized coefficients. These equations may be found here. As demonstrated in Table 6, the CFCS algorithm produces findings that are straightforward and simple to understand. It is essential to take into consideration the threshold value that has been chosen before beginning the construction of the internal relations matrix. A criteria of 0.45 will be employed for this investigation. When the value of Matrix T is below 0.45, it is assigned a value of zero, therefore suggesting that the previously observed causal relationship is not considered. Following the examination of the threshold value, Table 7 presents the precise total-relationships matrix. As previously stated, each component can be evaluated based on the following factors, which are illustrated in the figure and table above:

It is possible to quantify the relative relevance of each subcomponent in proportion to the entire system by using the horizontal vector, which is composed of D and R. When expressed in a different way, the symbol $(D + R)$ indicates the significance of the impact that factor I has on the entire system, in addition to the influence that other components of the system have on the factor. The vertical vector level, often known as the D-R, is a metric that measures the degree to which a certain component has an impact on the system. A high D-R correlation suggests a causal relationship, while a low D-R correlation suggests an effect. Green design, green image, and green transformation are regarded as causal variables in this research, but green logistics and green management systems are the considered effects. Green design is the first priority, as demonstrated in table 9, according to the Green Supplier Selection. According to the weights generated using fuzzy AHP, the following priorities are allocated to Green Environmental Systems, Green Logistics, Green Image, and Green Transformation.

In this research, the fuzzy VIKOR methodology is utilized to rank four different vendors according to five different criteria. The fuzzy AHP output determines the criterion and weight allocated to each criterion. Table 11 displays the fuzzy scale that was utilized throughout the course of the model's development. The decision matrix's outputs are displayed in Table 12 after the options have been weighed against a number of criteria. If the evaluation involves more than one expert, the matrix below displays the arithmetic mean of all of them. Table 13 displays both the positive and negative ideal values for the situation. Table 14 explains how to use both ideal solutions to create a normalized choice matrix. The variable v is set at 0.5, which represents the greatest group utility in this study. Based on the information shown in Table 15, the fuzzy values O, L, and Q can be transformed into precise numerical values. A ranking of the alternatives based on L, O, and Q is presented in Table 16, which also includes the crisp values O, L, and Q presented in the table. A case study backs up the suggested method, where various providers were assessed in a fuzzy environment that took into account the ambiguity and unpredictability of real-life scenarios as well as subjective human judgments. Although there have been studies that look at green supplier performance, here fuzzy MCDM methodologies are employed to evaluate suppliers' whole GSCM performance. Suppliers can use the evaluation to compare their own green performance to that of other suppliers and to get relevant input on areas where they can improve.

Table 1: Dimensions and related criteria

Criteria	Related Sub Criteria
Green design (G1)	Quality Regulations, Environmental Performances, Economic Performances
Green image (G2)	Quality of Service, : Quality of Technology, Supplier Customer Collaboration
Green transformation (G3)	Green Manufacturing, Packaging and Stock Politics, Remanufacturing
Green logistics (G4)	Organization of Logistics Networks, Re-cycling, Reusing Disposal
Green Management system (G5)	Waste management, Pollution control, ISO 14000 Certification

Table 2: The direct relation matrix

	G1	G2	G3	G4	G5
G1	(0.000,0.000,0.000)	(0.250,0.500,0.750)	(0.500,0.750,1.000)	(0.750,1.000,1.000)	(0.750,1.000,1.000)
G2	(0.000,0.250,0.500)	(0.000,0.000,0.000)	(0.250,0.500,0.750)	(0.500,0.750,1.000)	(0.500,0.750,1.000)
G3	(0.750,1.000,1.000)	(0.000,0.250,0.500)	(0.000,0.000,0.000)	(0.250,0.500,0.750)	(0.250,0.500,0.750)
G4	(0.000,0.250,0.500)	(0.250,0.500,0.750)	(0.250,0.500,0.750)	(0.000,0.000,0.000)	(0.750,1.000,1.000)
G5	(0.250,0.500,0.750)	(0.000,0.250,0.500)	(0.250,0.500,0.750)	(0.500,0.750,1.000)	(0.000,0.000,0.000)

Table 3: Fuzzy Scale

Code	Linguistic terms	L	M	U
1	No influence	0	0	0.251
2	Very low influence	0	0.251	0.51
3	Low influence	0.251	0.51	0.751
4	High influence	0.51	0.751	1.0
5	Very high influence	0.751	1.0	1.0

Table 4: The normalized fuzzy direct-relation matrix

	G1	G2	G3	G4	G5
G1	(0.000,0.000,0.000)	(0.067,0.133,0.200)	(0.133,0.200,0.267)	(0.200,0.267,0.267)	(0.200,0.267,0.267)
G2	(0.000,0.067,0.133)	(0.000,0.000,0.000)	(0.067,0.133,0.200)	(0.133,0.200,0.267)	(0.133,0.200,0.267)
G3	(0.200,0.267,0.267)	(0.000,0.067,0.133)	(0.000,0.000,0.000)	(0.067,0.133,0.200)	(0.067,0.133,0.200)
G4	(0.000,0.067,0.133)	(0.067,0.133,0.200)	(0.067,0.133,0.200)	(0.000,0.000,0.000)	(0.200,0.267,0.267)
G5	(0.067,0.133,0.200)	(0.000,0.067,0.133)	(0.067,0.133,0.200)	(0.133,0.200,0.267)	(0.000,0.000,0.000)

Table 5: The fuzzy total-relation matrix

	G1	G2	G3	G4	G5
G1	(0.056,0.264,0.991)	(0.089,0.318,1.068)	(0.184,0.455,1.335)	(0.274,0.585,1.476)	(0.290,0.617,1.476)
G2	(0.031,0.250,0.988)	(0.014,0.142,0.793)	(0.095,0.320,1.153)	(0.172,0.428,1.326)	(0.182,0.452,1.326)
G3	(0.220,0.426,1.048)	(0.024,0.222,0.880)	(0.050,0.227,0.948)	(0.136,0.408,1.232)	(0.144,0.430,1.232)
G4	(0.035,0.252,0.936)	(0.073,0.256,0.909)	(0.095,0.319,1.092)	(0.054,0.261,1.046)	(0.234,0.497,1.256)
G5	(0.090,0.293,0.989)	(0.017,0.199,0.871)	(0.095,0.309,1.102)	(0.168,0.413,1.264)	(0.060,0.269,1.054)

Table 6: The crisp total-relation matrix

	G1	G2	G3	G4	G5
G1	0.373	0.422	0.575	0.696	0.718
G2	0.361	0.253	0.45	0.562	0.579
G3	0.504	0.324	0.347	0.53	0.546
G4	0.355	0.357	0.44	0.39	0.604
G5	0.395	0.307	0.435	0.542	0.398

Table 7: By taking the threshold value into account, the crisp total-relationships matrix is created.

	G1	G2	G3	G4	G5
G1	0	0	0.575	0.696	0.718
G2	0	0	0	0.562	0.579
G3	0.504	0	0	0.53	0.546
G4	0	0	0	0	0.604
G5	0	0	0	0.542	0

Table 8: The DEMATEL final result

	R	D	D+R	D-R
G1	1.987	2.784	4.771	0.797
G2	1.663	2.205	3.867	0.542
G3	2.247	2.251	4.498	0.004
G4	2.721	2.145	4.866	-0.575
G5	2.844	2.077	4.922	-0.767

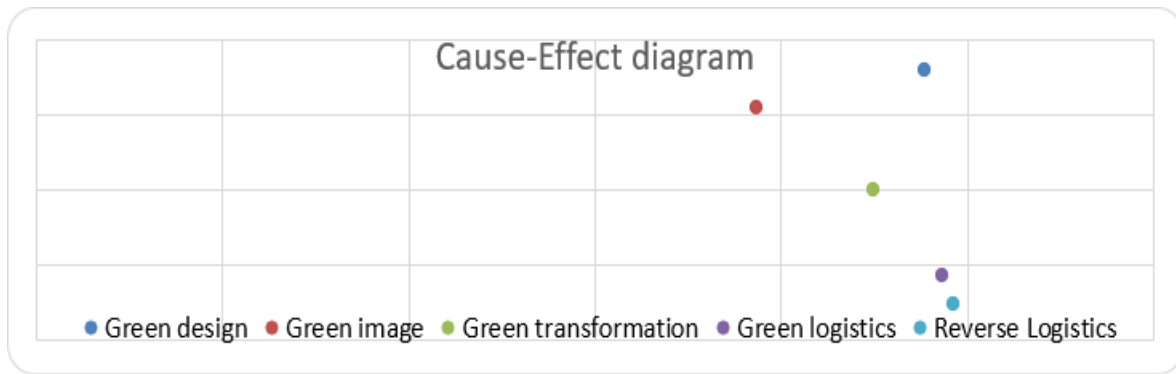


Figure 2-Cause-effect diagram
Table 9: Criteria weight using AHP

Criteria	Criterion weight
G1	0.265
G2	0.179
G3	0.169
G4	0.19
G5	0.197

Table 10: AHP Fuzzy Scale

Code	Linguistic Variables	L	M	U
1	Equal	1.0	1.0	1.0
2	Weak	0.50	1.0	1.50
3	Fairly Strong	1.50	2.0	2.50
4	Very Strong	2.50	3.0	3.50
5	Absolute	3.50	4.0	4.50

Table 11: VIKOR Fuzzy Scale

Code	Linguistic terms	L	M	U
1	Very Low	0	0	0.250
2	Low	0	0.250	0.50
3	Medium	0.250	0.50	0.750
4	High	0.50	0.750	1.0
5	Very High	0.750	1.0	1.0

Table 12: Decision Matrix

	G1	G2	G3	G4	G5
Supplier 1	(0.000,0.250,0.500)	(0.250,0.500,0.750)	(0.250,0.500,0.750)	(0.333,0.583,0.833)	(0.250,0.500,0.667)
Supplier 2	(0.250,0.500,0.750)	(0.083,0.333,0.583)	(0.250,0.500,0.750)	(0.583,0.833,1.000)	(0.000,0.250,0.500)
Supplier 3	(0.417,0.667,0.917)	(0.500,0.750,1.000)	(0.250,0.500,0.750)	(0.250,0.500,0.750)	(0.250,0.500,0.750)
Supplier 4	(0.250,0.500,0.750)	(0.250,0.500,0.750)	(0.167,0.417,0.667)	(0.167,0.417,0.667)	(0.417,0.667,0.917)

Table 13: The criteria include both positive and negative ideal solutions.

	Positive ideal	Negative ideal
G1	(0.417,0.667,0.917)	(0.000,0.250,0.500)
G2	(0.500,0.750,1.000)	(0.083,0.333,0.583)
G3	(0.250,0.500,0.750)	(0.167,0.417,0.667)
G4	(0.583,0.833,1.000)	(0.167,0.417,0.667)
G5	(0.417,0.667,0.917)	(0.000,0.250,0.500)

Table 14: The normalized decision matrix

	G1	G2	G3	G4	G5
Supplier 1	(0.091,0.455,1.000)	(0.273,0.273,0.818)	(0.858,0.000,0.858)	(0.300,0.300,0.801)	(0.273,0.182,0.727)
Supplier 2	(0.363,0.182,0.727)	(0.091,0.455,1.000)	(0.858,0.000,0.858)	(0.501,0.000,0.501)	(0.091,0.455,1.000)
Supplier 3	(0.545,0.000,0.545)	(0.545,0.000,0.545)	(0.858,0.000,0.858)	(0.200,0.400,0.900)	(0.363,0.182,0.727)
Supplier 4	(0.363,0.182,0.727)	(0.273,0.273,0.818)	(0.715,0.142,1.000)	(0.101,0.499,1.000)	(0.545,0.000,0.545)

Table 15: The O, L, and Q Fuzzy Values

Supplier	Fuzzy Q	Fuzzy O	Fuzzy L
1	(0.704,0.129,1.000)	(0.328,0.262,0.852)	(0.024,0.121,0.265)
2	(0.706,0.062,0.872)	(0.370,0.219,0.809)	(0.016,0.090,0.197)
3	(0.789,0.000,0.789)	(0.497,0.112,0.701)	(0.038,0.076,0.171)
4	(0.719,0.070,0.864)	(0.392,0.216,0.806)	(0.019,0.095,0.193)

Table 16: The crisp values O, L, Q and alternatives ranking

	Crisp value of L	Rank in L	Crisp value of O	Rank in O	Crisp value of Q	Rank in Q
Supplier 1	0.121	4	0.262	4	0.139	4
Supplier 2	0.09	2	0.219	3	0.073	3
Supplier 3	0.071	1	0.107	1	0	1
Supplier 4	0.091	3	0.211	2	0.071	2

4. Conclusion

In recent years, company's interest in GSCM operations has expanded, resulting in a vast body of study in the literature. For the purpose of making green operators more effective, it is of the utmost importance to improve the performance of Green Supply Chain Management (GSCM). In order to evaluate the total environmental performance of suppliers, the research resulted in the development of a hybrid fuzzy multi-criteria decision-making technique. Fuzzy VIKOR, fuzzy AHP, and fuzzy DEMATEL are the schemes that are utilized in this method. In order to validate the proposed approach, a case study is conducted, which involves contrasting four distinct alternatives that are capable of satisfying the prerequisites for environmentally responsible supply chain management. The relationships between several criteria and environmental factors are evaluated using MCDM approaches (Sarkis, 1998). These methods help firms achieve a balance between their other objectives and their concerns for the environment. The approaches of MCDM are currently being utilized in order to address a wide variety of decision-making issues that are associated with GSCM applications. These decisions include, among other things, the selection of environmentally friendly suppliers, the adoption of sustainability supply chain management benchmarking methodologies, the evaluation of green performance, the evaluation of green supplier development programs, and the establishment of important GSCM success criteria. First and foremost, the size of the GSCM and the criteria that should be used are decided. The interrelationships between the dimensions are then recovered utilizing fuzzy DEMATEL approach. For the purpose of calculating the criterion weights, which are determined by the significance of each dimension in relation to the other dimensions, the fuzzy AHP approach is utilized. For the last step, alternative suppliers are evaluated based on the GSCM activities they engage in, and organizations are ranked according to the GSCM performance they exhibit through the application of the fuzzy VIKOR method. This approach evaluates suppliers' overall performance in terms of GSCM activities, allowing suppliers or enterprises to compare their own relative performance levels and receive useful input on areas where they may improve in terms of green activities.

The proposed technique can be used to differentiate GSCM criteria and can be used to a wider number of providers especially in mining industry. The methodology can be used to evaluate and rate a wide range of tasks. At some point in the future, additional MCDM strategies, such as fuzzy cognitive map or DEA, might be utilized. It is possible that mathematical programming techniques will be utilized in upcoming research endeavors.

References

1. Arash Khalili Nasr Madjid Tavana Behrouz Alavi Hassan Mina, (2021), A novel fuzzy multi-objective circular supplier selection and order allocation model for sustainable closed-loop supply chains, *Journal of Cleaner Production*, Volume 287, 10 March 2021, 124994
2. Zhihua Chen, Xinguo Ming, Tongtong Zhou, Yuan Chang, (2020), Sustainable supplier selection for smart supply chain considering internal and external uncertainty: An integrated rough-fuzzy approach, *Applied Soft Computing*, Volume 87, February 2020, 106004.
3. R.Krishankumar,Y.Gowtham,Ifjaz Ahmed, K.S.Ravichandran,SamarjitKar, (2020), Solving green supplier selection problem using q-rung orthopair fuzzy-based decision framework with unknown weight information, *Applied Soft Computing*, Volume 94, September 2020, 106431
4. SepehrHendiani, Huchang Liao, Ruxue RenBenjamin Lev, (2020), A likelihood-based multi-criteria sustainable supplier selection approach with complex preference information, *Information Sciences*, Volume 536, October 2020, Pages 135-155

5. Željko Stević, Dragan Pamučar, Adis Puška, Prasenjit Chatterjee, (2020), Sustainable supplier selection in healthcare industries using a new MCDM method: Measurement of alternatives and ranking according to COMpromise solution (MARCOS), *Computers & Industrial Engineering*, Volume, 140, February 2020, 106231
6. Seyed Amin Seyed Haeri, Jafar Rezaei, (2019), A grey-based green supplier selection model for uncertain environments, *Journal of Cleaner Production*, Volume 221, 1 June 2019, Pages 768-784
7. Aijun Liu, Yaxuan Xiao, Hui Lu, Sang-Bing Tsai, Wei Song, (2019), A fuzzy three-stage multi-attribute decision-making approach based on customer needs for sustainable supplier selection, *Journal of Cleaner Production*, Volume 239, 1 December 2019, 118043
8. Mona Najar Vazifehdan, Soroush Avakh Darestani, (2019), Green Logistics Outsourcing Employing Multi-Criteria Decision Making and Quality Function Deployment in the Petrochemical Industry, *The Asian Journal of Shipping and Logistics*, Volume 35, Issue 4, December 2019, Pages 243-254
9. Qun Wu, Ligang Zhou, Yu Chen Huayou, Chen (2019), An integrated approach to green supplier selection based on the interval type-2 fuzzy best-worst and extended VIKOR methods, *Information Sciences*, Volume 502, October 2019, Pages 394-417
10. Shubham Gupta, Umang Soni, Girish Kumar, (2019), Green supplier selection using multi-criterion decision making under fuzzy environment: A case study in automotive industry, *Computers & Industrial Engineering*, Volume 136, October 2019, Pages 663-680
11. Mostafa Zandieh, Babak Aslanib, (2019), A hybrid MCDM approach for order distribution in a multiple-supplier supply chain: A case study, *Journal of Industrial Information Integration*, Volume 16, December 2019, 100-104
12. Mohd Sufiyan, Abid Haleem, Shahbaz Khan, Mohd Imran Khan (2019), Evaluating food supply chain performance using hybrid fuzzy MCDM technique, *Sustainable Production, and Consumption*, Volume 20, October 2019, Pages 40-57
13. Rukiye Kaya, Barbaros Yet, (2019), Building Bayesian networks based on DEMATEL for multiple criteria decision problems: A supplier selection case study, *Expert Systems with Applications*, Volume 134, 15 November 2019, Pages 234-248
14. Ireneusz Miciuła, Joanna Nowakowska Grunt, (2019), Using the AHP method to select an energy supplier for household in Poland, *Procedia Computer Science*, Volume 159, 2019, Pages 2324-2334
15. Mohammed Ahmed & Harris, Irina & Govindan, Kannan, 2019. A hybrid MCDM-FMOO approach for sustainable supplier selection and order allocation, *International Journal of Production Economics*, Elsevier, vol. 217(C), pages 171-184.
16. M. Abdel-Baseta, Victor Changb, Abdullhah Gamala, Florentin Smarandachec, (2019), An integrated neutrosophic ANP and VIKOR method for achieving sustainable supplier selection: A case study in importing field, *Computers in Industry*, 106 (2019) 94–110
17. Fuli Zhou, Xu Wang, Ming K. Lim, Yandong He, Longxiao Li, (2018), Sustainable recycling partner selection using fuzzy DEMATEL-AEW-FVIKOR: A case study in small-and-medium enterprises (SMEs), *Journal of Cleaner Production*, Volume 196, 20 September 2018, Pages 489-504
18. Armin Cheraghalipour, Saba Farsad, (2018), A bi-objective sustainable supplier selection and order allocation considering quantity discounts under disruption risks: A case study in plastic industry, *Computers & Industrial Engineering*, Volume 118, April 2018, Pages 237-250
19. Amir Arabsheybani, Mohammad Mahdi Paydar, Abdul Sattar Safaei, (2018), An integrated fuzzy MOORA method and FMEA technique for sustainable supplier selection considering quantity discounts and supplier's risk, *Journal of Cleaner Production*, Volume 190, 20 July 2018, Pages 577-591
20. Atefeh Amindoust, (2018), A resilient-sustainable based supplier selection model using a hybrid intelligent method, *Computers & Industrial Engineering*, Volume 126, 2018, pp. 122-135
21. Gülçin Büyüközkan Yağmur Karabulut, Jbid Arsenyan, (2017), RFID service provider selection: An integrated fuzzy MCDM approach, *Measurement*, Volume 112, December 2017, Pages 88-98
22. Sadeque Hamdan Ali Cheaitou, (2017), Supplier selection and order allocation with green criteria: An MCDM and multi-objective optimization approach, *Computers & Operations Research* Volume 81, May 2017, Pages 282-304
23. Fikri Dweiri, Sameer Kumar, Sharfuddin Ahmed Khan, Vipul Jain (2016), Corrigendum to “Designing an integrated AHP based decision support system for supplier selection in automotive industry” *Expert Systems with Applications* 62 (2016) 273–283, *Expert Systems with Applications*, Volume 72, 15 April 2017, Pages 467-468
24. Yu, Q., Hou, F. (2016). An approach for green supplier selection in the automobile manufacturing industry, *Kybernetes*, 45(4), 571–588. doi:10.1108/K-01-2015-0034
25. Samet Güner, Halil Ibrahim Cebeci, (2016), Multi-Criteria Decision Making Techniques for Green Supply Chain Management: A Literature Review, *Ethics and Sustainability Global Supply Chain Management*, IGI Global book series Advances in Logistics, Operations, and Management Science, (ALOMS) (ISSN: 2327-350X; eISSN: 2327- 3518)
26. Chung, C. C., Chao, L. C., & Lou, S. J. (2016). The Establishment of a Green Supplier Selection and Guidance Mechanism with the ANP and IPA. *Sustainability*, 8(3), 259. doi:10.3390/su8030259
27. Wu, C., & Barnes, D. (2016). An integrated model for green partner selection and supply chain construction. , *Journal of Cleaner Production*, 112, 2114–2132.
28. M Yazdani, S Hashemkhani Zolfani, EK Zavadskas, (2016), New integration of MCDM methods and QFD in the selection of green suppliers, *Journal of Business Economics and Management*, 2016, Volume 17, Pages 1097-1113

29. Uygun, Ö, & Dede, A. (2016). Performance evaluation of green supply chain management using integrated fuzzy multi-criteria decision-making techniques. *Computers & Industrial Engineering*. doi:10.1016/j.cie.2016.02.020
30. Awasthi, A., & Kannan, G. (2016). Green supplier development program selection using NGT and VIKOR under fuzzy environment. *Computers & Industrial Engineering*, 91, 100–108.
31. Hu, Z., Rao, C., Zheng, Y., & Huang, D. (2015). Optimization decision of supplier selection in green procurement under the mode of low carbon economy. *International Journal of Computational Intelligence Systems*, 8(3), 407–421. doi:10.1080/18756891.2015.1017375
32. Li, M., & Wu, C. (2015). Green supplier selection based on improved intuitionistic fuzzy TOPSIS model. *Metallurgical & Mining Industry*, 6, 193–205.
33. Guo, J. J., & Tsai, S. B. (2015). Discussing and evaluating green supply chain suppliers: A case study of the printed circuit board industry in China. *South African Journal of Industrial Engineering*, 26(2), 56–67. doi:10.7166/26-2-956
34. Akman, G. (2015). Evaluating suppliers to include green supplier development programs via fuzzy c-means and VIKOR methods. *Computers & Industrial Engineering*, 86, 69–82. doi:10.1016/j.cie.2014.10.013
35. Tsui, C. W., Tzeng, G. H., & Wen, U. P. (2015). A hybrid MCDM approach for improving the performance of green suppliers in the TFT-LCD industry. *International Journal of Production Research*, 53(21), 6436–6454. doi:10.1080/00207543.2014.935829
36. Mavi, R. K. (2015). Green supplier selection: A fuzzy AHP and fuzzy ARAS approach. *International Journal of Services and Operations Management*, 22(2), 165–188. doi:10.1504/IJSOM.2015.071528
37. Yazdani, M. (2014). An integrated MCDM approach to green supplier selection. *International Journal of Industrial Engineering Computations*, 5(3), 443–458. doi:10.5267/j.ijiec.2014.3.003
38. Dou, Y., Zhu, Q., & Sarkis, J. (2014). Evaluating green supplier development programs with a grey analytical network process-based methodology. *European Journal of Operational Research*, 233(2), 420–431. doi:10.1016/j.ejor.2013.03.004
39. Hsu, C. W., Kuo, R. J., & Chiou, C. Y. (2014). A multi-criteria decision-making approach for evaluating carbon performance of suppliers in the electronics industry. *International Journal of Environmental Science and Technology*, 11(3), 775–784. doi:10.1007/s13762-013-0265-5
40. Kannan, D., de Sousa Jabbour, A. B. L., & Jabbour, C. J. C. (2014). Selecting green suppliers based on GSCM practices: Using fuzzy TOPSIS applied to a Brazilian electronics company. *European Journal of Operational Research*, 233(2), 432–447. doi:10.1016/j.ejor.2013.07.023
41. Falatoonitoosi, E., Ahmed, S., & Sorooshian, S. (2014, March). A multi-criteria framework to evaluate supplier's greenness. In *Abstract and Applied Analysis* (Vol. 2014). Hindawi Publishing Corporation. doi:10.1155/2014/396923
42. Hsu, C. W., Kuo, T. C., Chen, S. H., & Hu, A. H. (2013). Using DEMATEL to develop a carbon management model of supplier selection in green supply chain management. *Journal of Cleaner Production*, 56, 164–172. doi:10.1016/j.jclepro.2011.09.012
43. Shen, L., Olfat, L., Govindan, K., Khodaverdi, R., & Diabat, A. (2013). A fuzzy multi-criteria approach for evaluating green supplier's performance in green supply chain with linguistic preferences. *Resources, Conservation and Recycling*, 74, 170–179. doi:10.1016/j.resconrec.2012.09.006
44. Mavi, R. K., Kazemi, S., Najafabadi, A. F., & Mousaabadi, H. B. (2013). Identification and assessment of logistical factors to evaluate a green supplier using the fuzzy logic DEMATEL method. *Polish Journal of Environmental Studies*, 22(2), 445–455.
45. Peng, J. (2012). Research on the optimization of green suppliers based on AHP and GRA. *Journal of Information and Computational Science*, 9(1), 173–182.
46. Tsui, C. W., & Wen, U. P. (2012). Developing the Green Supplier Selection Procedure Based on Analytical Hierarchy Process and Outranking Methods. In *International Conference on Industrial Engineering and Operations Management*, (pp. 3-6).
47. Büyüközkan, G., & Çifçi, G. (2012a). A novel hybrid MCDM approach based on fuzzy DEMATEL, fuzzy ANP, and fuzzy TOPSIS to evaluate green suppliers. *Expert Systems with Applications*, 39(3), 3000–3011. doi:10.1016/j.eswa.2011.08.162
48. Zhou, R., Ma, X., Li, S., & Li, J. (2012). The green supplier selection method for chemical industry with analytic network process and radial basis function neural network. *Advances in Information Sciences & Service Sciences*, 4(4), 147–158. doi:10.4156/aiss.vol4.issue4.18
49. Datta, S., Samantra, C., Mahapatra, S. S., Banerjee, S., & Bandyopadhyay, A. (2012). Green supplier evaluation and selection using VIKOR method embedded in fuzzy expert system with interval-valued fuzzy numbers. *International Journal of Procurement Management*, 5(5), 647–678. doi:10.1504/IJPM.2012.048880
50. Lee, A. H., Kang, H. Y., Hsu, C. F., & Hung, H. C. (2009). A green supplier selection model for the high-tech industry. *Expert Systems with Applications*, 36(4), 7917–7927. doi:10.1016/j.eswa.2008.11.052
51. Hsu, C. W., & Hu, A. H. (2009). Applying hazardous substance management to supplier selection using analytic network process. *Journal of Cleaner Production*, 17(2), 255–264. doi:10.1016/j.jclepro.2008.05.004
52. Chen, Y., Larbani, M., & Chang, Y. (2009). Multi-objective data envelopment analysis. *Journal of the Operational Research Society*, 60(11): 1556-1566
53. Tuzkaya, G., Ozgen, A., Ozgen, D., & Tuzkaya, U. R. (2009). Environmental performance evaluation of suppliers: A hybrid fuzzy multi-criteria decision approach. *International*