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House of Quality-Based Analysis of Green Supply Chain Management for the Sustainable Investment Decisions with Interval Type 2 Fuzzy Hybrid Model

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Abstract: The aim of the study is to propose a set of criteria for the customer needs and technical requirements of green supply chain management in the sustainable investment decisions. For that, house of quality has a unique role to evaluate the customer and technical factors at the same time. Accordingly, house of quality-based analysis of green supply chain management for the sustainable investment decisions is applied for measuring the performance of technical requirements with respect to customer expectations. A hybrid decision making method is applied for ranking the technical factors of green supply chain management for the sustainable investment decisions. Interval type 2 fuzzy DEMATEL is used for weighting the criteria of customer expectations and then interval type 2 fuzzy TOPSIS is employed for ranking the factors of technical requirements for the green supply chain management. The findings show that reuse of product and services is the most significant criterion. It shows that companies should firstly focus on this issue to gain an opportunity to reduce costs. Another important conclusion is that waste management is the most important technical requirement for the green supply chain management. Therefore, it is recommended that companies should make technological investments in waste management. In this context, they should provide necessary comprehensive machines, materials and equipment in the context of innovative strategy, employ qualified personnel capable of using this equipment and give necessary training to the existing personnel.
Key words: Green supply chain management; House of quality; Investment; Interval type 2 fuzzy sets; DEMATEL; TOPSIS

1 Introduction

With globalization, there has been a significant increase in world trade. The main reason for this is the abolition of trade borders between countries. This increasing trade around the world has been effective in increasing both production and consumption. As a result, there has been a significant increase in the competition in the market. High competition has led companies to develop new strategies. Otherwise, they will not be able to continue their activities in this harsh competitive environment. Within this framework, companies have tried to produce innovative strategies in order to gain competitive advantage (Gabrielsson et al., 2016).

Logistics sector is one of the most important sectors affected by globalization. This increased trade has made the logistics sector more important worldwide. In order to maintain international trade in a healthy way, the products must be delivered to the other party completely. In this context, the concept of supply chain is the general name given to the movement of the product, service or money flow from the supplier to the customer and the activities within this process. This concept has emerged especially in order to meet the many needs arising from increasing international trade. In this period, a good logistics strategy was needed to adapt to the change in the production market and to manage more complex logistics networks (Ceniga and Sukalova, 2015).

The most important problem in the logistics sector is considered as carbon dioxide emission due to excessive energy consumption. This has become a serious problem for the ecological environment. However, sensitivity to environmental issues is increasing throughout the world. As a result, it has become necessary for logistics companies to take action against this problem (Paksoy et al., 2019). In this context, logistics companies have taken serious steps to find innovative solutions. For this purpose, the most prominent solution is the green supply chain implementation. It is a kind of supply chain management in which environmentally friendly product or service production strategies are combined (Zhu et al., 2017). It mainly aims to reduce environmental negative impacts of companies. In addition, it also increases efficiency and provides a major competitive advantage in innovation and processes. Green purchasing, green production and material management, green distribution and marketing and reverse logistics are accepted main implementations of this issue (Shibin et al., 2016; Tachizawa et al., 2015).

In this study, it is aimed to evaluate the green supply chain management for the sustainable investment decisions. For this purpose, a set of criteria for the customer needs and technical requirements of green supply chain management is proposed. In the analysis process, interval type 2 fuzzy DEMATEL is used to weight the criteria of customer expectations. On the other side, technical requirement factors for the green supply chain management are ranked by using interval type 2 fuzzy TOPSIS approach. According to the analysis results, strategies can be developed to obtain the sustainable investment policies by selecting the criteria of green supply chain management.

This study includes many different novelties. Firstly, house of quality approach is implemented to evaluate the customer and technical factors at the same time. This situation provides us to understand the most significant technical requirement based on these expectations. In addition to this situation, interval type-2 fuzzy logic is firstly considered in this study to make analysis for logistic industry. Hence, this issue has an important contribution to the originality of this study. Finally, a weighted set of criteria is provided to understand the customer expectations regarding green supply chain management subject.

This study has mainly 5 different sections. In this section, general information related to the issues of logistic, supply chain management and green supply chain management are provided. In the second section, the studies regarding green supply chain management and investment decisions are analyzed. The third section includes the explanations about the methods used in this study. Furthermore, analysis results are shared in the fourth section. In the last section, necessary recommendations are discussed.

2 Literature Review

The green supply chain management subject was discussed in the literature very much. It is obvious that most of these studies are related to the performance analysis of this issue. Chin et al. focused on the green supply chain management performance in Malaysia (Chin et al., 2015). They concluded that companies should consider environmental factors to provide sustainability in supply chain management activities. Also this issue was identified in (Cousins et al., 2019). Vanalle et al. evaluated the performance of supply chain activities for Brazilian automotive industry (Vanalle et al., 2017). The similar result was also underlined according to the analysis results. Parallel to them, other studies emphasized the importance of this factor (Geng et al., 2017; Li et al., 2016; Govindan et al. 2015) .

Additionally, it is seen that different methodologies were taken into consideration in these studies. (Dubey et al., 2015; Tachizawa et al., 2015; Kirchoff et al., 2016) conducted a survey analysis to measure the performance of the green supply chain in many different regions. In this process, they asked different questions to many people. According to their answers, they aimed to identify the important points. On the other side, (Uygun and Dede, 2016; Kusi-Sarpong et al., 2016) considered fuzzy multi-criteria decision making techniques to reach this objective. In the analysis process, firstly, they defined many different indicators. With the help of these methodologies, they tried to find the significances of these indicators.

Some studies defined that an important factor of green supply management is customer satisfaction. For instance, in (Laari et al., 2016) was stated that companies should consider customer expectations in green supply chain operations. Similarly, (Chavez et al., 2016; Teixeira et al., 2016; Zhu et al. 2017) conducted an analysis to improve the performance of the green supply chain activities. They reached the conclusion that customers should be satisfied for the success of the green supply chain management. Furthermore, (Zhu et al., 2017; Schmidt et al., 2017; Seles et al., 2016; Luthra et al., 2015) aimed to analyze this situation and identified that companies should understand and satisfy customer expectations to have higher performance in green supply chain management.

Moreover, risk assessment of the green supply chain management was made by many different researchers. They mainly aimed to identify the significant risk of the companies in this process. After that, they tried to identify which of these risks are more important for the companies. In the final stage, necessary actions were defined to manage these risks. For instance, (Mangla et al., 2015) determined 25 common risks of the green supply chain management by reviewing the similar studies in the literature for Indian companies. These risks are weighted by using fuzzy AHP approach. Also in (Paksoy et al., 2019) was made this analysis by using the same methodology. In addition, (Wang et al., 2016; Shibin et al., 2016; Tachizawa et al., 2015) are other studies which performed similar analysis.

On the other hand, investment decisions on green supply chain management were considered in many different studies. As an example, (Bai et al., 2016) conducted a study to manage investment in green supply management. In the analysis process, fuzzy clustering approach is considered. In (Yan et al., 2018) was also made similar analysis while implementing prisoner's dilemma on competing retailers' investment in green supply chain management. Additionally, (Sun et al., 2019) made a similar analysis and concluded that government subsidy mechanism plays a very significant role to make investment in green supply chain management, (Wu et al., 2019); Yang et al., 2019; Rostamzadeh et al.,2015) also focused on similar issues in their studies. As a result of the literature review, it is determined that a new study can be conducted to evaluate investment issues in green supply management with a new methodology, such as interval type-2 fuzzy logic.

3 Methodology

In this section, different methods used in this study are explained. In this framework, firstly, interval type-2 fuzzy sets are explained. After that, necessary information is given about interval type-2 fuzzy DEMATEL and interval type-2 fuzzy TOPSIS.

3.1 IT2 fuzzy sets

$\widetilde{A}$ refers to the type-2 fuzzy set. On the other side, the membership function is given as $\mu_{\widetilde{A}(x,u)}$. It can get a value between 0 and 1. The details of these items are given on the equation (1) (Xu et al., 2019; Liu et al., 2019; Dinçer et al., 2019a).

$$\widetilde{A} = \left\{\left((x,u),\mu_{\widetilde{A}(x,u)}\right)\middle|\forall_x \in X,\forall_u \in J_x \subseteq [0,1]\right\} \text{ or } \widetilde{A} = \int_{x\in X}\int_{u\in J_x}\mu_{\widetilde{A}}(x,u)/(x,u)\ J_x \subseteq [0,1] \quad (1)$$

Moreover, this membership function can be replaced with Σ regarding the discrete universe. Equation (2) gives information about this process.

$$\widetilde{A} = \int_{x\in X}\int_{u\in J_x} 1/(x,u)\ J_x \subseteq [0,1] \quad (2)$$

$\widetilde{A}_i^U$ and $\widetilde{A}_i^L$ explain the upper and lower trapezoidal membership functions detailed in the equation (3).

$$\widetilde{A}_i = \left(\widetilde{A}_i^U,\widetilde{A}_i^L\right) = \left(\left(a_{i1}^U,a_{i2}^U,a_{i3}^U,a_{i4}^U;H_1\left(\widetilde{A}_i^U\right),H_2\left(\widetilde{A}_i^U\right)\right),\left(a_{i1}^L,a_{i2}^L,a_{i3}^L,a_{i4}^L;H_1\left(\widetilde{A}_i^L\right),H_2\left(\widetilde{A}_i^L\right)\right)\right) \quad (3)$$

On the other side, the equations (4)-(8) give all details about the calculation process.

$$\widetilde{A}_1 \oplus \widetilde{A}_2 = \left(\widetilde{A}_1^U,\widetilde{A}_1^L\right) \oplus \left(\widetilde{A}_2^U,\widetilde{A}_2^L\right) = \begin{pmatrix}\left(a_{11}^U + a_{21}^U,a_{12}^U + a_{22}^U,a_{13}^U + a_{23}^U,a_{14}^U + a_{24}^U;min\left(H_1\left(\widetilde{A}_1^U\right),H_1\left(\widetilde{A}_2^U\right)\right),min\left(H_2\left(\widetilde{A}_1^U\right),H_2\left(\widetilde{A}_2^U\right)\right)\right),\\ \left(a_{11}^L + a_{21}^L,a_{12}^L + a_{22}^L,a_{13}^L + a_{23}^L,a_{14}^L + a_{24}^L;min\left(H_1\left(\widetilde{A}_1^L\right),H_1\left(\widetilde{A}_2^L\right)\right),min\left(H_2\left(\widetilde{A}_1^L\right),H_2\left(\widetilde{A}_2^L\right)\right)\right)\end{pmatrix} \quad (4)$$

$$\widetilde{A}_1 \ominus \widetilde{A}_2 = \left(\widetilde{A}_1^U,\widetilde{A}_1^L\right) \ominus \left(\widetilde{A}_2^U,\widetilde{A}_2^L\right) = \begin{pmatrix}\left(a_{11}^U - a_{24}^U,a_{12}^U - a_{23}^U,a_{13}^U - a_{22}^U,a_{14}^U - a_{21}^U;min\left(H_1\left(\widetilde{A}_1^U\right),H_1\left(\widetilde{A}_2^U\right)\right),min\left(H_2\left(\widetilde{A}_1^U\right),H_2\left(\widetilde{A}_2^U\right)\right)\right),\\ \left(a_{11}^L - a_{24}^L,a_{12}^L - a_{23}^L,a_{13}^L - a_{22}^L,a_{14}^L - a_{21}^L;min\left(H_1\left(\widetilde{A}_1^L\right),H_1\left(\widetilde{A}_2^L\right)\right),min\left(H_2\left(\widetilde{A}_1^L\right),H_2\left(\widetilde{A}_2^L\right)\right)\right)\end{pmatrix} \quad (5)$$

$$\widetilde{A}_1 \otimes \widetilde{A}_2 = \left(\widetilde{A}_1^U,\widetilde{A}_1^L\right) \otimes \left(\widetilde{A}_2^U,\widetilde{A}_2^L\right) = \begin{pmatrix}\left(a_{11}^U \times a_{21}^U,a_{12}^U \times a_{22}^U,a_{13}^U \times a_{23}^U,a_{14}^U \times a_{24}^U;min\left(H_1\left(\widetilde{A}_1^U\right),H_1\left(\widetilde{A}_2^U\right)\right),min\left(H_2\left(\widetilde{A}_1^U\right),H_2\left(\widetilde{A}_2^U\right)\right)\right),\\ \left(a_{11}^L \times a_{21}^L,a_{12}^L \times a_{22}^L,a_{13}^L \times a_{23}^L,a_{14}^L \times a_{24}^L;min\left(H_1\left(\widetilde{A}_1^L\right),H_1\left(\widetilde{A}_2^L\right)\right),min\left(H_2\left(\widetilde{A}_1^L\right),H_2\left(\widetilde{A}_2^L\right)\right)\right)\end{pmatrix} \quad (6)$$

$$k\widetilde{A}_1 = \left(k \times a_{11}^U,k\times a_{12}^U,k \times a_{13}^U,k \times a_{14}^U;H_1\left(\widetilde{A}_1^U\right),H_2\left(\widetilde{A}_1^U\right)\right), \left(k \times a_{11}^L,k\times a_{12}^L,k \times a_{13}^L,k \times a_{14}^L;H_1\left(\widetilde{A}_1^L\right),H_2\left(\widetilde{A}_1^L\right)\right) \quad (7)$$

$$\frac{\widetilde{A}_1}{k} = \left(\frac{1}{k}\times a_{11}^U,\frac{1}{k}\times a_{12}^U,\frac{1}{k}\times a_{13}^U,\frac{1}{k}\times a_{14}^U;H_1\left(\widetilde{A}_1^U\right),H_2\left(\widetilde{A}_1^U\right)\right), \left(\frac{1}{k}\times a_{11}^L,\frac{1}{k}\times a_{12}^L,\frac{1}{k}\times a_{13}^L,\frac{1}{k}\times a_{14}^L;H_1\left(\widetilde{A}_1^L\right),H_2\left(\widetilde{A}_1^L\right)\right) \quad (8)$$

3.2 IT2 fuzzy DEMATEL

DEMATEL approach is used to identify the importance of different criteria under the complex environment. In addition to this issue, the main advantage of DEMATEL approach is that it can be used to identify the impact relationship map among the criteria. Hence, it can be possible to understand the influencing and influenced criteria. This methodology can be considered with interval type-2 fuzzy logic. In the first step of the analysis process, expert opinions are converted to the interval type-2 fuzzy logic (Dinçer and Yüksel, 2019; Pandey et al., 2019; Dinçer et al., 2019b,c; Tang and Dinçer, 2019). Initial direct relation matrix is generated in the second step as in the equation (9) and (10).

$$\widetilde{Z}=\begin{bmatrix} 0 & \widetilde{z}_{12} & \cdots & \cdots & \widetilde{z}_{1n} \\ \widetilde{z}_{21} & 0 & \cdots & \cdots & \widetilde{z}_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \widetilde{z}_{n1} & \widetilde{z}_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{9}$$

$$\widetilde{Z} = \frac{\widetilde{Z}^1+\widetilde{Z}^2+\widetilde{Z}^3+\ldots\widetilde{Z}^n}{n} \tag{10}$$

Thirdly, this matrix is normalized with the help of the equations (11), (12) and (13).

$$\widetilde{X}=\begin{bmatrix} \widetilde{x}_{11} & \widetilde{x}_{12} & \cdots & \cdots & \widetilde{x}_{1n} \\ \widetilde{x}_{21} & \widetilde{x}_{22} & \cdots & \cdots & \widetilde{x}_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \widetilde{x}_{n1} & \widetilde{x}_{n2} & \cdots & \cdots & \widetilde{x}_{nn} \end{bmatrix} \tag{11}$$

$$\tilde{x}_{ij} = \frac{\tilde{z}_{ij}}{r} = \left(\frac{z_{\acute{a}ij}}{r},\frac{z_{\acute{b}ij}}{r},\frac{z_{\acute{c}ij}}{r},\frac{z_{\acute{d}ij}}{r};H_1\left(z_{ij}^U\right),H_2\left(z_{ij}^U\right)\right),\left(\frac{z_{\acute{e}ij}}{r},\frac{z_{\acute{f}ij}}{r},\frac{z_{\acute{g}ij}}{r},\frac{z_{\acute{h}ij}}{r};H_1\left(z_{ij}^L\right),H_2\left(z_{ij}^L\right)\right) \tag{12}$$

$$r = max\left(max_{1\le i\le n}\sum_{j=1}^{n} Z_{\acute{d}_{ij}},max_{1\le i\le n}\sum_{j=1}^{n} Z_{\acute{d}_{ij}}\right) \tag{13}$$

After that, in the next step, the total influence fuzzy matrix ($\widetilde{T}$) is created by using the equations (14)-(18).

$$X_{\acute{a}}=\begin{bmatrix} 0 & a'_{12} & \cdots & \cdots & a'_{1n} \\ a'_{21} & 0 & \cdots & \cdots & a'_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a'_{n1} & a'_{n2} & \cdots & \cdots & 0 \end{bmatrix}, \ldots, X_{\acute{h}}=\begin{bmatrix} 0 & h'_{12} & \cdots & \cdots & h'_{1n} \\ h'_{21} & 0 & \cdots & \cdots & h'_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ h'_{n1} & h'_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{14}$$

$$\widetilde{T} = \lim_{k\to\infty} \widetilde{X} + \widetilde{X}^2 + \ldots + \widetilde{X}^k \tag{15}$$

$$\widetilde{T}=\begin{bmatrix} \widetilde{t}_{11} & \widetilde{t}_{12} & \cdots & \cdots & \widetilde{t}_{1n} \\ \widetilde{t}_{21} & \widetilde{t}_{22} & \cdots & \cdots & \widetilde{t}_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \widetilde{t}_{n1} & \widetilde{t}_{n2} & \cdots & \cdots & \widetilde{t}_{nn} \end{bmatrix} \tag{16}$$

$$\tilde{t}_{ij} = \left(a''_{ij},b''_{ij},c''_{ij},d''_{ij};H_1\left(\tilde{t}_{ij}{}^U\right),H_2\left(\tilde{t}_{ij}{}^U\right)\right),\left(e''_{ij},f''_{ij},g''_{ij},h''_{ij};H_1\left(\tilde{t}_{ij}{}^L\right),H_2\left(\tilde{t}_{ij}{}^L\right)\right) \tag{17}$$

$$\left[a''_{ij}\right] = X_{\acute{a}} \times (I - X_{\acute{a}})^{-1},\ldots,\ \left[h''_{ij}\right] = X_{\acute{h}} \times \left(I - X_{\acute{h}}\right)^{-1} \tag{18}$$

Finally, the influence degrees are calculated as in the equations (19) and (20).

$$\widetilde{D}_i = \left[\sum_{j=1}^{n} \tilde{t}_{ij}\right]_{n\times 1}' \tag{19}$$

$$\widetilde{R}_i = \left[\sum_{i=1}^{n} \tilde{t}_{ij}\right]_{1\times n} \tag{20}$$

The sum of all vector rows is represented by $\widetilde{D}_i$ whereas the sum of all vector columns is named as $\widetilde{R}_i$. Hence, $\left(\widetilde{D}_i + \widetilde{R}_i\right)$ demonstrates the total degree of the influence among criteria. Also, the defuzzification process is performed to calculate the weighting results of criteria as in the equations (21)-(24).

$$Def_T = \frac{\frac{(u_U-l_U)+(\beta_U\times m_{1U}-l_U)+(\alpha_U\times m_{2U}-l_U)}{4}+l_U+\left[\frac{(u_L-l_L)+(\beta_L\times m_{1L}-l_L)+(\alpha_L\times m_{2L}-l_L)}{4}+l_L\right]}{2} \tag{21}$$

$$Def_T = T = \left[t_{ij}\right]_{n\times n},\ i,j = 1,2,\ldots,n \tag{22}$$

$$\widetilde{D}_i^{def} = r = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} = (r_i)_{n\times 1} = (r_1,\ldots,r_i,\ldots,r_n) \quad (23)$$

$$\widetilde{R}_i^{def} = y = \left[\sum_{i=1}^{n} t_{ij}\right]'_{1\times n} = (y_j)'_{1\times n} = (y_1,\ldots,y_i,\ldots,y_n) \quad (24)$$

3.3 Interval type 2 fuzzy TOPSIS

TOPSIS approach is a type of multicriteria decision making models. The main aim of this methodology is to rank different alternatives (Opricovic and Tzeng, 2004). In this process, positive (A^+) and negative (A^-) ideal solutions are identified. They are demonstrated on the equation (25). In this equation, the term v_{ij} gives information about the weighted values (Yüksel et al., 2019).

$$A^+ = max\,(v_1,v_2,v_3,\ldots v_n) \quad (25)$$

In addition to this process, the values of D+ and D- are computed as in the equations (26) and (27) (Chen et al., 2019).

$$D_i^+ = \sqrt{\sum_{i=1}^{m} (v_i - A_i^+)^2} \quad (26)$$

$$D_i^- = \sqrt{\sum_{i=1}^{m} (v_i - A_i^-)^2} \quad (27)$$

Moreover, the closeness coefficient (CCi) is calculated in the final step. The details are shown in the equation (28) (Efe, 2019).

$$CC_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad (28)$$

4 Analysis

In this study, it is aimed to analyze the house of quality-based factors of green supply chain management for the sustainable investment decisions. For this purpose, a hybrid model based on interval type 2 fuzzy sets is proposed. The steps of the analysis are detailed as follows.

Step 1. Define the problem of customer and technical factors of green supply chain management. For that, a set of criteria is defined with the supported literature as seen in Table 1 and 2 respectively.

Table 1 Customer Expectations of Green Supply Chain Management

Criteria	Literature
Reducing the pollution (Criterion 1)	(Franzoni, 2011; Khoshnava et. al., 2018; Sun et. al., 2017)
Clean energy sources (Criterion 2)	(Bhattacharya et. al., 2015; Tao et. al., 2016; Kucukvar et. al., 2016)
Reuse of product and services (Criterion 3)	(Kriwet et. al., 1995; Ferrer, 1997; Krikke et. al., 1999)
Varieties of distribution channels (Criterion 4)	(Onat et. al., 2015; Doll et. al. 2017)

Table 2 Technical Requirements of Green Supply Chain Management

Criteria	Literature
Waste management (Criterion 1)	(Deif , 2011; Islam et. al., 2017)
Energy efficiency (Criterion 2)	(Klassen and Whybark, 1999; Vachon, 2007; Baines et. al, 2012)
Recycling process (Criterion 3)	(Johnson and Wang, 1995; Mishra et. al., 2012; Misni and Lee, 2017)
Integrated transport systems (Criterion 4)	(Jensen et. al., 2001; Jensen, 2008; Martinsen and Björklund, 2012)

Step 2. Appoint the expert team to collect the linguistic evaluation for the criteria. Three decision makers are selected from the industry. They are experienced at least ten years in the field of clean technology and supply chain. The expert valuation results for the customer and technical criteria are given by using the linguistic scales in Table 3 and 4. And the results are illustrated in Table 5 and 6.

Table 3 Evaluation Scales for the Criteria

Criteria	IT2TrFNs
Absolutely Low (AL)	((0.0,0.0,0.0,0.0;1.0), (0.0,0.0,0.0,0.0;1.0))
Very Low (VL)	((0.0075, 0.0075, 0.015, 0.0525;0.8), (0.0,0.0,0.02,0.07;1.0))
Low (L)	((0.0875, 0.12, 0.16, 0.1825;0.8), (0.04,0.10,0.18,0.23;1.0))
Medium Low (ML)	((0.2325, 0.255, 0.325, 0.3575;0.8), (0.17,0.22,0.36,0.42;1.0))
Medium (M)	((0.4025, 0.4525, 0.5375, 0.5675;0.8), (0.32,0.41,0.58,0.65;1.0))
Medium High (MH)	((0.65, 0.6725, 0.7575, 0.79;0.8), (0.58,0.63,0.80,0.86;1.0))
High (H)	((0.7825, 0.815, 0.885, 0.9075;0.8), (0.72,0.78,0.92,0.97;1.0))
Very High (VH)	((0.9475, 0.985, 0.9925, 0.9925;0.8), (0.93,0.98,1.0,1.0;1.0))
Absolutely High (AH)	((1.0, 1.0, 1.0, 1.0; 1.0), (1.0, 1.0, 1.0, 1.0; 1.0))

Table 4 Evaluation Scales for the Alternatives

Alternatives	IT2TrFNs
Very Poor (VP)	((0,0,0,0.1;1,1), (0,0,0,0.05;0.9,0.9))
Poor (P)	((0,0.1,0.1,0.3;1,1), (0.05,0.1,0.1,0.2;0.9,0.9))
Medium Poor (MP)	((0.1,0.3,0.3,0.5;1,1), (0.2,0.3,0.3,0.4;0.9,0.9))
Fair (F)	((0.3,0.5,0.5,0.7;1,1), (0.4,0.5,0.5,0.6;0.9,0.9))
Good (G)	((0.5,0.7,0.7,0.9;1,1), (0.6,0.7,0.7,0.8;0.9,0.9))
Very Good (VG)	((0.7,0.9,0.9,1;1,1), (0.8,0.9,0.9,0.95;0.9,0.9))
Best (B)	((0.9,1,1,1;1,1), (0.95,1,1,1;0.9,0.9))

Table 5 Linguistic Evaluations for the Criteria of Customer Expectation

	C1			C2			C3			C4		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
C1	-	-	-	M	M	MH	M	M	MH	M	ML	M
C2	M	M	M	-	-	-	ML	M	MH	ML	M	M
C3	MH	MH	M	MH	MH	M	-	-	-	M	M	MH
C4	MH	MH	MH	MH	MH	M	M	M	MH	-	-	-

Table 6 Linguistic Evaluations of Technical Requirements for the Decision Matrix

Criteria/Alternatives	Waste management (Alternative 1)			Energy efficiency (Alternative 2)			Recycling process (Alternative 3)			Integrated transport systems (Alternative 4)		
	DM1	DM2	DM3	DM 1	DM 2	DM 3	DM 1	DM 2	DM 3	DM 1	DM 2	DM 3
Reducing the pollution (Criterion 1)	VG	B	B	G	F	F	G	VG	G	MP	F	F
Clean energy sources (Criterion 2)	B	B	VG	G	F	VG	G	VG	F	G	MP	MP
Reuse of product and services (Criterion 3)	G	G	G	G	F	F	B	B	VG	G	VG	F
Varieties of distribution channels (Criterion 4)	G	F	MP	F	F	F	G	F	F	B	B	B

Step 3. Weight the criteria of customer expectations. For this purpose, the computation procedures of interval type 2 fuzzy DEMATEL is applied and the results are given in Table 7.

Table 7 Defuzzified Total Relation Matrix and the Weights for the Criteria

	C1	C2	C3	C4	r	y	r+y	r-y	Weights
C1	3.43	3.59	3.33	3.03	13.37	14.83	28.21	-1.46	0.251
C2	3.36	3.25	3.14	2.87	12.61	14.89	27.50	-2.28	0.245
C3	3.97	3.99	3.54	3.38	14.88	13.78	28.66	1.10	0.255
C4	4.08	4.07	3.77	3.31	15.23	12.59	27.83	2.64	0.248

According to the results, Criterion 3 has the highest importance in the criteria of customer expectations while criterion 2 is the weakest important factor among the criteria set.

Step 4. Rank the alternatives of technical requirements. The method of TOPSIS based on the interval type 2 fuzzy sets is applied for measuring the house of quality-based performance of green supply chain management for the sustainable investment decisions. The results are represented in Table 8.

Table 8 Ranking Results for the Performance Measurement

	D+	D-	Ci	Ranking
Waste management (Alternative 1)	0.853	1.141	0.572	1
Energy efficiency (Alternative 2)	1.206	0.438	0.266	4
Recycling process (Alternative 3)	0.819	0.886	0.520	2
Integrated transport systems (Alternative 4)	1.196	0.775	0.393	3

The ranking results demonstrate that waste management (alternative 1) has the best house of quality-based performance of technical requirement for the green supply chain management whereas energy efficiency (alternative 2) is ranked at last among the technical requirements.

5 Conclusion

This study aims to evaluate the green supply chain management for the sustainable investment decisions. For this purpose, the house of quality-based factors of green supply chain management for the sustainable investment decisions are determined. In this framework, 4 different criteria are defined related to the customer expectations of green supply chain management. On the other side, with respect to the technical requirements, different 4 factors are identified based on literature review. In the analysis process, the criteria of customer expectations are weighted by using interval type-2 fuzzy DEMATEL. Additionally, with the help of interval type-2 fuzzy TOPSIS method, the alternatives of technical requirements are ranked.

The results show that reuse of product and services (Criterion 3) has the highest weight. In addition, it is also determined that reducing the pollution (Criterion 1) is the second most important criterion. The issue of product reuse is the most prominent aspect in green supply chain management. The main reason for this is that thanks to re-used products, companies have the opportunity to reduce costs. This has a direct and significant impact on the profitability of these companies. In the literature, (Kriwet et. al., 1995; Ferrer, 1997; Krikke et. al., 1999) reached the similar conclusion.

In addition to them, the ranking results indicate that waste management (alternative 1) has the best house of quality-based performance of technical requirement for the green supply chain management. On the other side, energy efficiency (alternative 2) takes the second-best place among the technical requirements. As can be seen from these results, companies should make technological investments in waste management. The waste management process involves the use of many comprehensive machines, materials and equipment. In this framework, it is important that companies provide these tools and equipment in the context of innovative strategy. However, qualified personnel capable of using this equipment should also be employed. Existing personnel are also required to receive the necessary training. This will provide the necessary technical competencies for an efficient green supply chain investment. In the future studies, a different methodology can be considered to make a comparative analysis.

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