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Research Article

An Integrated Fuzzy DEMATEL and Intuitionistic Fuzzy TOPSIS Method to Evaluate Sustainable Suppliers

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ABSTRACT

Sustainability has gained more attention in an attempt to avoid unwanted results in the business environment, since its main objective is to minimize the negative impact on the economy, society, and the environment. Supplier relationship is one of the critical concepts in a sustainable supply chain management. Companies ought to measure their candidate supplier's performance in terms of sustainability. This study aims to suggest an efficient alternative integrated Multi-Criteria-Decision-Making (MCDM) method in order to select a sustainable supplier. In this method, an integrated Fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) method and Intuitionistic Fuzzy Technique for Order Preference by Similarity to Ideal Solution (IF-TOPSIS) method is proposed to evaluate sustainable supplier performance. A case study is conducted in a Turkish chemical company operating in the FMCG industry.

Keywords: Sustainable Supplier Performance, Supply Chain Management, Multi Criteria Decision Making, Fuzzy DEMATEL, Intuitionistic Fuzzy Sets, TOPSIS.

1. Introduction

Supply chain management (SCM) has gained more importance in the business environment with the increasing competition and globalization. In this context, the aim of SCM is to organize all activities from the source of raw materials to final customers to reduce the total supply chain cost and improve customer satisfaction. Research findings have proved that SCM performance positively affects a company's competitiveness in the market (Chang et al., 2011: 1850).

The supply chain is a complex system, which contains a number of independent companies with conflicted goals. Therefore, it is a complicated management process to organize all activities that are conducted to accomplish the overall supply chain success. A long-term, sustainable relationship among supply chain members is one of the important factors that help to overcome these difficulties. Supplier relationship management (SRM) gains more importance in SCM as the business world contains increasing unpredictability. Recently, SRM has become one of the key issues in SCM. Companies can be able to rapidly respond to changes in the market and meet evolving customer requirements by establishing long-term partnerships with their suppliers.

A successful SRM must consider several aspects such as supplier selection, performance evaluation, and development. Supplier evaluation is one of the most important success factors in a supply chain since it helps to decrease material costs and gain competitive advantage (Chang et al., 2011:1850). Therefore, suitable and accurate supplier selection is a critical decision-making process in SRM. Many criteria are taken into account for selecting and evaluating the performance of suppliers. A successful supplier selection process highly depends on the determination of the right key performance indicators. Using company strategic goal focused supplier evaluation criteria improves the effectiveness of the supplier selection process.

Traditionally, the main focus of organizations is to manage internal operations to increase profits. Related to this view, managers have mostly focused on cost, quality, on time delivery and efficiency when evaluating supplier performance. However, using only these classical key performance indicators has become insufficient for competitive advantage in today's market conditions. Today, globalization and increased production volumes have brought some environmental and ethical problems. This situation is forcing companies to undertake some preventive actions. As a result, sustainability has gained a lot of attention in the business world. Sustainability results from the idea of leaving a better world for future generations and in this context, balancing social, environmental, and economic needs when conducting a business. Figure 1 shows factors that trigger sustainable supply chain practices. Sustainable supply chain management (SSCM) differs from classical SCM by focusing on environmental and social issues in addition to economic aspects. In other words, the aim of the SSCM is to minimize the environmental and social problems while at the same time maximizing the supply chain profitability (Hassini et al., 2012: 70). Foerstl et al. (2010) stated that irresponsible supplier behavior could directly affect buyer companies in terms of costly legal obligations, reputational damage, and adverse publicity. Furthermore, 20% of the companies have considered sustainability issues as their largest supply chain risk, and 25% of the companies have required suppliers to conform to social and ecological standards in order to minimize supply chain risks. Sustainable supplier evaluation, whereby environmental and social factors are considered in addition to the traditional factors, has become popular in today's business environment.

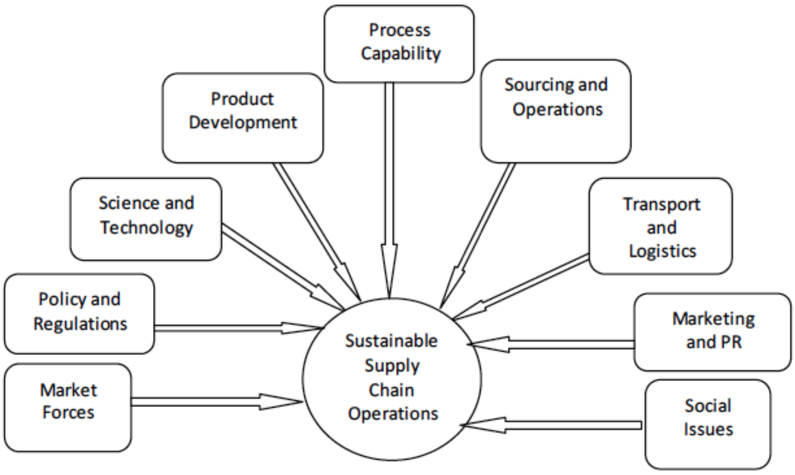

Figure 1. Factors that trigger sustainable supply chain practices

Defining the most suitable key performance indicators in a supplier evaluation process is a decision-making process in which more than one criterion is considered. Therefore, multi-criteria decision-making methods are well-suited, since they provide an opportunity to evaluate many criteria simultaneously. Although MCDM are used extensively in sustainable supplier selection (SSS) literature, the studies which consider integrated MCDM, are still rare in the corresponding literature (Büyükozkan and Karabulut, 2018). Additionally to this, none of them examine a sustainable supplier evaluation process based on the TBL approach in a chemical company using an integrated fuzzy DEMATEL and IF-TOPSIS method. However, environmental protection has high strategic importance in the chemical industry due to high costs, and in addition to this, risky healthcare issues and high profitability of the industry makes social aspects critical. For this reason, this study aimed to analyse the sustainable supplier selection process in a chemical company, and a case study is conducted in a Turkish chemical company, which has a complex supply chain network. In the two-phased integrated method, the fuzzy DEMATEL method is used to determine the causal relationship among the company's sustainable supplier selection criteria. Additionally, the IF-TOPSIS method is applied to evaluate the candidate suppliers. IF-TOPSIS method is a successful method that is easy to implement and requires less complicated calculations compared to some other MCDM. Additionally, it is capable of dealing with vagueness and uncertainty when uncertain and imprecise decision information exist. For this reason, IF-TOPSIS is selected to deal with SSS problem proposed in this study. According to the latest literature review proposed by Schramm et al. 2020, the fuzzy DEMATEL and IF-TOPSIS method has never been used as an integrated manner before to solve SSS problem. The contribution of this study is to provide an effective and practical method to solve the SSS problem. Hence, the proposed integrated method suggests to apply a combination of effective MCDM methods, fuzzy DEMATEL and IF-TOPSIS, to solve SSS problem.

The remainder of this paper is organized as follows. Section 2 presents a literature review about SSS problem. In section 3, criteria to evaluate sustainable supplier selection are explained. Section 4 contains the integrated solution methodology used to evaluate sustainable supplier, and Section 5 illustrates a real-life case study, in which a Turkish chemical company’s sustainable supplier selection process is analysed. Finally, conclusion and future research are provided in Section 6.

2. Review of Literature

Supplier selection problem is one the important decision process in a supply chain management. Since the performance of suppliers has a great effect on the overall supply chain success, firms consider this process as one of the strategic supply chain management decisions. Supplier selection problem has been considered in many studies since the 1960s. Researchers who want to broaden their knowledge about the classic supplier selection problem can examine the systematic literature review studies conducted by Ho et al. (2009) and Chai et al. (2013). With the spread of globalization in trade, the supply chains have expanded and started to include many companies around the world. Global supply chain management has brought many advantages to firms, but it has also made it quite difficult to control this complex structure. As a result, environmental problems in the supply chain management began to emerge. In order to overcome this problem, one of the subjects that attracted the attention of researchers in the literature is the green supplier selection. Green supplier selection focuses on environmental issues and suggests that firms should consider environmental criteria in addition to cost criteria when evaluating supplier performance. The green supply chain problem has been researched many times in the literature. Those who wish to explore studies conducted in this area can benefit from the recent literature review by Govindan et al. (2015).

As this study focuses on the issue of SSS, the relevant literature is examined in more detail in this section.

Recently, SSCM with the Triple Bottom Line (TBL) approach, in which social, environmental, and economic initiatives are considered to evaluate supplier performance, has been popular in literature. Many researchers considered the TBL of sustainability, environmental, social, and economic criteria in their research (Seuring and Müller 2008, Seuring and Müller 2008, Seuring et al. 2008, Govindan et al. 2013, Seuring 2013, Seuring and Gold 2013, Sarkis and Dhavale 2015, Gören 2018, Luthra et al. 2017, Memari et al. 2019).

Bai and Sarkis (2010) used the grey system and rough theory to integrate sustainability into the supplier selection process. Büyüközkan and Ciftci (2011) used the fuzzy ANP method to solve a sustainable supplier selection problem in a Turkish white good company. Amindoust et al. (2012) combined the clustering approach and the MCDM methods to solve a sustainable supplier selection problem. Shaw et al. (2012) considered cost, quality rejection percentage, late delivery percentage, greenhouse gas emission and demand criteria to evaluate candidate suppliers. They performed the fuzzy AHP method to analyse the weight of the related criteria. In this study, a fuzzy multi-objective linear programming is applied for supplier selection and quota allocation. Govindan et al. (2013) used linguistic terms to evaluate supplier performance and then they developed the fuzzy TOPSIS method to rank suppliers.

Kannan (2013) combined the fuzzy multi attribute utility theory and multi-objective programming to select the best green supplier that proves economic and environmental criteria, and allocate the optimum order quantities among suppliers. Hsu et al. (2013) developed the DEMATEL method to investigate the interrelationships among carbon management criteria in green supply chain management (GSM). Bai and Sarkis (2014) considered the complexity of the sustainable supply chain performance measurement process. They applied a two-stage method using the neighbourhood rough set theory to determine the key performance indicators for sustainable supplier performance evaluation, and DEA (data envelopment analysis) is conducted to benchmark and measure the performance of suppliers by using the corresponding KPI. The sensitivity of the KPI set formation and performance results are showed by applying an additional analysis. Chaharsooghi and Ashrafi (2014) examined SSCM and presented a new model for sustainable supplier selection problem in their study. Azadnia et al. (2015) studied sustainable supplier selection and order allocation problem, and they presented an integrated approach of rule-based weighted fuzzy method, fuzzy AHP, and multi-objective mathematical programming to these problems. The Neofuzzy TOPSIS is used to choose the best supplier that meets the sustainability requirements. Fallahpour et al. (2017) studied a decision support model for SSS in SSCM by using the fuzzy TOPSIS method.

Taticchi et al. (2013) performed a literature review to analyze the potential for the development of the SSS research area. Brandenburg et al. (2014) presented a literature review in which 134 papers on the SSS literature analyzed. Öztürk and Özçelik (2014) used fuzzy TOPSIS method to solve the SSS problem. Zimmer et al. (2016) studied a literature review to investigate models that deal with the SSS problem. Their study covers 143 articles published from 1997 to 2014. Their study shows that AHP, ANP, and fuzzy-based approaches are the most popular methods that are used in SSS literature. Schramm et al. (2020) presented a literature review in which considered MCDM/A approaches for supporting sustainable supplier selection. They analyzed 82 reviewed papers published over the last three decades. Their study showed that %55 reviewed approaches are based on the integration of the methods. They also claimed that AHP and TOPSIS methods are the most popular methods in both cases. Su et al. (2016) integrated the grey theory and DEMATEL to overcome the disadvantages caused by the incomplete information in the SSCM problem. Their application results show that recycle/reuse/reduce criterion is significantly important to determine suitable sustainable supplier Luthra et al. (2017) introduced an integrated multi-criteria method, which is composed of AHP and VIKOR methods, to solve the SSS problem. They applied their method to examine an Indian Automobile company's SSS process. According to their application results environmental costs, quality, price, health and safety, and environmental competencies have the highest importance among 22 SSS criteria. Liu et al. (2018) developed an integrated model using ANP and VIKOR methods to solve SSS problem. In order to solve uncertainty and imprecision problems, they applied their method in an interval type-2 fuzzy environment. Khan et al. (2018) used fuzzy Shannon Entropy and fuzzy-Inference system to solve the SSS problem. Their real-life application results show that 'quality', cleaner technology' and 'information disclosure' criteria may have a significant effect on the supplier's sustainability qualification. Azimifard et al. (2018) examined the SSS problem with using AHP and TOPSIS methods. In their real-life application, they solved a sustainable supplier selection problem in the Iranian steel industry using four main criteria. Jauhar and Pant (2017) proposed an integrated model in which, DEA combined with DE and MORE to examine the SSS problem. They suggested that the proposed model improves the efficiency of DEA and generates more realistic solutions. Ahmadi et al. (2017) focused on the social sustainability criteria to investigate this dimension's effect on the supply chain. In this study, a novel MCDM called as the 'best worst method' (BMW) has been used as a solution method. Their application results indicate that 'contractual stakeholders influence' criterion is one of the most important social sustainability criteria. Memari et al. (2019) extended fuzzy TOPSIS model with using an intuitionistic fuzzy set to solve SSS problem. They indicated that their model is successful in solving the imprecise SSS problem since the intuitionistic fuzzy numbers are powerful to handle uncertainty. They considered thirty sub-criteria and nine main criteria to evaluate the sustainability of suppliers of an automotive spare parts manufacturer. Jain and Singh (2020) developed a two-phase model for SSS problem. Firstly, they applied fuzzy Kano Model in order to determine must-be criteria for sustainable suppliers. And then, they implemented three distinct fuzzy inference system to solve SSS problem. To test the performance of the proposed method, they conducted a case study application in the iron and steel industry of India. Chen et al. (2020) proposed a novel rough-fuzzy DEMATEL-TOPSIS method to solve SSS problem for a smart supply chain.

3. Criteria to Select Sustainable Supplier

In the past decades, traditional supplier selection criteria, which contain economic aspects, were used in the literature. However, the environmental and ethical issues that came with the process of globalization forced companies to consider additional aspects. Therefore, environmental and social aspects have gained importance in the supplier selection process. Several criteria have been used in the literature to select sustainable supplier. A framework for competency in sustainable supplier selection is constructed. Consequently, the criteria that belong to the three main dimensions of sustainability are considered as shown in Table 1 These criteria have been developed based on a literature research and experts' decisions derived in Section 5.

a. Economic Dimension

1. Quality: Conformance to customer requirements and material specifications, rejection rate and the time between receiving and acceptance of the order. The quality level of a supplier is determined by a high level of conformance to customer requirements and material specifications and a low level of rejection rate and short time spend for quality control.

2. Delivery: On time delivery performance, short lead times. Delivery performance is evaluated by delivering the right amount of material at the right time and at the right place in the right condition. This attribute is considered as advantage because it has a positive effect on customer satisfaction.

3. Service: The level of service, which is given after materials are delivered by the supplier. The service level of a supplier can be defined by the response time to complaints, spare parts availability, and maintenance service. This is a positive attribute since it increases customer satisfaction.

4. Cost/ Price: This criterion is composed of the price of the materials, transportation costs, inventory costs, custom and insurance costs, and the rest of the service prices provided by the supplier.

5. Flexibility: Ability of meeting last minute operational changes, flexibility in payment, flexibility in delivery time. This should be considered as a positive attribute since it affects customer level in a positive direction.

b. Environmental Dimension

1. Resource consumption: Consumption of raw materials, energy, and water during the production process. This factor should be considered as an advantage.

2. Pollution control: Air emissions, wastewater, solid wastes, and use of harmful materials are related to pollution control performance. Decreasing the quantity of air emission, waste water, solid wastes, and use of harmful materials increases the pollution control performance level of the supplier.

3. Environmental management system: Being environmentally certified, such as meeting the ISO14001 standard. Environmental management system practices improve the suppliers' responsibility for environmental aspects in their operations.

4. Green product: Application of green standards and competency to meet environmental regulations in the production process of a product or service such as recycling, remanufacturing, and reverse logistics.

5. Environmental management competencies: Capability of realizing environmental management competencies. This criterion refers to the ability of the supplier to develop environmental management awareness among all the individuals in the supply chain and the supplier's green image.

c. Social Dimension

1. Stakeholders' rights: Meeting stakeholders' requirements and expectations such as working hours, overtime hour and payment, insurance, shareholder payout ratio, and other. Some examples of stakeholders are employees, shareholders, customers, suppliers, financial creditors, and governments.

2. Health and Safety: Health and safety training at work, providing accurate workplace conditions and equipment to prevent workplace accidents and increase workplace safety.

3. Respect for the policy: This attribute indicates the supplier's commitment to comply with local regulations and policies.

Economic	
C1: Quality	(Lee et al. 2009, Kuo et al. 2010, Zhu et al. 2010, Buyukozkan and Cifci 2011, Mafakheri et al. 2011, Punniyamoorthy et al. 2011, Yeh and Chuang 2011, Tseng and Chiu 2013, Orji and Wei 2014, Öztürk and Özçelik 2014, Jiang et al. 2016, Fallahpour et al. 2017)
C2: Delivery	(Kuo et al. 2010, Zhu et al. 2010, Mafakheri et al. 2011, Yeh and Chuang 2011, Tseng and Chiu 2013, Orji and Wei 2014, Öztürk and Özçelik 2014, Grover et al. 2016, Jiang et al. 2016, Fallahpour et al. 2017)
C3: Service	(Kuo et al. 2010, Chang et al. 2011, Punniyamoorthy et al. 2011, Tseng and Chiu 2013, Orji and Wei 2014, Jiang et al. 2016, Fallahpour et al. 2017)
C4: Cost/ Price	(Awasthi et al. 2010, Keskin et al. 2010, Kuo et al. 2010, Zhu et al. 2010, Chang et al. 2011, Mafakheri et al. 2011, Punniyamoorthy et al. 2011, Yeh and Chuang 2011, Tseng and Chiu 2013, Orji and Wei 2014, Öztürk and Özçelik 2014, Grover et al. 2016, Jiang et al. 2016, Fallahpour et al. 2017, Chen et al. 2020)
C5: Flexibility	(Zhu et al. 2010, Tseng and Chiu 2013, Jiang et al. 2016, Fallahpour et al. 2017, Chen et al. 2020)
Environmental	
E1:Resource consumption	(Zhu et al. 2010, Bai and Sarkis 2014, Öztürk and Özçelik 2014, Jiang et al. 2016)
E2:Pollution control	(Lee et al. 2009, Awasthi et al. 2010, Keskin et al. 2010, Zhu et al. 2010, Bai and Sarkis 2014, Orji and Wei 2014, Öztürk and Özçelik 2014, Grover et al. 2016, Jiang et al. 2016)
E3:Environmental management system	(Humphreys et al. 2003, Hsu and Hu 2009, Lee et al. 2009, Awasthi et al. 2010, Kuo et al. 2010, Zhu et al. 2010, Mafakheri et al. 2011, Yeh and Chuang 2011, Tseng and Chiu 2013, Bai and Sarkis 2014, Orji and Wei 2014, Öztürk and Özçelik 2014, Grover et al. 2016, Jiang et al. 2016, Fallahpour et al. 2017)
E4: Green product	(Lee et al. 2009, Zhu et al. 2010, Tseng and Chiu 2013, Orji and Wei 2014, Öztürk and Özçelik 2014, Grover et al. 2016, Jiang et al. 2016, Fallahpour et al. 2017, Chen et al. 2020)
E5:Environmental management competencies	(Humphreys et al. 2003, Hsu and Hu 2009, Lee et al. 2009, Buyukozkan and Cifci 2011, Mafakheri et al. 2011, Punniyamoorthy et al. 2011, Jiang et al. 2016)
Social	
S1: Stakeholders' rights	(Kuo et al. 2010, Orji and Wei 2014, Jiang et al. 2016)
S2: Health and safety	(Keskin et al. 2010, Kuo et al. 2010, Orji and Wei 2014, Öztürk and Özçelik 2014, Grover et al. 2016, Jiang et al. 2016, Fallahpour et al. 2017)
S3: Respect for the policy	(Kuo et al. 2010, Orji and Wei 2014, Jiang et al. 2016)

Table 1. Sustainable Supplier Selection Criteria

4. Solution Methodology

In this study, a two-phased integrated multi criteria decision making (MCDM) method is suggested to solve sustainable supplier performance evaluation problem.

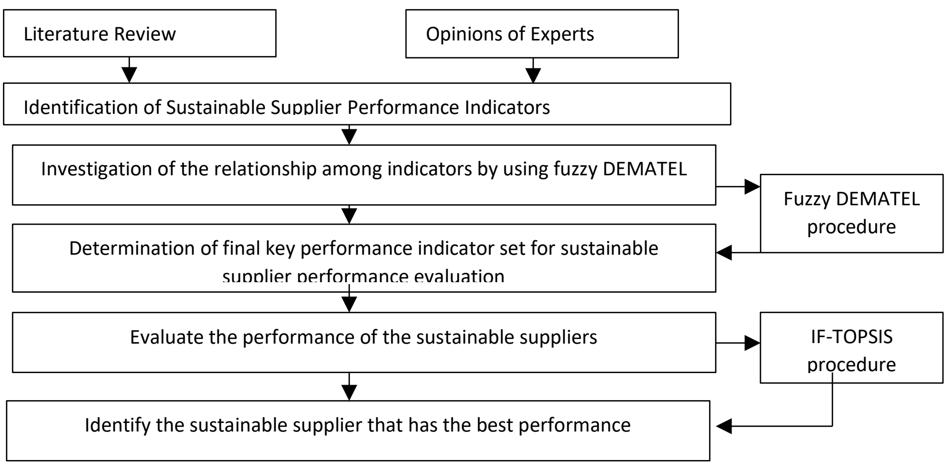

Figure 2. Steps of the proposed integrated method

In the first phase, the fuzzy DEMATEL method is applied to evaluate the importance level of sustainable supplier selection indicators and investigate the casual relationships among them. In the second phase, the IF-TOPSIS method is applied to rank the sustainable suppliers based on their performance levels. The steps of the proposed method are presented in Figure 2.

4.1. Fuzzy DEMATEL Method

It is possible to classify the MCDM into two groups: multi-attribute decision making (MADM) and multi-objective decision-making (MODM). The DEMATEL method is one of the MADM methods, which was developed by Gabus and Fontela in 1973 (Gabus and Fontela, 1973). It is one of the well-known MCDM methods in which experts′ attitudes are used to overcome complex problems. Relationship matrices and diagrams are used in this method to visualize the structure of complicated casual relationships. Owing to its ability to visualize complicated causal relationships, it is a very useful and popular method in the literature.

Decision makers can be able to determine the most important criteria that affect other criteria by using the impact-relation map (IRM) of the criteria presented in the solution of the DEMATEL method. The DEMATEL method evaluates problem related criteria to find out the most important one that has the greatest effect on the strategic solution. Therefore, managers can focus on the reduced number of criteria in order to make a strategic decision for their company (Chang et al. 2011: 1852; Lin, 2013: 33). In the literature, the DEMATEL method has been combined with other multi-criteria methods such as TOPSIS, ANP, and VIKOR. A hybrid combination of this method has been applied to solve various types of complex problems such as supplier selection location selection, machine selection, airline security evaluation, e-learning assessment, and hospital service quality (Chang et al. (2011); Dalalah et al. (2011); Lee et al. (2011); Büyüközkan and Cifci (2012); Gharakhani (2012); Lin (2013);Govindan et al. (2015); Tsai et al. (2015); Jiang et al. (2016))

It has been well-known that many real-world applications contain intangible criteria, and for this reason, the classical numerical scale is not suitable to describe and evaluate them properly. In order to handle the uncertainty and the vagueness of the decision process, the fuzzy DEMATEL method is used in the literature. Since supplier selection criteria are composed of quantitative and qualitative criteria, it is more effective to evaluate these criteria by the linguistic scale. Therefore, the fuzzy DEMATEL method is used in this study.

The fuzzy DEMATEL consists of eight steps, which are presented below (Chang et al., 2011: 1853-1854; Lin, 2013: 35-36, Tsai et al., 2015: 9-11).

Step 1: Determination of problem related criteria and fuzzy scale. The industry specific criteria have been determined in collaboration with company experts and academicians. The eight decision makers (DMs)(two academicians and six managers from the case company's Purchasing, Production, R&D, and Supply Chain departments) are invited to evaluate the interrelationship among the criteria by using the fuzzy linguistic scale suggested by Li (1999) are used to express interrelations. The linguistic scale is shown in Table 2.

Linguistic terms	Influence score	Triangular fuzzy numbers
No influence (No)	0	(0,0,0.25)
Low influence (L)	1	(0,0.25,0.50)
Medium influence (M)	2	(0.25,0.50,0.75)
High influence (H)	3	(0.50, 0.75,1.00)
Very high influence (VH)	4	(0.75,1.00, 1.00)

Table 2. The Fuzzy Linguistic Scale

In the literature, triangular fuzzy numbers (TFNs) are generally used for the sake of simplicity. There have been many TFNs developed in the literature. One of the appropriate TFNs that have been used to convert the preferences scale of the crisp DEMATEL is considered in this study.

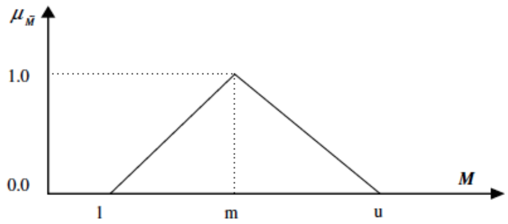

Figure 3. Triangular fuzzy number, $\widetilde{M}$

A fuzzy number $\widetilde{M}$ is a convex normalized fuzzy set $\widetilde{M}$ of the real line R as follows (Zimmermann 1996):

It exists such that one $x_0 \in R$ with $\mu_{\widetilde{M}}(x_0) = 1$

Where, x_0 is called mean value of $\widetilde{M}$ and $\mu_{\widetilde{M}}(x)$ is piecewise continuous.

In this study, three operations on triangular fuzzy number are conducted. These operations are illustrated as follows: If $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ are supposed as two triangular fuzzy numbers then:

$$M_1 \oplus M_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \tag{1}$$

$$M_1 \ominus M_2 = (l_1 - l_2, m_1 - m_2, u_1 - u_2) \tag{2}$$

$$M_1 \otimes M_2 = (l_1 * l_2, m_1 * m_2, u_1 * u_2) \tag{3}$$

$$M_1{}^{-1} = (l_1, m_1, u_1)^{-1} \approx (\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}) \tag{4}$$

Step 2: Generate the average matrix, which is also referred to as initial fuzzy direct relation matrix. In this step, each expert is required to evaluate the degree to which he or she believes the factor *i* affects the factor *j* in order to determine influential interrelations among the criteria set$\{C_1, C_2, \ldots C_n\}$. K indicates the total number of experts. An initial direct relation matrix $\tilde{A}$ is a n x n matrix derived by pair-wise comparisons, which can be calculated by using Eq. (5). $\widetilde{a_{ij}}$ is denoted as the degree to which the criterion i affects the criterion j, i.e, $\tilde{A}$ =$[\widetilde{a_{ij}}]_{nxn}$.

$$\widetilde{a_{ij}} = \frac{1}{K}\sum_{k=1}^{K} \widetilde{x_{ij}^k} \tag{5}$$

Step 3: Normalization of the fuzzy direct relation matrix. The normalized direct relation matrix $\tilde{X}$ $\left(\tilde{X} = [\widetilde{x_{ij}}]_{nxn}\right)$, can be derived by normalizing the average matrix ***A*** by using Eq. (6) and Eq. (7)

$$\tilde{X} = \lambda \, x \, \tilde{\boldsymbol{A}} \tag{6}$$

$$\lambda = min\left[\frac{1}{max_i \sum_{j=1}^{n}|a_{ij}|}, \frac{1}{max_j \sum_{i=1}^{n}|a_{ij}|}\right] \tag{7}$$

Step 4: Calculate the fuzzy total relation matrix $\tilde{\boldsymbol{T}}$. The fuzzy total relation matrix $\tilde{\boldsymbol{T}}$ can be calculated by summing direct effects and all of the indirect effects using Eq. (8), where I is denoted as the identity matrix.

$$\tilde{T} = \tilde{X}\,(I - \tilde{X})^{-1} \tag{8}$$

Step 5: Determination of causal relationships. The sum of rows and the sum of columns are separately denoted as $\tilde{D}$ and $\tilde{R}$ within the fuzzy total influence matrix $\tilde{\boldsymbol{T}}$. The $\tilde{D}$ and $\tilde{R}$ values indicate both the direct and the indirect influences between the criteria. The $\tilde{D}$ and $\tilde{R}$ values are computed by using Eq. (9), (10).

$$\widetilde{D_\iota} = \sum_{i=1}^{n} \widetilde{T_{\iota J}} \qquad (i = 1,2, \ldots\ldots, n) \tag{9}$$

$$\widetilde{R_\iota} = \sum_{j=1}^{n} \widetilde{T_{\iota J}} \qquad (j = 1,2, \ldots\ldots, n) \tag{10}$$

Step 6: Defuzzify the fuzzy linguistic values and obtain explicit values. Explicit values of the $(\widetilde{D_\iota^{Def}} + \widetilde{R_\iota^{Def}})$ and $(\widetilde{D_\iota^{Def}} - \widetilde{R_\iota^{Def}})$ are computed using Eq. (11) and (12).

$$\widetilde{D_\iota^{Def}} + \widetilde{R_\iota^{Def}} = \frac{1}{4}(l + 2n + u) \tag{11}$$

$$\widetilde{D_\iota^{Def}} - \widetilde{R_\iota^{Def}} = \frac{1}{4}(l + 2n + u) \tag{12}$$

Step 7: Compute the prominence $(\widetilde{D_\iota^{Def}} + \widetilde{R_\iota^{Def}})$ and relation $(\widetilde{D_\iota^{Def}} - \widetilde{R_\iota^{Def}})$ values. The prominence and relation values represent the influence level and the casual relation between the criteria. The prominence and relation values in four different conditions can be interpreted as below.

Criteria with positive $(\widetilde{D_\iota^{Def}} - \widetilde{R_\iota^{Def}})$ and high $(\widetilde{D_\iota^{Def}} + \widetilde{R_\iota^{Def}})$ values: These criteria are classified as cause criteria, and have a strong effect on the other criteria. Therefore, these criteria are the driving factors for making decisions.

Criteria with positive $(\widetilde{D_\iota^{Def}} - \widetilde{R_\iota^{Def}})$ value and low $(\widetilde{D_\iota^{Def}} + \widetilde{R_\iota^{Def}})$ value: These criteria are classified as cause criteria, and have an effect on a few other criteria. This shows that the criteria are independent and do not have a strong influence on the solution of the problem.

Criteria with negative $(\widetilde{D_\iota^{Def}} - \widetilde{R_\iota^{Def}})$ value and high $(\widetilde{D_\iota^{Def}} + \widetilde{R_\iota^{Def}})$ value: These criteria are classified as effect criteria, and are highly influenced by other criteria. The effect group can be improved indirectly through the cause criteria.

Criteria with negative $(\widetilde{D_\iota^{Def}} - \widetilde{R_\iota^{Def}})$ value and low $(\widetilde{D_\iota^{Def}} + \widetilde{R_\iota^{Def}})$ value: These criteria are classified as effect criteria, and are slightly influenced by other criteria. This indicates that the criteria are comparatively independent, and are not key criteria to solve the problem.

Step 8: Produce a casual diagram. A causal and effect graph can be obtained by mapping the dataset of $(\widetilde{D_\iota^{Def}} + \widetilde{R_\iota^{Def}}, \widetilde{D_\iota^{Def}} - \widetilde{R_\iota^{Def}})$. The casual diagram shows the causal relationships and interactive influences between the various criteria.

4.2. IF-TOPSIS Method

Intuitionistic fuzzy sets (IFS) are extension of fuzzy sets, which are developed by Atanassov in 1986. IFS provide a proper approach to handle vagueness. Additionally to the membership degree, IFS offer a solution to the problem of vagueness with a non-membership degree. There are four different type of IFS, single-valued, interval valued, triangular, and trapezoidal IFS. In this paper we use triangular IFSs. Assume that A is an IFS in X:

$$A = \{x, \mu_A(x), \upsilon_A(x) | x \in X\}, \quad (13)$$

where:

$\mu_A: X \to [0,1]$ and $\upsilon_A: X \to [0,1]$; $0 \leq \mu_A(x) + \upsilon_A(x) \leq 1$ for all $x \in X$. (14)

In IFS A, $\mu_A(x)$ and $\upsilon_A(x)$ are respectively indicate the membership and non-membership degrees. Additionally, triangular IFS have also another value,$\pi_A(x)$ which is called as intuitionistic index or hesitancy degree. $\pi_A(x)$ value indicates certainty of x.

$$\pi_A(x) = 1 - \mu_A(x) - \upsilon_A(x)$$

and $0 \leq \pi_A(x) \leq 1$ for all $x \in X$. (15)

$\pi_A(x)$ value indicates the certainty level of the information concerning x. When the value of $\pi_A(x)$ is a small number, information is more confident.

IF-TOPSIS was initially proposed by Boran et al. (2009). Since then, it has been applied to various decision-making problems such as location analysis, supplier selection, project evaluation, investment selection, 3PL provider selection, portfolio selection, machine selection (Boran et al. 2009; Büyükozan and Güleryüz, 2016; Uyanık et al. 2020; Güler et al. 2019; Memari et al. 2019).

The application steps of IF-TOPSIS consists of the following steps:

Step 1: Determine the importance level of each DM's evaluation based on the experience and the department of the DM. Since some of the decision-makers have different education, knowledge, and experience levels, their opinions may have a different importance level accordingly. Assume that $D_k = [\mu_k, v_k, \pi_k]$ is the intuitionistic fuzzy number for ranking of k^{th} DM. Therefore, the weight of the k^{th} DM can be calculated as:

$$\lambda_k = \frac{\left(\mu_k + \pi_k\left(\frac{\mu_k}{\mu_k + v_k}\right)\right)}{\sum_{k=1}^{l}\left(\mu_k + \pi_k\left(\frac{\mu_k}{\mu_k + v_k}\right)\right)}, \quad \sum_{k=1}^{l}\lambda_k = 1 \quad (16)$$

Step 2: Construct the aggregated intuitionistic fuzzy decision matrix according to the DMs opinions. Assume, $A = \{A_1, A_2, A_3, \ldots A_m\}$ is a set of alternatives.

An Intuitionistic Fuzzy Weighted Averaging (IFWA) operator can be applied to aggregate the group decisions as below:

$R = (r_{ij})_{mxn}$, where

$$r_{ij} = IFWA_\lambda(r_{ij}^{(1)}, r_{ij}^{(2)}, \ldots\ldots r_{ij}^{(l)}) = \lambda_1 r_j^{(1)} \oplus \lambda_2 r_j^2 \oplus, \ldots, \oplus \lambda_k r_j^{(l)}$$

$$= \left[1 - \prod_{k=1}^{l}(1-\mu_{ij}^{(k)})^{\lambda k}, \prod_{k=1}^{l}(v_{ij}^{(k)})^{\lambda k}, \prod_{k=1}^{l}(1-\mu_{ij}^{(k)})^{\lambda k} - \prod_{k=1}^{l}(v_{ij}^{(k)})^{\lambda k}\right] \quad (17)$$

Where $r_{ij} = \left(\mu_{Ai}(x_j), v_{Ai}(x_j), \pi_{Ai}(x_j)\right)(i = 1,2,\ldots,m; j = 1,2,\ldots.,n)$.

According to the Eq. (17), the aggregated intuitionistic fuzzy decision matrix can be presented as below:

$$R = \begin{bmatrix} \mu_{A1}(x_1), v_{A1}(x_1), \pi_{A1}(x_1) & \mu_{A1}(x_2), v_{A1}(x_2), \pi_{A1}(x_2) \ldots\ldots & \mu_{A1}(x_n), v_{A1}(x_n), \pi_{A1}(x_n) \\ \mu_{A2}(x_1), v_{A2}(x_1), \pi_{A2}(x_1) & \mu_{A2}(x_2), v_{A2}(x_2), \pi_{A2}(x_2). \ldots\ldots & \mu_{A2}(x_n), v_{A2}(x_n), \pi_{A2}(x_n) \\ \vdots & \vdots & \ldots \ddots \\ \mu_{Am}(x_1), v_{Am}(x_1), \pi_{Am}(x_1) & \mu_{Am}(x_2), v_{Am}(x_2), \pi_{Am}(x_2). \ldots\ldots & \mu_{Am}(x_n), v_{Am}(x_n), \pi_{Am}(x_n) \end{bmatrix}$$

$$R = \begin{bmatrix} r_{11} & \cdots & r_{1m} \\ \vdots & \ddots & \vdots \\ r_{n1} & \cdots & r_{nm} \end{bmatrix}$$

Step 3: Determine the weight of criteria based on the DM's evaluations.

Assume that $w_j^{(k)} = \left[\mu_j^{(k)}, v_j^{(k)}, \pi_j^{(k)}\right]$ is an intuitionistic fuzzy number given to criterion x_j by the k^th^ DM. The weight of criteria can be calculated as:

$$\omega_j = IFWA_\lambda\left(w_j^{(1)}, w_j^{(2)}, \ldots\ldots w_j^{(l)}\right) = \lambda_1 w_j^{(1)} \oplus \lambda_2 w_j^2 \oplus, \ldots, \oplus \lambda_k w_j^{(l)}$$

$$= \left[1 - \prod_{k=1}^{l}(1-\mu_{ij}^{(k)})^{\lambda k}, \prod_{k=1}^{l}(v_{ij}^{(k)})^{\lambda k}, \prod_{k=1}^{l}(1-\mu_{ij}^{(k)})^{\lambda k} - \prod_{k=1}^{l}(v_{ij}^{(k)})^{\lambda k}\right] \quad (18)$$

$$W = [w_1, w_2, w_3, \ldots\ldots, w_j]$$

Step 4: Calculate the aggregated weighted intuitionistic fuzzy decision matrix with using the calculated criteria weights (W) and the aggregated intuitionistic fuzzy decision matrix as shown below:

$$R \otimes W = \{\langle x, \mu_{Ai}(x).\mu_w(x), v_{Ai}(x) + v_w(x) - v_{Ai}(x).v_w(x)\rangle I x \in X\} \quad (19)$$

Next,

$$\pi_{Ai}w(x) = 1 - v_{Ai}(x) - v_w(x) - \mu_{Ai}(x).\mu_w(x) + v_{Ai}(x).v_w(x) \quad (20)$$

And then, the aggregated weighted intuitionistic fuzzy decision matrix is determined as:

$$\hat{R} = \begin{bmatrix} r'_{11} & r'_{12} & r'_{13} & \cdots & r'_{1m} \\ r'_{21} & r'_{22} & r'_{23} & \cdots & r'_{2m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ r'_{n1} & r'_{n2} & r'_{n3} & \cdots & r'_{nm} \end{bmatrix}$$

An element of the aggregated weighted intuitionistic fuzzy decision matrix can be symbolized as $r'_{ij} = (\mu'_{ij}, v'_{ij}, \pi'_{ij}) = (\mu_{A_iw}(x_j), v_{A_iw}(x_j), \pi_{A_iw}(x_j))$.

Step 5: Calculate the distances from positive and negative ideal points. Let J_1 and J_2 represent benefit criteria and cost criteria, respectively. Here, A^+ is intuitionistic fuzzy positive-ideal solution and A^- is intuitionistic fuzzy negative-ideal solution. So, A^+ and A^- can be calculated as:

$$A^+ = ((\mu_{A^+w}(x_j), \left(\upsilon_{A^+w}(x_j)\right) \text{ and, } A^- = ((\mu_{A^-w}(x_j), \left(\upsilon_{A^-w}(x_j)\right) \quad (21)$$

where,

$$\mu_{A^+w}(x_j) = ((max_i \mu_{A_i.w}(x_j) \big| j \in J_1), (min_i \mu_{A_{i.w}} \big| j \in J_2) \quad (22)$$

$$\upsilon_{A^+w}(x_j) = ((max_i \upsilon_{A_i.w}(x_j) \big| j \in J_1), (min_i \upsilon_{A_{i.w}} \big| j \in J_2) \quad (23)$$

$$\mu_{A^-w}(x_j) = ((min_i \mu_{A_i.w}(x_j) \big| j \in J_1), (max_i \mu_{A_{i.w}} \big| j \in J_2) \quad (24)$$

$$\upsilon_{A^-w}(x_j) = ((min_i \upsilon_{A_i.w}(x_j) \big| j \in J_1), (max_i \upsilon_{A_{i.w}} \big| j \in J_2) \quad (25)$$

Step 6: Determine the separation measures of the intuitionistic fuzzy sets of the available alternatives. There are different proposed methods to calculate the separation measures. In this paper we use normalized Euclidean distance. The distance of each alternative from the positive and negative ideal points are computed as follows:

$$S^+ = \sqrt{\frac{1}{2n}\sum_{j=1}^{n}\left[(\mu_{Ai.w}(x_j) - \mu_{A^+w}(x_j))^2 + ((\upsilon_{A_i.w}(x_j) - \upsilon_{A^+w}(x_j))^2 + (\pi_{A_iw}(x_j) - \pi_{A^+w}(x_j))^2\right]} \quad (26)$$

$$S^- = \sqrt{\frac{1}{2n}\sum_{j=1}^{n}\left[(\mu_{Ai.w}(x_j) - \mu_{A^-w}(x_j))^2 + ((\upsilon_{A_i.w}(x_j) - \upsilon_{A^-w}(x_j))^2 + (\pi_{A_iw}(x_j) - \pi_{A^-w}(x_j))^2\right]} \quad (27)$$

Step 7: Calculate the relative closeness coefficient (CC_i) for the intuitionistic ideal solution. The relative closeness coefficient of an alternative A_i with respect to A^+ is identified as below:

$$CC_i = \frac{S_i^-}{S_i^- + S_i^+} \quad \text{where } 0 \leq CC_i \leq 1 \quad (28)$$

Step 8: Rank the alternatives according to descending order of CC_i values.

5. Case Study

Hayat Kimya is a Turkish chemical company, which has been operating in the FMCG industry since 1987. The company has the first and the biggest research and development facility in Turkey's FMCG industry. Hayat Kimya's pursuit is to implement an integrated management system, which is composed of quality, health and safety, and environmental aspects at all stages of the supply chain activities. Thus, Hayat Kimya is selected as a case company in this study to investigate the sustainable supplier performance evaluation process. The company aims to determine the best supplier for the one of the most critical raw materials. For this reason, the purchasing department has identified three potential supplier firms for supplier selection applications. In the first part of the case study, a fuzzy DEMATEL method is proposed to analyze the importance level of sustainable supplier selection criteria and investigate the casual relationships among the criteria set. A preliminary step was carried out to test the industrial suitability of the determined criteria. Decision-makers are asked to eliminate criteria that are not suitable for the company's supplier selection process. Hence, the accuracy of the criteria set is confirmed by decision-makers. Afterward, the IF-TOPSIS method is used to evaluate the performance of the suppliers based on criteria set determined by fuzzy DEMATEL.

Is the criterion relevant to the company's supplier performance evaluation process?		
Criteria	Yes	No
Quality		
Delivery		
Service		
Cost/ Price		
Flexibility		
Capacity		
Capability of R&D		
Resource consumption		
Pollution control		
Environmental management system		
Green transport		
Green product		
Green packaging		
Environmental management competencies		
Green design		
Green warehousing		
Green technology		
Stakeholders' rights		
Health and safety		
Discrimination		
Respect for Religious and Cultural Issues		
Respect for the policy		

Table 3. Questionnaire for Adjustment of Supplier Performance Evaluation Criteria Set

In order to analyze the sustainable supplier selection process, a committee of experts with three members at different positions is constructed.

Sustainable supplier selection criteria importance level analysis with Fuzzy DEMATEL method is conducted as follows:

Step 1: The list of sustainable supplier selection criteria is shown to the DMs, and they are asked whether the related criteria are pertinent to their company. Table 3 consists of criteria alternatives that are evaluated by the DMs. By using DMs' comments and feedbacks, the final criteria set is derived as shown in Table 1. The supplier performance evaluation criteria symbols in this study are as follows: quality (C1), delivery (C2), service (C3), cost/price (C4), flexibility (C5), resource consumption (E1), pollution control (E2), environmental management system (E3), green product (E4), environmental management competencies (E5), stakeholders' rights (S1), health and safety (S2), respect for the policy (S3). Then, a detailed literature research is conducted for the criteria set determined in this step. The related literature review is presented in Table 1.

Step 2: In this step, a questionnaire is designed for the fuzzy DEMATEL, in which each criterion is defined briefly for easy understanding and response. Then, respondents are asked to analyze the casual relationships among the criteria by using a fuzzy linguistic scale, which is shown in Table 2. Casual relationships within and among the criteria are interpreted through paired comparison analysis to generate the initial fuzzy direct relation matrix. The average initial fuzzy direct relation matrix is obtained through Eq. (5) as shown in Table 4 below.

Step 3: After obtaining the average initial fuzzy direct matrix**,** the normalized fuzzy direct relation matrix is acquired through Eq. (6) and Eq. (7). In Table 5, the normalized direct relation matrix is presented.

Step 4: The fuzzy total relation matrix is obtained using Eq. (8) from the normalized direct relation matrix. The fuzzy total relation matrix is presented in Table 6.

Step 5: Causal relationships are determined by using Eq. (9), (10). The $\widetilde{D}$ and $\tilde{R}$ values are computed by the sum of rows and the sum of columns within the fuzzy total influence matrix.

Step 6: Defuzzification of the $\left(\breve{D}+\tilde{R}\right)$ and $\left(\breve{D}-\tilde{R}\right)$ values is conducted through Eq. (11) and (12).

Step 7: Computation of the prominence $(\widetilde{D_\iota{}^{Def}} + \widetilde{R_\iota^{Def}})$ and relation $(\widetilde{D_\iota{}^{Def}} - \widetilde{R_\iota^{Def}})$ values. The $(\widetilde{D_\iota{}^{Def}} + \widetilde{R_\iota^{Def}})$ values show the importance of all supplier performance evaluation attributes. $(\widetilde{D_\iota{}^{Def}} - \widetilde{R_\iota^{Def}})$ values assign supplier performance evaluation criteria into cause and effect groups. Table 7 consists of the $(\breve{D}+\tilde{R})$, $(\breve{D}-\tilde{R})$, and $(\widetilde{D_\iota{}^{Def}} + \widetilde{R_\iota^{Def}})$, $(\widetilde{D_\iota{}^{Def}} - \widetilde{R_\iota^{Def}})$ values

	C1	**C2**	**C3**	**C4**	**C5**	**S1**	**S2**	**S3**
C1	(0,0,0)	(0.25,0.5,0.75)	(0.67, 0.92,1)	(0.33, 0.58,0.83)	(0.33,0.58,0.83)	(0.5, 0.75, 1)	(0,0.25,0.5)	(0.5, 0.8,1)
C2	(0.8,1,1)	(0,0,0)	(0.75,1,1)	(0.33, 0.58,0.83)	(0.5, 0.75,1)	(0,0.25,0.5)	(0,0.25,0.5)	(0, 0.3, 0.5)
C3	(0.8,1,1)	(0.17,0.33,0.58)	(0, 0, 0)	(0.33, 0.58,0.83)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1)	(0,0.25,0.5)	(0, 0.3, 0.5)
C4	(0, 0,0.25)	(0.25,0.5,0.75)	(0.25, 0.5, 0.75)	(0, 0, 0)	(0.33,0.58,0.83)	(0,0.25,0.5)	(0,0.25,0.5)	(0, 0.3, 0.5)
C5	(0, 0,0.25)	(0.5,0.75,0.75)	(0.75, 1, 1)	(0.5, 0.75,1)	(0, 0, 0)	(0, 0.17, 0.4)	(0,0.25,0.5)	(0, 0.3, 0.5)
E1	(0, 0,0.25)	(0, 0,0.25)	(0, 0.25, 0.5)	(0.17, 0.42, 0.67)	(0, 0, 0.25)	(0, 0,0.3)	(0,0.25,0.5)	(0.25, 0.5,0.75)
E2	(0, 0,0.25)	((0, 0,0.25)	(0, 0,0.25)	(0.08, 0.33, 0.58)	(0, 0, 0.25)	(0, 0,0.3)	(0,0.25,0.5)	(0.5,0.8,1)
E3	(0.1,0.25,0.5)	(0, 0,0.25)	(0, 0,0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0.3, 0.5, 0.8)	(0,0.25,0.5)	(0.5, 0.8,1)
E4	(0, 0,0.25)	(0, 0,0.25)	(0, 0,0.25)	(0.17, 0.42, 0.67)	(0, 0, 0.25)	(0,0.25,0.5)	(0,0.25,0.5)	(0.25, 0.5,0.75)
E5	(0, 0,0.25)	(0, 0,0.25)	(0, 0,0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0,0.25,0.5)	(0,0.25,0.5)	(0.25, 0.5,0.75)
S1	(0, 0,0.25)	(0, 0,0.25)	(0, 0,0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0,0,0)	(0,0.25,0.5)	(0.25, 0.5,0.75)
S2	(0,0.08,0.33)	(0, 0,0.25)	(0, 0,0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0.5, 0.75, 1)	(0,0,0)	(0.5,0.8,1)
S3	(0,0.08,0.33)	(0, 0,0.25)	(0, 0,0.25)	(0.17, 0.42, 0.67)	(0, 0, 0.25)	(0,0.25,0.5)	(0.5, 0.75,1)	(0,0,0)

	E1	**E2**	**E3**	**E4**	**E5**
C1	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0,0, 0.25)	(0,0, 0.25)
C2	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0,0, 0.25)	(0,0, 0.25)
C3	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0,0, 0.25)	(0,0, 0.25)
C4	(0.33,0.58,0.83)	(0, 0.25,0.5)	(0, 0.25,0.5)	(0, 0.3, 0.5)	(0, 0.3, 0.5)
C5	(0, 0, 0.25)	(0, 0, 0.25)	(0, 0.25,0.5)	(0,0, 0.25)	(0,0, 0.25)
E1	(0, 0, 0)	(0.25,0.5,0.75)	(0, 0.25,0.5)	(0.5, 0.8, 1)	(0.33,0.6,0.83)
E2	(0.25,0.5,0.75)	(0, 0, 0)	(0.5, 0.75, 1)	(0.5, 0.8, 1)	(0.33,0.6,0.83)
E3	(0.5, 0.75, 1)	(0.5, 0.75, 1)	(0, 0, 0)	(0.75, 1, 1)	(0.75, 1, 1)
E4	(0.25,0.5,0.75)	(0.5, 0.75, 1)	(0.5, 0.75, 1)	(0, 0, 0)	(0.75, 1, 1)
E5	(0.25,0.5,0.75)	(0.5, 0.75, 1)	(0.5, 0.75, 1)	(0.75, 1, 1)	(0, 0, 0)
S1	(0,0, 0.25)	(0,0, 0.25)	(0,0, 0.25)	(0,0, 0.25)	(0,0, 0.25
S2	(0,0, 0.25)	(0,0, 0.25)	(0,0, 0.25)	(0,0, 0.25)	(0,0, 0.25
S3	(0.25,0.5,0.75)	(0.17,0.42,0.67)	(0.5,0.75,1)	(0.5, 0.8, 1)	(0.5, 0.8,1)

Table 4. Fuzzy Average Direct Relationship Matrix

	C1	C2	C3	C4	C5	S1	S2	S3
C1	(0,0,0)	(0.08,0.1,0.1)	(0.23,0.19,0.13)	(0.08,0.1,0.1)	(0.08,0.1,0.1)	(0.2,0.14,0.1)	(0,0.05,0.1)	(0.15,0.1,0.13)
C2	(0.2, 0.19, 0.13)	(0,0,0)	(0.23,0.19,0.13)	(0.08,0.1,0.1)	(0.15,0.14,0.13)	(0,0.05,0.1)	(0,0.05,0.1)	(0,0,0.06)
C3	(0.2, 0.19, 0.13)	(0, 0,0.03)	(0,0,0)	(0.08,0.1,0.1)	(0.08,0.1,0.1)	(0.2,0.14,0.1)	(0,0.05,0.1)	(0,0,0.06)
C4	(0, 0,0.03)	(0.08,0.1,0.1)	(0.08,0.1,0.1)	(0,0,0)	(0.08,0.1,0.1)	(0,0.05,0.1)	(0,0.05,0.1)	(0,0,0.06)
C5	(0, 0,0.03)	(0.08,0.1,0.1)	(0.23,0.19,0.13)	(0.15,0.14,0.13)	(0,0,0)	(0,0.05,0.1)	(0,0.05,0.1)	(0,0,0.06)
E1	(0, 0,0.03)	(0, 0,0.03)	(0,0.05,0.06)	(0.08,0.1,0.1)	(0, 0,0.03)	(0,0,0)	(0,0.05,0.1)	(0.08,0.1,0.1)
E2	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)	(0,0.05,0.06)	(0, 0,0.03)	(0,0,0)	(0,0.05,0.1)	(0.15,0.1,0.13)
E3	(0,0.05,0.06)	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)	(0.1,0.1,0.1)	(0,0.05,0.1)	(0.15,0.1,0.13)
E4	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)	(0.08,0.1,0.1)	(0, 0,0.03)	(0,0.05,0.1)	(0,0.05,0.1)	(0.08,0.1,0.1)
E5	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)	(0,0.05,0.1)	(0,0.05,0.1)	(0.08,0.1,0.1)
S1	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)	(0,0,0)	(0,0.05,0.1)	(0.08,0.1,0.1)
S2	(0,0.05,0.06)	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)	(0.2,0.14,0.1)	(0,0,0)	(0.15,0.1,0.13)
S3	(0,0.05,0.06)	(0, 0,0.03)	(0, 0,0.03)	(0.08,0.1,0.1)	(0, 0,0.03)	(0,0.05,0.1)	(0.2,0.14,0.1)	(0,0,0)

	E1	E2	E3	E4	E5
C1	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)
C2	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)
C3	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)
C4	(0.08,0.1,0.1)	(0,0.05,0.06)	(0,0.05,0.06)	(0,0,0.06)	(0,0,0.06)
C5	(0, 0,0.03)	(0, 0,0.03)	(0,0.05,0.06)	(0, 0,0.03)	(0, 0,0.03)
E1	(0,0,0)	(0.08,0.1,0.1)	(0,0.05,0.06)	(0.15,0.1,0.13)	(0.08,0.1,0.1)
E2	(0.08,0.1,0.1)	(0,0,0)	(0.15,0.14,0.13)	(0.15,0.1,0.13)	(0.08,0.1,0.1)
E3	(0.15,0.14,0.13)	(0.15,0.14,0.13)	(0,0,0)	(0.23,0.2,0.13)	(0.23,0.2,0.13)
E4	(0.08,0.1,0.1)	(0.15,0.14,0.13)	(0.15,0.14,0.13)	(0,0,0)	(0.23,0.2,0.13)
E5	(0.08,0.1,0.1)	(0.15,0.14,0.13)	(0.15,0.14,0.13)	(0.23,0.2,0.13)	(0,0,0)
S1	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)
S2	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)	(0, 0,0.03)
S3	(0.08,0.1,0.1)	(0,0.05,0.06)	(0.15,0.14,0.13)	(0.15,0.1,0.13)	(0.15,0.1,0.13)

Table 5. Fuzzy Normalized Direct Relation Matrix

	C1	C2	C3	C4	C5	S1	S2	S3
C1	(0.09,0.11,0.28)	(0.10,0.14,0.32)	(0.31,0.30,0.42)	(0.16,0.23,0.45)	(0.13,0.18,0.36)	(0.22,0.29,0.49)	(0.03,0.18,0.41)	(0.21,0.32,0.57)
C2	(0.32,0.29,0.38)	(0.05,0.0,0.23)	(0.37,0.33,0.41)	(0.17,0.24,0.43)	(0.22,0.24,0.37)	(0.11,0.22,0.42)	(0.01,0.17,0.39)	(0.07,0.23,0.49)
C3	(0.26,0.24,0.35)	(0.04,0.06,0.24)	(0.10,0.11,0.26)	(0.13,0.19,0.39)	(0.12,0.15,0.32)	(0.21,0.26,0.44)	(0.01,0.14,0.36)	(0.06,0.19,0.46)
C4	(0.05,0.09,0.30)	(0.09,0.13,0.32)	(0.13,0.19,0.38)	(0.05,0.13,0.36)	(0.11,0.15,0.35)	(0.03,0.18,0.43)	(0.00,0.17,0.40)	(0.02,0.24,0.52)
C5	(0.09,0.10,0.27)	(0.10,0.14,0.30)	(0.30,0.28,0.38)	(0.20,0.24,0.43)	(0.06,0.08,0.24)	(0.06,0.18,0.39)	(0.00,0.15,0.37)	(0.02,0.19,0.46)
E1	(0.01,0.06,0.29)	(0.01,0.03,0.26)	(0.02,0.10,0.34)	(0.12,0.21,0.44)	(0.01,0.04,0.28)	(0.02,0.13,0.40)	(0.03,0.19,0.41)	(0.17,0.32,0.55)
E2	(0.00,0.06,0.31)	(0.01,0.03,0.27)	(0.01,0.05,0.33)	(0.07,0.18,0.43)	(0.01,0.03,0.29)	(0.03,0.15,0.42)	(0.05,0.21,0.43)	(0.30,0.40,0.61)
E3	(0.00,0.12,0.36)	(0.01,0.03,0.29)	(0.01,0.07,0.36)	(0.10,0.18,0.44)	(0.01,0.04,0.32)	(0.11,0.27,0.51)	(0.06,0.25,0.47)	(0.37,0.47,0.66)
E4	(0.01,0.07,0.32)	(0.01,0.03,0.28)	(0.02,0.06,0.34)	(0.14,0.23,0.47)	(0.01,0.04,0.31)	(0.04,0.21,0.46)	(0.04,0.22,0.45)	(0.26,0.39,0.61)
E5	(0.00,0.06,0.30)	(0.01,0.02,0.26)	(0.01,0.05,0.32)	(0.08,0.14,0.40)	(0.01,0.03,0.29)	(0.03,0.19,0.44)	(0.04,0.21,0.42)	(0.26,0.37,0.58)
S1	(0.00,0.01,0.18)	(0.00,0.00,0.16)	(0.00,0.01,0.20)	(0.01,0.02,0.23)	(0.00,0.01,0.18)	(0.00,0.03,0.21)	(0.01,0.08,0.26)	(0.09,0.13,0.36)
S2	(0.00,0.07,0.25)	(0.00,0.01,0.19)	(0.00,0.03,0.23)	(0.02,0.05,0.28)	(0.00,0.02,0.21)	(0.16,0.19,0.38)	(0.03,0.06,0.25)	(0.19,0.22,0.44)
S3	(0.01,0.12,0.36)	(0.01,0.04,0.29)	(0.02,0.07,0.36)	(0.14,0.23,0.49)	(0.01,0.05,0.32)	(0.05,0.22,0.49)	(0.18,0.31,0.52)	(0.18,0.30,0.54)

	E1	E2	E3	E4	E5
C1	(0.05,0.10,0.36)	(0.03,0.09,0.36)	(0.06,0.12,0.39)	(0.07,0.13,0.40)	(0.07,0.12,0.38)
C2	(0.03,0.08,0.34)	(0.01,0.07,0.34)	(0.02,0.10,0.37)	(0.03,0.10,0.37)	(0.02,0.10,0.36)
C3	(0.02,0.07,0.32)	(0.01,0.06,0.31)	(0.02,0.08,0.34)	(0.02,0.09,0.35)	(0.02,0.08,0.33)
C4	(0.09,0.22,0.43)	(0.02,0.17,0.40)	(0.01,0.19,0.43)	(0.03,0.22,0.44)	(0.02,0.20,0.42)
C5	(0.02,0.09,0.33)	(0.01,0.08,0.32)	(0.01,0.14,0.38)	(0.01,0.11,0.36)	(0.01,0.10,0.34)
E1	(0.09,0.18,0.35)	(0.18,0.27,0.44)	(0.13,0.25,0.44)	(0.29,0.37,0.51)	(0.22,0.31,0.46)
E2	(0.22,0.30,0.47)	(0.17,0.22,0.38)	(0.33,0.37,0.52)	(0.40,0.42,0.54)	(0.31,0.36,0.49)
E3	(0.34,0.38,0.53)	(0.38,0.40,0.53)	(0.28,0.30,0.45)	(0.57,0.53,0.58)	(0.53,0.50,0.55)
E4	(0.24,0.32,0.48)	(0.34,0.37,0.51)	(0.35,0.39,0.54)	(0.31,0.33,0.44)	(0.46,0.46,0.53)
E5	(0.24,0.30,0.46)	(0.34,0.36,0.49)	(0.35,0.38,0.52)	(0.49,0.47,0.53)	(0.27,0.28,0.39)
S1	(0.02,0.03,0.23)	(0.01,0.03,0.23)	(0.02,0.04,0.25)	(0.03,0.04,0.25)	(0.03,0.04,0.24)
S2	(0.03,0.05,0.27)	(0.03,0.05,0.27)	(0.05,0.06,0.29)	(0.06,0.07,0.30)	(0.06,0.07,0.28)
S3	(0.22,0.30,0.50)	(0.18,0.27,0.47)	(0.32,0.37,0.55)	(0.39,0.43,0.57)	(0.36,0.40,0.55)

Table 6. Fuzzy Total Relation Matrix

Criteria	$(\breve{D}+\tilde{R})$	$(\breve{D}-\tilde{R})$	$(\widetilde{D_i^{Def}}+\widetilde{R_i^{Def}})$	$(\widetilde{D_i^{Def}}-\widetilde{R_i^{Def}})$
C1	(2.39,3.71,9.13)	(0.70,0.91,1.238)	4.74	0.94
C2	(1.88,2.97,8.28)	(0.99,1.50,1.483)	4.03	1.37
C3	(2.33,3.38,8.75)	(-0.28,0.07,0.140)	4.46	0.00
C4	(2.04,4.60,10.40)	(-0.74,0.01,-0.080)	5.41	-0.20
C5	(1.59,2.92,8.40)	(0.18,0.83,0.721)	3.96	0.64
E1	(2.89,4.89,10.27)	(-0.31,0.03,0.121)	5.74	-0.03
E2	(3.61,5.22,10.51)	(0.22,0.33,0.435)	6.14	0.33
E3	(4.71,6.32,11.51)	(0.81,0.75,0.609)	7.22	0.73
E4	(4.93,6.43,11.41)	(-0.47,-0.19,0.084)	7.30	-0.19
E5	(4.51,5.89,10.71)	(-0.25,-0.18,0.078)	6.75	-0.13
S1	(1.30,3.01,8.45)	(-0.84,-2.03,-2.491)	3.94	-1.85
S2	(1.13,3.29,8.75)	(0.16,-1.37,-1.504)	4.11	-1.02
S3	(4.29,6.89,12.87)	(-0.17,-0.65,-0.835)	7.74	-0.58

Table 7. The values of $(\breve{D}+\tilde{R})$, $(\breve{D}-\tilde{R})$, and $(\widetilde{D_i^{Def}}+\widetilde{R_i^{Def}})$, $(\widetilde{D_i^{Def}}-\widetilde{R_i^{Def}})$

The results from the causal diagram are interpreted as follows: the evaluation criteria, namely, quality (C1), delivery (C2), service (C3), flexibility (C5), pollution control (E2), environmental management system (E3) are divided into the cause criteria group, while cost/price (C4), resource consumption (E1), green product (E4), environmental management competencies (E5), stakeholders' rights (S1), health and safety (S2), respect for the policy (S3) are considered as effect criteria group. Since cause criteria have impact on the entire supplier evaluation system, they should be considered as strategically important. Managers need to pay more attention to these criteria in order to achieve the overall goal of the system.

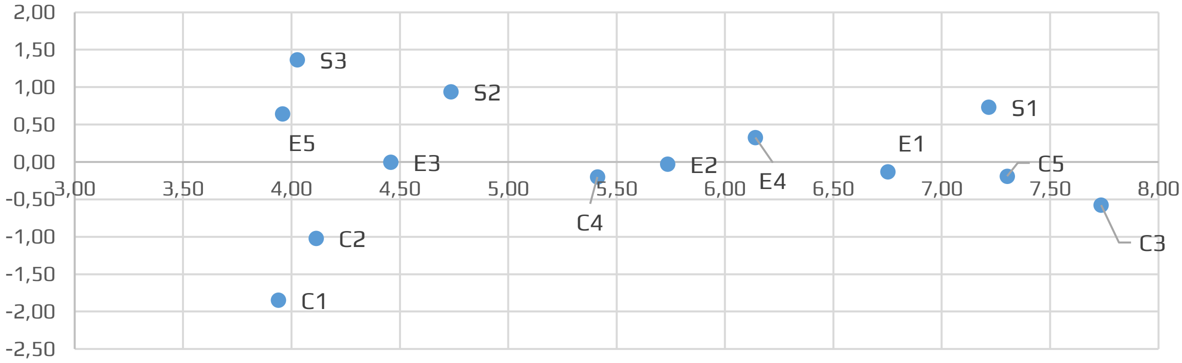

Figure 4. Cause and Effect Diagram

The most important criterion that influences sustainable supplier selection process is determined as environmental management system (E3) with the highest D+R value and positive D-R value. On the other hand, stakeholders' rights (S1) and health and safety (S2) have the lowest D-R value, which means that they are greatly affected by the other criteria. Therefore, they are eliminated from the criteria set and remaining eleven criteria are used in IF-TOPSIS method.

Sustainable supplier selection process is conducted with using IF-TOPSIS method. Three experts have involved to supplier selection process. They have been asked to evaluate three candidate suppliers based on sustainable supplier selection criteria determined in the previous section.

The proposed IF-TOPSIS procedure consists of the following steps:

Step 1: DM importance levels are determined based on their length of the experience in the fields and the effects on the supplier evaluation process by using linguistic terms given in Table 8.

Linguistic Term	IFS
Very Important (VI)	[0.9,0.10]
Important (I)	[0.75,0.20]
Medium (M)	[0.5,0.45]
Unimportant (U)	[0.35, 0.60]
Very Unimportant (VU)	[0.35, 0.60]

Table 8. Linguistic terms for ranking the importance of the DMs

The weights of three DMs are respectively determined using Eq. (16) as follows:

$$\lambda_1 = \frac{\left(0.9+0\left(\frac{0.9}{0.9+0.1}\right)\right)}{\left(0.9+0\left(\frac{0.9}{0.9+0.1}\right)\right)+\left(0.75+0.05\left(\frac{0.75}{0.75+0.20}\right)\right)+\left(0.75+0.05\left(\frac{0.75}{0.75+0.20}\right)\right)} = 0.357$$

$$\lambda_2 = \frac{\left(0.75+0.05\left(\frac{0.75}{0.75+0.20}\right)\right)}{\left(0.9+0\left(\frac{0.9}{0.9+0.1}\right)\right)+\left(0.75+0{,}05\left(\frac{0.75}{0.75+0.20}\right)\right)+\left(0.75+0.05\left(\frac{0.75}{0.75+0.20}\right)\right)} = 0.321$$

$$\lambda_3 = \frac{\left(0.75+0.05\left(\frac{0.75}{0.75+0.20}\right)\right)}{\left(0.9+0\left(\frac{0.9}{0.9+0.1}\right)\right)+\left(0.75+0{,}05\left(\frac{0.75}{0.75+0.20}\right)\right)+\left(0.75+0.05\left(\frac{0.75}{0.75+0.20}\right)\right)} = 0.321$$

Step 2: The aggregated intuitionistic fuzzy decision matrix is constructed based on the opinions of DMs. The linguistic terms presented in Table 9 are used to rate each alternative supplier with respect to each criterion.

Linguistic Term	IFS
Extremely Good (EG)	[1;0;0.]
Very Good (VG)	[0.75,0.1,0.15]
Good (G)	[0.6,0.25,0.15]
Moderately Good (MG)	[0.5,0.4,0.1]
Medium (M)	[0.5,0.5,0]
Moderately Bad (MB)	[0.4,0.5,0.1]
Bad (B)	[0.25,0.60,0.15]
Very Bad (VB)	[0.1,0.75,0.15]
Very very Bad (VVB)	[0,0.9,0.1]

Table 9. Linguistic terms for rating alternatives

The evaluation of alternative suppliers based on criteria are determined in linguistic terms as in Table 10.

	Supplier 1			Supplier 2			Supplier 3		
Criteria	**DM1**	**DM2**	**DM3**	**DM1**	**DM2**	**DM3**	**DM1**	**DM2**	**DM3**
C1	G	M	G	VG	VG	VG	M	G	M
C2	G	G	G	G	G	G	G	G	G
C3	G	VG	G	MG	G	G	VG	G	VG
C4	VG	VG	VG	G	G	G	MG	G	G
C5	MG	M	G	M	G	G	MG	G	MG
E1	G	G	VG	G	MG	MG	VG	VG	G
E2	VG	VG	VG	VG	VG	VG	VG	VG	VG
E3	VG	G	VG	MG	G	MG	G	G	G
E4	M	M	M	MG	M	MG	G	MG	G
E5	VG	VG	VG	VG	G	VG	G	VG	G
S3	VG	VG	VG	VG	VG	VG	VG	VG	VG

Table 10. Performance Evaluation of Suppliers based on criteria

The linguistic terms in Table 10 are converted into intuitionistic fuzzy numbers by using the scale given in Table 9. The aggregated intuitionistic fuzzy decision matrix is calculated by using Eq. 17 as shown in Table 11.

Criteria	Supplier 1	Supplier 2	Supplier 3
C1	[0.57, 0.31, 0.12]	[0.75, 0.10, 0.15]	[0.53, 0.40, 0.07]
C2	[0.60, 0.25, 0.15]	[0.60, 0.25, 0.15]	[0.60, 0.25, 0.15]
C3	[0.66, 0.19, 0.16]	[0.57, 0.30, 0.14]	[0.71, 0.13, 0.16]
C4	[0.75, 0.10, 0.15]	[0.60, 0.25, 0.15]	[0.57, 0.30, 0.14]
C5	[0.53, 0.37, 0.10]	[0.57, 0.32, 0.11]	[0.53, 0.34, 0.12]
E1	[0.66, 0.19, 0.16]	[0.54, 0.34, 0.12]	[0.71, 0.13, 0.16]
E2	[0.75, 0.10, 0.15]	[0.75, 0.10, 0.15]	[0.75, 0.10, 0.15]
E3	[0.71, 0.13, 0.16]	[0.53, 0.34, 0.12]	[0.60, 0.25, 0.15]
E4	[0.50, 0.50, 0.00]	[0.50, 0.43, 0.07]	[0.57, 0.29, 0.14]
E5	[0.75, 0.10, 0.15]	[0.71, 0.13, 0.16]	[0.66, 0.19, 0.16]
S3	[0.75, 0.10, 0.15]	[0.75, 0.10, 0.15]	[0.75, 0.10, 0.15]

Table 11. Aggregated Intuitionistic Fuzzy Decision Matrix

Step 4: The importance weight of criteria is evaluated based on the DM's evaluations. In this step, the linguistic terms shown in Table 11 are used to evaluate each criterion.

Linguistic Term	IFS
Very Important (VI)	[0.9;0.0]
Important (I)	[0.8;0.1]
Moderately Important (MI)	[0.7;0.2]
Medium (M)	[0.5;0.5]
Unimportant (U)	[0.3;0.5]
Very Unimportant (VU)	[0.2;0.7]

Table 11. Linguistic terms for rating criteria

The importance level of criteria determined by DMs are given in Table 12. The provided linguistic terms are converted into intuitionistic fuzzy numbers by using the scale given in Table 11. And then, the aggregated importance of criteria are calculated using Eq. (18) as shown in Table 13.

Criteria	DM1	DM2	DM3
C1	VI	VI	I
C2	VI	VI	I
C3	I	VI	I
C4	VI	I	I
C5	I	MI	MI
E1	MI	M	M
E2	M	MI	M
E3	MI	I	MI
E4	M	M	U
E5	I	U	M
S3	VI	I	I

Table 12. Criteria Importance Level Evaluation

Criteria	Intuitionistic Fuzzy Criteria Weights
C1	[0.88, 0.00, 0.12]
C2	[0.88, 0.00, 0.12]
C3	[0.84, 0.00, 0.16]
C4	[0.84, 0.00, 0.16]
C5	[0.74, 0.16, 0.10]
E1	[0.58, 0.36, 0.06]
E2	[0.58, 0.37, 0.05]
E3	[0.74, 0.16, 0.10]
E4	[0.44, 0.50, 0.06]
E5	[0.60, 0.28, 0.12]
S3	[0.84, 0.00, 0.16]

Table 13. Aggregated Intuitionistic fuzzy criteria evaluation matrix

Step 5: The aggregated weighted intuitionistic fuzzy decision matrix is generated with using Eq. (19) and Eq. (20) as shown in Table 14.

Criteria	Supplier 1	Supplier 2	Supplier 3
C1	[0.50, 0.31, 0.19]	[0.66, 0.10, 0.24]	[0.47, 0.40, 0.13]
C2	[0.53, 0.25, 0.22]	[0.53, 0.25, 0.22]	[0.53, 0.25, 0.22]
C3	[0.55, 0.19, 0.26]	[0.48, 0.30, 0.23]	[0.60, 0.13, 0.27]
C4	[0.63, 0.10, 0.27]	[0.51, 0.25, 0.24]	[0.48, 0.30, 0.23]
C5	[0.40, 0.47, 0.14]	[0.42, 0.43, 0.15]	[0.40, 0.45, 0.16]
E1	[0.38, 0.48, 0.14]	[0.31, 0.58, 0.11]	[0.41, 0.45, 0.14]
E2	[0.43, 0.44, 0.13]	[0.43, 0.44, 0.13]	[0.43, 0.44, 0.13]
E3	[0.52, 0.27, 0.20]	[0.39, 0.45, 0.16]	[0.44, 0.37, 0.19]
E4	[0.22, 0.75, 0.03]	[0.22,0.71,0.06]	[0.25, 0.65, 0.10]
E5	[0.45, 0.35, 0.20]	[0.42,0.38,0.20]	[0.39, 0.42, 0.19]
S3	[0.63, 0.10, 0.27]	[0.63,0,10,0.27]	[0.63, 0.10, 0.27]

Table 14. Aggregated weighted intuitionistic fuzzy decision matrix

Step 6: Intuitionistic fuzzy positive-ideal solution (A^+) and intuitionistic fuzzy negative-ideal solution A^- are calculated as in Table 15.

Criteria	A^+	A^-
C1	[0.66, 0.10, 0.24]	[0.47, 0.40, 0.13]
C2	[0.53, 0.25, 0.22]	[0.53, 0.25, 0.22]
C3	[0.60, 0.13, 0.27]	[0.48, 0.30, 0.23]
C4	[0.63, 0.10, 0.27]	[0.48, 0.30, 0.23]
C5	[0.42, 0.43, 0.15]	[0.40, 0.47, 0.14]
E1	[0.41, 0.45, 0.14]	[0.31, 0.58, 0.11]
E2	[0.43, 0.44, 0.13]	[0.43, 0.44, 0.13]
E3	[0.52, 0.27, 0.20]	[0.39, 0.45, 0.16]
E4	[0.25, 0.65, 0.10]	[0.22, 0.75, 0.03]
E5	[0.45, 0.35, 0.20]	[0.39, 0.42, 0.19]
S3	[0.63, 0.10, 0.27]	[0.63, 0.10, 0.27]

Table 15. The Intuitionistic Fuzzy Positive-ideal and Negative ideal solution

Step 7: The separation measures of the intuitionistic fuzzy sets of the suppliers are calculated with using Eq. (26) and Eq. (27). And the relative closeness coefficient (CC_i) value of each supplier is calculated with using Eq. (28). The separation measures and the relative closeness coefficient values of each supplier is shown in Table 16.

Supplier	S^+	S^-	CC_i
Supplier 1	0.067	0.087	0.56
Supplier 2	0.087	0.082	0.49
Supplier 3	0.101	0.067	0.40

Table 16. The relative closeness coefficient and separation measures of each supplier

Step 8: According to the CC_i values the performance ranking of suppliers is determined as S1>S2>S3. Therefore, S1 can be selected as the most suitable sustainable supplier for this company.

6. Discussion and Conclusion

Due to the unfavorable results of the process of globalization, companies are required to undertake some preventive actions in order to protect the world against harmful effects such as pollution, increased carbon footprint, global warming, ethical problems, and unfair trade conditions. In accordance with sustainability, companies ought to be responsible for the society and the environment when they are pursuing to increase their profitability. SSCM aims to organize all activities in the supply chain to generate, protect, and develop long-term environmental, social, and economic values for all stakeholders. This is to ensure that supplier selection from a sustainability perspective is a necessity. Sustainability should start from the point of origin of a product or service and continue to the point of consumption where the end customer receives the product or service. Since supply chain success highly depends on the performance of the organizations in the chain, selection of supplier is a critical concept in a supply chain. Companies need to establish close relationships with their suppliers to ensure standard quality of products and on-time delivery. The supplier selection process has to be carried out systematically in the supply chain. Companies should perform preventive actions to improve the poor performance of their supplier. The chemical industry is clearly one of the critical industries in terms of environmental and human health applications. Recently, sustainable supplier selection problem has been considered in the literature many times. However, studies that directly address issues related to analyzing sustainable supplier selection are still limited. For this reason, this study has dealt with a company operating in the chemical sector in order to analyze the sustainable supplier selection process.

The most critical part of the supplier selection process is to determine the key performance indicators to select the most suitable supplier. Accurate supplier evaluation criteria need to support the company's strategic goals. In addition, supplier evaluation criteria should be realistic, measurable, clearly understandable, and coherent. In this context, the study developed a questionnaire-based survey built on the results of a comprehensive literature review and expert opinions. Therefore, the applicability of the sustainable criteria in the chemical industry is verified.

This study focused on proposing an effective method for SSS problem. In this study, a sustainable supplier selection process is investigated in the chemical industry based on the TBL approach. An integrated fuzzy DEMATEL and IF-TOPSIS method is proposed to select the best supplier, which has the greatest sustainable performance. In order to test the credibility of the proposed integrated model, a case study is conducted in a Turkish chemical company. Thirteen important SSS evaluation criteria based on TBL approach were determined from an extensive literature review and DM's inputs. In the first step, the fuzzy DEMATEL method is applied to determine causal relationships among thirteen sustainable supplier evaluation criteria. According to the fuzzy DEMATEL results, two selection criteria are removed from the criteria set since they are greatly affected by the other criteria. Thus, the sustainable supplier selection process is carried out with a set of criteria consisting of eleven criteria. Since, the fuzzy DEMATEL is a suitable method for dealing with a complex set of criteria in a fuzzy group decision environment, it can be suggested to use in real-life when working with a large criteria set. In the second step, IF-TOPSIS method is implemented to identify the supplier, which has the best sustainable supplier performance. The advantage of IF-TOPSIS method is to provide a simple evaluation process when using a large set of criteria. This study suggests that the proposed integrated method provides a practical and applicable solution to many decision problems that must deal with complex criteria by group decision in a fuzzy environment.

Nevertheless, this study contains some limitations that might lead to future studies. First, the initial criteria set have been constructed by identifying thirteen important supplier selection criteria for sustainability in the supply chain. Larger criteria set could have been used with considering other criteria and dimensions. Second, due to the structure of MCDM methods, the evaluations are made based on human judgments and results may contain subjectivity. Additionally, a sensitivity analysis could also be conducted to test the proposed method robustness. In the future studies, different MCDM approaches (such as PROMETHEE, ELECTRE and COPRAS) can be suggested to solve the same problem and results of the proposed method can be compared. Additionally, the proposed method can be applied to other companies in the chemical industry in order to broaden the scope of this research. Thus, the reliability of the sustainable criteria set can be approved for the chemical industry.

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