Karadeniz Fen Bilimleri Dergisi, 12(1), 296-316, 2022. DOI: 10.31466/kfbd.1060512

KFBD

Karadeniz Fen Bilimleri Dergisi

The Black Sea Journal of Sciences

ISSN (Online): 2564-7377

Araştırma Makalesi / Research Article

Green Supplier Selection in the Textile Industry Using MCDM Methods Under the Interval-Valued Intuitionistic Fuzzy Environment

Melda KOKOÇ[1*]

Abstract

The importance of protecting the environment is increasing day by day due to environmental concerns such as global warming, human toxicity, eutrophication, and water scarcity. For this reason, companies have started to change their production processes to be enviromentally friendly. One of the necessary changes is to supply raw materials and/or products that are less harmful to the environment. Therefore, companies have to procure raw materials and/or products from green suppliers. This study, it is aimed to evaluate green suppliers for a textile industry under the interval-valued intuitionistic fuzzy (IVIF) environment, considering various environmental and economic criteria. AHP and TOPSIS methods are integrated under the IVIF environment to be used in the evaluation process of green suppliers. In the integrated method, the IVIF-AHP method is used to calculate criterion weights and the IVIF-TOPSIS method is used to rank green suppliers. At the end of the study, a sensitivity analysis is conducted to observe the effects of changes in the weights of the criteria in the selection of green suppliers for the textile industry.

Keywords: AHP, IVIF sets, MCDM, supplier selection, textile industry, TOPSIS

Aralık-Değerli Sezgisel Bulanık Ortamda ÇKKV Yöntemleri Kullanılarak Tekstil Endüstrisinde Yeşil Tedarikçi Seçimi

Öz

Küresel ısınma, insan toksisitesi, ötrofikasyon, su kıtlığı gibi çevresel kaygılar nedeniyle çevreyi korumanın önemi her geçen gün artmaktadır. Bu nedenle firmalar üretim süreçlerini çevre dostu olacak şekilde değiştirmeye başlamışlardır. Gerekli değişikliklerden biri, çevreye daha az zarar veren hammadde ve/veya ürünler tedarik etmektir. Bu nedenle şirketler, yeşil tedarikçilerden hammadde ve/veya ürün tedarik etmek zorundadır. Bu çalışmada, bir tekstil endüstrisi için yeşil tedarikçilerin çeşitli çevresel ve ekonomik kriterler göz önünde bulundurularak aralık-değerli sezgisel bulanık (ADSB) ortamda değerlendirilmesi amaçlanmıştır. AHP ve TOPSIS yöntemleri, yeşil tedarikçilerin değerlendirme sürecinde kullanılmak üzere ADSB ortamda entegre edilmiştir. Entegre edilen yöntemde, ADSB-AHP yöntemi kriter ağırlıklarını hesaplamak için ve ADSB-TOPSIS yöntemi, yeşil tedarikçileri sıralamak için kullanılmıştır. Çalışmanın sonunda, tekstil sektörü için yeşil tedarikçi seçiminde kriterlerin ağırlıklarındaki değişikliklerin etkilerini gözlemlemek için bir duyarlılık analizi yapılmıştır.

Keywords: AHP, ADSB kümeler, ÇKKV, tedarikçi seçimi, tekstil endüstrisi, TOPSIS

[1]Gazi University, Rectorate, 06560, Ankara, Turkey, meldakokoc@gazi.edu.tr

[1]https://orcid.org/0000-0003-2035-9777

[*]**Sorumlu Yazar/Corresponding Author** **Geliş/Received:** 20.01.2022 **Kabul/Accepted:** 24.05.2022

1. Introduction

All over the world awareness of both firms and consumers on the environmental consciousness has increased over the past three decades. Consumers request from firms to satisfy their expectations at the highest level with eco-friendly products (Ecer, 2020). Therefore, being a respectful company is closely related to the improvement of production and supply processes in the production of environmentally friendly products and services, the limitation of hazardous materials, recycling activities, etc. In today’s globalized world, green supplier selection (GSS) has been a very significant issue for companies because of government regulations, environmental protection interests, rapidly depleting natural resources, and stronger public awareness about environmental issues (Javad and Javad, 2020). GSS requires the inclusion of environmental criteria such as recycling, air pollution, and energy efficiency into the conventional criteria such as cost, service level, and quality in the supplier selection (SS) process. In other words, GSS integrates environmental protection awareness into conventional SS. (Banaeian, Mobli, Fahimnia, Nielsen, and Omid, 2018).

The textile and apparel industries are among the biggest polluters on the planet. Therefore, the textile and apparel industry needs to adapt to environmentally friendly practices to reduce environmental concerns such as global warming, human toxicity, eutrophication, water scarcity, etc. That is why the green supplier's selection for the textile supply chain has become a key strategy. Research on green supplier evaluation has taken more attention day by day from academic and industrial sectors (Guo, Liu, Zhang, and Yang, 2017). Especially, this research area has been popular in the literature for the last 20 years. However, it is seen that the studies on GSS for the textile sector have been carried out especially in the last 6 years and there are few papers on this subject in the literature. Some studies on GSS in the textile industry are presented in Table 1.

Acar, Onden, and Gurel (2016) analysed green and other criteria in the SS for the textile industry by 28 experts using the fuzzy AHP. Amindoust and Saghafinia (2017) offered a modular fuzzy inference system model to evaluate textile suppliers considering sustainability criteria. Guo et al. (2017) developed a FAD based MCDM framework to assess the supplier performance. Gören and Şenocak (2018) offered an integrated model including Taguchi loss functions and MACBETH to solve the GSS problem. In this model weights of criteria were calculated by using MACBETH and then suppliers were ranked by using Taguchi loss functions considering weights of criteria. B. Ecer, Aktas, and Kabak (2019) integrated AHP and VIKOR methods to determine the best green suppliers. Guarnieri and Trojan (2019) developed a multi-criteria model by integrating Copeland’s method, AHP, and ELECTRE-TRI methods to support the SS process. Ulutas, Topal, and Bakhat (2019) developed a methodology to assess and rank green suppliers. In this methodology, FPSI was used to determine the weights of attributes, and FROV was used to rank the suppliers.

Table 1. Literature review on GSS in textile industry.

Author(s)	Method(s)	Main Criteria	Sets
Acar et al. (2016)	FAHP	Cost, Delivery, Environmental management, Pollution control, Service, Green product, Quality, Strategic alliance	Fuzzy sets
Guo et al. (2017)	FAD-based MCDM Method	Quality, Cost, Delivery, Technology, Service, Environmental competency	Fuzzy sets
Amindoust and Saghafinia (2017)	Fuzzy Inference System Model	Quality, Cost, Delivery, Labour health and work safety, Environmental management system, Pollution control, Inventory level reduction, Social equities,	Fuzzy sets
Gören and Şenocak (2018)	MACBETH, Taguchi Loss Function	Quality, Production capacity, Delivery time, Price, Management and organization, Service level, Environmental competencies	Crisp sets
Guarnieri and Trojan (2019)	Copeland's method, AHP, ELECTRE-TRI	Traditional criteria, Socio-environmental criteria	Crisp sets
B. Ecer et al. (2019)	AHP, VIKOR	Green design, Green packaging, Green image, Green production, Environmental management system	Crisp sets
Ulutas et al. (2019)	FROV, FPSI	Cost, Defective rate, Green transportation, Environmental management, Green warehousing, Late delivery rate, Pollution control, Technical assistance, Technological capability,	Fuzzy sets
Yang and Wang (2020)	FAHP, FTOPSIS	Economic criteria, Social criteria, Environmental criteria	Fuzzy sets
Celik, Yucesan, and Gul (2021)	IT2F-BWM, IT2F-TODIM	Environmental, Business structure of supplier, Quality, Social, Cost/Price, Risk, Capability of supplier	Interval type-2 fuzzy numbers

Yang and Wang (2020) proposed an integrated MCDM model using the fuzzy AHP and the fuzzy TOPSIS to analyse suppliers according to green innovation criteria in textile manufacturing companies in China. Celik et al. (2021) combined BWM and TODIM methods under the IT2FSs. IT2FBWM is used to determine evaluation criteria and IT2F-TODIM is used to select a green supplier. Because a lot of studies are conducted in the literature concerning GSS, an overview of the articles related to the textile industry is analysed. Generally, authors (s) preferred different MCDM methods such as AHP, VIKOR, and TOPSIS because of the multi-criteria nature of the GSS. Another notable point is the set type. Some authors (B. Ecer et al., 2019; Gören and Şenocak, 2018; Guarnieri and Trojan, 2019) use crisp sets to evaluate and select suppliers. But, in some complex real life problems, decision makers may not have adequate information to assign crisp values. Some authors (Acar et al., 2016; Amindoust and Saghafinia, 2017; Guo et al., 2017; Ulutas et al., 2019; Yang and Wang, 2020) use fuzzy sets to deal with the ambiguity of linguistic terms. However, the fuzzy sets theory is not enough to define the linguistic terms due to the fact that the belonging of the element to the set is represented by the only membership degree in the fuzzy set theory (Abdullah and Najib, 2014; Boran, Genc, Kurt, and Akay, 2009; Tooranloo andIranpour, 2017). Furthermore, it is determined that the hesitant degree is not taken into account in the papers on this research area. The hesitant degree plays an important role when the membership and non-membership degrees are not very different for two IVIFSs. Also, the hesitant degree is effective to describe the human nature of linguistic terms.

Many authors (Abdullah and Najib, 2014; S. M. Chen, Yang, Yang, Sheu, and Liau, 2012; T. Y. Chen, Wang, and Lu, 2011; Kokoc and Ersoz, 2021; Oztaysi, Onar, Kahraman, and Yavuz, 2017; Tooranloo and Iranpour, 2017) support that IVIF sets are more effective than crisp sets or fuzzy sets to represent human opinions. IVIF sets theory has been applied in a wide variety of fields by adapting it with different methods in the literature. A detailed literature study on the application areas and the methods of IVIF sets theory is included in Kokoc and Ersoz (2021)'s study.

With this motivation, in this study, an integrated MCDM method considering both the environmental protection criteria and the traditional SS criteria for GSS is developed under the IVIF environment. This MCDM method utilizes IVIF sets' strength in describing the membership, non-membership, and hesitancy for expert evaluations. The first stage gives the criteria weights by using the IVIF-AHP method that an extended version of the method suggested by Onar et al. (2015). This extension is performed by integrating the formula used to calculate weights of experts and consistency analysis into the Onar et al. (2015)'s method. The second stage using IVIF-TOPSIS proposed by Oztaysi et al. (2017) gives the rank of alternative based on criteria weights.

The consistency of IVIF sets in preference relations is conducted so as to check the quality of judgments provided by experts with paired comparisons. However, some studies that proposed the MCDM method for IVIF sets (Kahraman, Oztaysi, and Onar, 2020; Onar, Oztaysi, Otay, and Kahraman, 2015; Oztaysi et al., 2017; Tooranloo and Iranpour, 2017; Wu, Huang, and Cao, 2013) disregard the consistency analysis. In the proposed MCDM method, the multiplicative consistency analysis proposed by Liao, Xu, and Xia (2014) is used to check the consistency of PCMs.

The proposed model follows a multi-criteria modelling process, which includes: i) definition of objective and criteria; ii) calculation of weights for criteria by using IVIF-AHP; iii) evaluation of green suppliers on the criteria by using IVIF-TOPSIS. To the best of the authors' knowledge, this study is the first in which IVIF-AHP and IVIF-TOPSIS are used in GSS in the textile industry. This study also stands out with its use of IVIF sets in this research area.

The rest of the paper is organized as follows. The preliminaries about IVIF sets theory are presented in "Materials and Methods" section. Then, the proposed MCDM model for GSS is explained in this section. In "Results and Discussion" section, the case study is performed for the textile industry and the results are presented. In addition, a sensitivity analysis is conducted to observe the changing of the alternatives' ranking with respect to the possible changes of criteria' weights. In the last section, this study is summarized.

2. Materials and Methods

Here, basic definitions, operators, and relations are explained for the IVIFSs. The hybrid method in which IVIF-TOPSIS and IVIF-AHP methods are integrated is detailed. Furthermore, the case study is performed for GSS in the textile industry.

2.1.Preliminaries

Definition 1 (Atanassov andGargov, 1989) Let *IVIFS(X)* denotes the family of all the *IVIFSs* over the universe of discourse $X=\{x_1,x_2,...,x_n\}$ and $\tilde{A}\in IVIFS(X)$ be an IVIFV given by $\tilde{A}=\left\langle\left[\mu_{\tilde{A}}^L(x),\mu_{\tilde{A}}^U(x)\right],\left[v_{\tilde{A}}^L(x),v_{\tilde{A}}^U(x)\right]\right\rangle$. In addition, the hesitancy degree of $\tilde{A}$ is defined as $\pi_{\tilde{A}}=\left[\pi_{\tilde{A}}^L(x),\pi_{\tilde{A}}^U(x)\right]=\left\langle\left[1-\mu_{\tilde{A}}^U(x)-v_{\tilde{A}}^U(x)\right],\left[1-\mu_{\tilde{A}}^L(x)-v_{\tilde{A}}^L(x)\right]\right\rangle$.

Definition 2 (Atanassov andGargov, 1989) Let $\tilde{A},\tilde{B}\in IVIFS(X)$. A subset relation $\tilde{A}\subset\tilde{B}$ is represented as below.

$\tilde{A}\subset\tilde{B}\Leftrightarrow \mu_{\tilde{A}}^L(x)\le\mu_{\tilde{B}}^L(x)$, $\mu_{\tilde{A}}^U(x)\le\mu_{\tilde{B}}^U(x)$, $v_{\tilde{A}}^L(x)\ge v_{\tilde{B}}^L(x)$ and $v_{\tilde{A}}^U(x)\ge v_{\tilde{B}}^U(x)$, $\forall x\in X$.

In addition, $\tilde{A}=\tilde{B}\Leftrightarrow\tilde{A}\subset\tilde{B}$ and $\tilde{A}\supset\tilde{B}$.

Definition 3 (Xu, 2007) Let $\tilde{A}_j=([\mu_{\tilde{A}_j}^L(x),\mu_{\tilde{A}_j}^U(x)],[v_{\tilde{A}_j}^L(x),v_{\tilde{A}_j}^U(x)])$ for $j=1,2,...,n$ is a collection of IVIFVs. The IVIF weighted arithmetic (IVIFWA) operator are defined as:

$$IVIFWA_\omega(\tilde{A}_1,\tilde{A}_2,...,\tilde{A}_n)=\sum_{j=1}^{n}\omega_j\tilde{A}_j$$
$$=\left(\left[1-\prod_{j=1}^{n}\left(1-\mu_{\tilde{A}_j}^L\right)^{\omega_j},1-\prod_{j=1}^{n}\left(1-\mu_{\tilde{A}_j}^U\right)^{\omega_j}\right],\left[\prod_{j=1}^{n}\left(v_{\tilde{A}_j}^L\right)^{\omega_j},\prod_{j=1}^{n}\left(v_{\tilde{A}_j}^U\right)^{\omega_j}\right]\right) \quad (1)$$

where ω_j is the weight of IVIFVs under condition $\omega_j\in[0,1]$ and $\sum_{j=1}^{n}\omega_j=1$.

2.2.Hybrid MCDM Methodology

The procedure for performing the proposed framework is defined below step by step:

Step 1. Determine the weights of experts by using Equation 2 proposed by Mishra et al. (2020), considering the preference scale in Table 2.

$$\lambda_k = \frac{\mu_k^L + \pi_k^L \left(\frac{\mu_k^L}{\mu_k^L + v_k^L} \right) + \mu_k^U + \pi_k^U \left(\frac{\mu_k^U}{\mu_k^U + v_k^U} \right)}{\sum_{k=1}^{l} \mu_k^L + \pi_k^L \left(\frac{\mu_k^L}{\mu_k^L + v_k^L} \right) + \mu_k^U + \pi_k^U \left(\frac{\mu_k^U}{\mu_k^U + v_k^U} \right)} \quad (2)$$

Table 2. Preference scale for weights of experts.

Linguistic Terms	Corresponding IVIFVs
Very important-(VI)	([0.80,0.95], [0.00,0.05])
Important-(I)	([0.65,0.75], [0.15,0.20])
Medium-(M)	([0.45,0.55], [0.30,0.45])
Unimportant-(U)	([0.20,0.30], [0.55,0.70])
Very unimportant-(VU)	([0.00,0.10], [0.80,0.90])

Step 2. Create the linguistic pairwise comparison matrix (PCM) of criteria considering the expert's opinion for each expert as in Table 3.

Table 3. Linguistic PCM.

Expert k	Criterion 1	Criterion 2	…	Criterion n
Criterion 1	EE			
Criterion 2		EE		
…			EE	
Criterion n				EE

Step 3. Convert the linguistic terms to their corresponding IVIF sets using Table 4 to obtain an individual IVIF PCM $\tilde{R}_k$ for each expert. $\tilde{R}_k = (\tilde{r}_{ijk})_{nxn} = ([\mu_{ijk}^L, \mu_{ijk}^U],[v_{ijk}^L, v_{ijk}^U])_{nxn}$ are formed as in Equation 3 where $i(i=1,2,...,n)$ and $j(j=1,2,...,n)$ represent criterion number. The reciprocal value of the $([\mu_{ijk}^L, \mu_{ijk}^U],[v_{ijk}^L, v_{ijk}^U])$ in $\tilde{R}_k$ is denoted as $([v_{ijk}^L, v_{ijk}^U],[\mu_{ijk}^L, \mu_{ijk}^U])$. For exactly equal (EE) it is assigned that ([0.5, 0.5], [0.5, 0.5]) with the reciprocal value ([0.5, 0.5], [0.5, 0.5]).

Table 4. Preference scale for weights of criteria.

Linguistic Terms	IVIFVs
Absolutely High-(AH)	([0.80,0.85], [0.05,0.10])
Very High-(VH)	([0.75,0.80], [0.10,0.15])
High-(H)	([0.65,0.70], [0.15,0.20])
Medium High-(MH)	([0.55,0.60], [0.25,0.30])
Approximately Equal-(AE)	([0.40,0.45], [0.35,0.45])
Medium Low-(ML)	([0.25,0.30], [0.55,0.60])
Low-(L)	([0.15,0.20], [0.65,0.70])
Very Low-(VL)	([0.10,0.15], [0.75,0.80])
Absolutely Low-(AL)	([0.05,0.10], [0.80,0.85])

$$\tilde{R}_k = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \\ \left[\mu^L_{11k},\mu^U_{11k}\right],\left[v^L_{11k},v^U_{11k}\right] & \left[\mu^L_{12k},\mu^U_{12k}\right],\left[v^L_{12k},v^U_{12k}\right] & \cdots & \left[\mu^L_{1nk},\mu^U_{1nk}\right],\left[v^L_{1nk},v^U_{1nk}\right] \\ \left[\mu^L_{21k},\mu^U_{21k}\right],\left[v^L_{21k},v^U_{21k}\right] & \left[\mu^L_{22k},\mu^U_{22k}\right],\left[v^L_{22k},v^U_{22k}\right] & \cdots & \left[\mu^L_{2nk},\mu^U_{2nk}\right],\left[v^L_{2nk},v^U_{2nk}\right] \\ \vdots & \vdots & \ddots & \vdots \\ \left[\mu^L_{n1k},\mu^U_{n1k}\right],\left[v^L_{n1k},v^U_{n1k}\right] & \left[\mu^L_{n2k},\mu^U_{n2k}\right],\left[v^L_{n2k},v^U_{n2k}\right] & \cdots & \left[\mu^L_{nnk},\mu^U_{nnk}\right],\left[v^L_{nnk},v^U_{nnk}\right] \end{array} \quad (3)$$

Step 4. Analyse the consistency of each IVIF PCM by using the multiplicative consistency analysis proposed by Liao, Xu, and Xia (2014). Consistency analysis stages are explained below.

(1) A perfect (or approximate) multiplicative consistent matrix ($\bar{R} = (\bar{r}_{ij})_{nxn}$) is constructed using following rules.

(i) For $j > i+1$, let $\bar{r}_{ij} = \left(\left[\bar{\mu}^L_{ij},\bar{\mu}^U_{ij}\right],\left[\bar{v}^L_{ij},\bar{v}^U_{ij}\right]\right)$ where

$$\bar{\mu}^L_{ij} = \frac{\sqrt[j-i-1]{\prod_{k=i+1}^{j-1}\mu^L_{ik}\mu^L_{kj}}}{\sqrt[j-i-1]{\prod_{k=i+1}^{j-1}\mu^L_{ik}\mu^L_{kj}} + \sqrt[j-i-1]{\prod_{k=i+1}^{j-1}(1-\mu^L_{ik})(1-\mu^L_{kj})}}, \quad \bar{\mu}^U_{ij} = \frac{\sqrt[j-i-1]{\prod_{k=i+1}^{j-1}\mu^U_{ik}\mu^U_{kj}}}{\sqrt[j-i-1]{\prod_{k=i+1}^{j-1}\mu^U_{ik}\mu^U_{kj}} + \sqrt[j-i-1]{\prod_{k=i+1}^{j-1}(1-\mu^U_{ik})(1-\mu^U_{kj})}}$$

$$\bar{v}^L_{ij} = \frac{\sqrt[j-i-1]{\prod_{k=i+1}^{j-1}v^L_{ik}v^L_{kj}}}{\sqrt[j-i-1]{\prod_{k=i+1}^{j-1}v^L_{ik}v^L_{kj}} + \sqrt[j-i-1]{\prod_{k=i+1}^{j-1}(1-v^L_{ik})(1-v^L_{kj})}}, \quad \bar{v}^U_{ij} = \frac{\sqrt[j-i-1]{\prod_{k=i+1}^{j-1}v^U_{ik}v^U_{kj}}}{\sqrt[j-i-1]{\prod_{k=i+1}^{j-1}v^U_{ik}v^U_{kj}} + \sqrt[j-i-1]{\prod_{k=i+1}^{j-1}(1-v^U_{ik})(1-v^U_{kj})}}$$

(ii) For $j = i+1$, let $\bar{r}_{ij} = r_{ij}$.

(iii) For $j < i$, let $\bar{r}_{ij} = \left(\left[\bar{v}^L_{ji},\bar{v}^U_{ji}\right],\left[\bar{\mu}^L_{ji},\bar{\mu}^U_{ji}\right]\right)$.

(iv) End.

(2) Let p is the number of iterations, N is the maximum number of iteration, and τ is the consistency threshold. Assuming σ = 1/N be the iteration step, the distance between the $R^{(p)}$ and $\bar{R}$ is calculated using Equation 4. If $d(\bar{R}, R^{(p)}) < \tau$, then output $R^{(p)}$; otherwise go to next stage.

$$d(\bar{R}, R^{(p)}) = \frac{1}{4(n-1)(n-2)} \sum_{i=1}^{n-1} \sum_{k=i+1}^{n} \begin{pmatrix} \left|\bar{\mu}_{ij}^{L} - \mu_{ij}^{L(p)}\right| + \left|\bar{\mu}_{ij}^{U} - \mu_{ij}^{U(p)}\right| + \left|\bar{v}_{ij}^{L} - \bar{v}_{ij}^{L(p)}\right| + \\ \left|\bar{v}_{ij}^{U} - \bar{v}_{ij}^{U(p)}\right| + \left|\bar{\pi}_{ij}^{L} - \bar{\pi}_{ij}^{L(p)}\right| + \left|\bar{\pi}_{ij}^{U} - \bar{\pi}_{ij}^{U(p)}\right| \end{pmatrix} \quad (4)$$

(3) The inconsistent matrix is repaired using the following equations, where $i, j = 1, 2, ..., n$. After the inconsistent matrix is repaired, the distance is recalculated by returning to the previous stage.

$$\hat{\mu}_{ij}^{L(p)} = \frac{(\mu_{ij}^{L(p)})^{1-p\sigma}(\bar{\mu}_{ij}^{L})^{p\sigma}}{(\mu_{ij}^{L(p)})^{1-p\sigma}(\bar{\mu}_{ij}^{L})^{p\sigma} + (1-\mu_{ij}^{L(p)})^{1-p\sigma}(1-\bar{\mu}_{ij}^{L})^{p\sigma}}, \quad \hat{\mu}_{ij}^{U(p)} = \frac{(\mu_{ij}^{U(p)})^{1-p\sigma}(\bar{\mu}_{ij}^{U})^{p\sigma}}{(\mu_{ij}^{U(p)})^{1-p\sigma}(\bar{\mu}_{ij}^{U})^{p\sigma} + (1-\mu_{ij}^{U(p)})^{1-p\sigma}(1-\bar{\mu}_{ij}^{U})^{p\sigma}}$$

$$\hat{v}_{ij}^{L(p)} = \frac{(v_{ij}^{L(p)})^{1-p\sigma}(\bar{v}_{ij}^{L})^{p\sigma}}{(v_{ij}^{L(p)})^{1-p\sigma}(\bar{v}_{ij}^{L})^{p\sigma} + (1-v_{ij}^{L(p)})^{1-p\sigma}(1-\bar{v}_{ij}^{L})^{p\sigma}}, \quad \hat{v}_{ij}^{U(p)} = \frac{(v_{ij}^{U(p)})^{1-p\sigma}(\bar{v}_{ij}^{U})^{p\sigma}}{(v_{ij}^{U(p)})^{1-p\sigma}(\bar{v}_{ij}^{U})^{p\sigma} + (1-v_{ij}^{U(p)})^{1-p\sigma}(1-\bar{v}_{ij}^{U})^{p\sigma}}$$

Step 5. Aggregate the consistent IVIF PCMs using IVIFWA operator to obtain collective IVIF PCM $\tilde{R} = (\tilde{r}_{ij})_{nxn} = \left(\left[\mu_{ij}^{L}, \mu_{ij}^{U}\right], \left[v_{ij}^{L}, v_{ij}^{U}\right]\right)_{nxn}$ as in Equation 5.

$$\tilde{R} = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \\ \left[\mu_{11}^{L}, \mu_{11}^{U}\right], \left[v_{11}^{L}, v_{11}^{U}\right] & \left[\mu_{12}^{L}, \mu_{12}^{U}\right], \left[v_{12}^{L}, v_{12}^{U}\right] & \cdots & \left[\mu_{1n}^{L}, \mu_{1n}^{U}\right], \left[v_{1n}^{L}, v_{1n}^{U}\right] \\ \left[\mu_{21}^{L}, \mu_{21}^{U}\right], \left[v_{21}^{L}, v_{21}^{U}\right] & \left[\mu_{22}^{L}, \mu_{22}^{U}\right], \left[v_{22}^{L}, v_{22}^{U}\right] & \cdots & \left[\mu_{2n}^{L}, \mu_{2n}^{U}\right], \left[v_{2n}^{L}, v_{2n}^{U}\right] \\ \vdots & \vdots & \ddots & \vdots \\ \left[\mu_{n1}^{L}, \mu_{n1}^{U}\right], \left[v_{n1}^{L}, v_{n1}^{U}\right] & \left[\mu_{n2}^{L}, \mu_{n2}^{U}\right], \left[v_{n2}^{L}, v_{n2}^{U}\right] & \cdots & \left[\mu_{nn}^{L}, \mu_{nn}^{U}\right], \left[v_{nn}^{L}, v_{nn}^{U}\right] \end{array} \quad (5)$$

Step 6. Obtain the score judgment matrix $\tilde{S} = (\tilde{s}_{ij})_{nxn} = \left[\mu_{ij}^{L} - v_{ij}^{U}, \mu_{ij}^{U} - \mu_{ij}^{L}\right]$ as in Equation 6 and the interval multiplicative matrix $\tilde{A} = (\tilde{a}_{ij})_{nxn} = \left[10^{\left(\mu_{ij}^{L} - v_{ij}^{U}\right)}, 10^{\left(\mu_{ij}^{U} - \mu_{ij}^{L}\right)}\right]$ as in Equation 7. The aim of this step is to convert the score judgment matrix $\tilde{S} = (\tilde{s}_{ij})_{nxn}$ to the matrix $\tilde{A} = (\tilde{a}_{ij})_{nxn}$ whose values are between 0 and 10.

$$\tilde{S} = \begin{array}{c} \\ C_1 \\ \vdots \\ C_n \end{array} \begin{array}{ccc} C_1 & \cdots & C_n \\ \left[\mu_{11}^{L} - v_{11}^{U}, \mu_{11}^{U} - \mu_{11}^{L}\right] & \cdots & \left[\mu_{1n}^{L} - v_{1n}^{U}, \mu_{1n}^{U} - \mu_{1n}^{L}\right] \\ \vdots & \ddots & \vdots \\ \left[\mu_{n1}^{L} - v_{n1}^{U}, \mu_{n1}^{U} - \mu_{n1}^{L}\right] & \cdots & \left[\mu_{nn}^{L} - v_{nn}^{U}, \mu_{nn}^{U} - \mu_{nn}^{L}\right] \end{array} \quad (6)$$

$$\tilde{A}=\begin{array}{c} \\ C_1 \\ \vdots \\ C_n \end{array}\begin{array}{ccc} C_1 & \cdots & C_n \\ \left[10^{\left(\mu_{11}^L-v_{11}^U\right)},10^{\left(\mu_{11}^U-\mu_{11}^L\right)}\right] & \cdots & \left[10^{\left(\mu_{1n}^L-v_{1n}^U\right)},10^{\left(\mu_{1n}^U-\mu_{1n}^L\right)}\right] \\ \vdots & \ddots & \vdots \\ \left[10^{\left(\mu_{n1}^L-v_{n1}^U\right)},10^{\left(\mu_{n1}^U-\mu_{n1}^L\right)}\right] & \cdots & \left[10^{\left(\mu_{nn}^L-v_{nn}^U\right)},10^{\left(\mu_{nn}^U-\mu_{nn}^L\right)}\right] \end{array} \quad (7)$$

Step 7. Calculate the priority vector of the interval multiplicative matrix $\tilde{A}=(\tilde{a}_{ij})_{nxn}$ by determining the $\tilde{w}_i$ interval for each criterion using Equation 8.

$$\tilde{w}_i=\left[\frac{\sum_{j=1}^{n}\tilde{a}_{ij}^L}{\sum_{i=1}^{n}\sum_{j=1}^{n}\tilde{a}_{ij}^U},\frac{\sum_{j=1}^{n}\tilde{a}_{ij}^U}{\sum_{i=1}^{n}\sum_{j=1}^{n}\tilde{a}_{ij}^L}\right]=\left[w_i^L,w_i^U\right] \quad i=1,2,...,n \quad (8)$$

Step 8. Obtain the possibility degree matrix $P=(p_{ij})_{nxn}$ by using Equation 9.

$$P(\tilde{w}_i>\tilde{w}_j)=p_{ij}=\frac{\min\left(\left(w_i^U-w_i^L+w_j^U-w_j^L\right),\max\left(0,w_i^U-w_j^L\right)\right)}{\left(w_i^U-w_i^L\right)+\left(w_j^U-w_j^L\right)} \quad (9)$$

where $p_{ij}\geq 0$, $p_{ij}+p_{ji}=1$, $p_{ii}=0.5$.

Step 9. Prioritize possibility degrees by Equation 10.

$$w_i=\frac{1}{n}\left[\sum_{j=1}^{n}p_{ij}+\frac{n}{2}-1\right] \quad (10)$$

Step 10. Normalize the weights vector by Equation 11.

$$w_i^T=\frac{w_i}{\sum_{i=1}^{n}w_i} \quad (11)$$

Weights of each main criterion and its sub-criteria are calculated using steps 2-10. After these steps, the second phase is started by collecting evaluations of experts' in step 11. The second phase is ended by ranking the alternatives.

Step 11. Collect the experts' evaluations using the scale presented in Table 4 for the alternatives.

Step 12. Convert to the linguistic evaluations to IVIF values to form the decision matrices $\tilde{D}_k$ for each experts as in Equation 12.

$$\tilde{D}_k = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{cccc} A_1 & A_2 & \cdots & A_m \\ \left[\mu^L_{11k},\mu^U_{11k}\right],\left[v^L_{11k},v^U_{11k}\right] & \left[\mu^L_{12k},\mu^U_{12k}\right],\left[v^L_{12k},v^U_{12k}\right] & \cdots & \left[\mu^L_{1mk},\mu^U_{1mk}\right],\left[v^L_{1mk},v^U_{1mk}\right] \\ \left[\mu^L_{21k},\mu^U_{21k}\right],\left[v^L_{21k},v^U_{21k}\right] & \left[\mu^L_{22k},\mu^U_{22k}\right],\left[v^L_{22k},v^U_{22k}\right] & \cdots & \left[\mu^L_{2mk},\mu^U_{2mk}\right],\left[v^L_{2mk},v^U_{2mk}\right] \\ \vdots & \vdots & \ddots & \vdots \\ \left[\mu^L_{n1k},\mu^U_{n1k}\right],\left[v^L_{n1k},v^U_{n1k}\right] & \left[\mu^L_{n2k},\mu^U_{n2k}\right],\left[v^L_{n2k},v^U_{n2k}\right] & \cdots & \left[\mu^L_{nmk},\mu^U_{nmk}\right],\left[v^L_{nmk},v^U_{nmk}\right] \end{array} \quad (12)$$

Step 13. Calculate positive ideal solution (PIS) and negative ideal solution (NIS) for kth expert are calculated from Equations 13 and 14. Here $\left(\left[\mu^L_{1*k},\mu^U_{1*k}\right],\left[v^L_{1*k},v^U_{1*k}\right]\right)$ and $\left(\left[\mu^L_{1-k},\mu^U_{1-k}\right],\left[v^L_{1-k},v^U_{1-k}\right]\right)$ represent maximum and minimum IVIF values, respectively, among the values of alternatives for ith criterion.

$$I\tilde{S}^+_k = \left(\left(\left[\mu^L_{1*k},\mu^U_{1*k}\right],\left[v^L_{1*k},v^U_{1*k}\right]\right),\left(\left[\mu^L_{2*k},\mu^U_{2*k}\right],\left[v^L_{2*k},v^U_{2*k}\right]\right),\cdots\cdots,\left(\left[\mu^L_{n*k},\mu^U_{n*k}\right],\left[v^L_{n*k},v^U_{n*k}\right]\right)\right) \quad (13)$$

$$I\tilde{S}^-_k = \left(\left(\left[\mu^L_{1-k},\mu^U_{1-k}\right],\left[v^L_{1-k},v^U_{1-k}\right]\right),\left(\left[\mu^L_{2-k},\mu^U_{2-k}\right],\left[v^L_{2-k},v^U_{2-k}\right]\right),\cdots\cdots,\left(\left[\mu^L_{n-k},\mu^U_{n-k}\right],\left[v^L_{n-k},v^U_{n-k}\right]\right)\right) \quad (14)$$

Step 14. Calculate the separation measure D^{*k}_j and D^{-k}_j between the alternatives and PIS ($I\tilde{S}^+_k$) and NIS($I\tilde{S}^-_k$) for each expert using Equations 15 and 16, respectively.

$$D^{*k}_j = \sqrt{\frac{1}{2}\sum_{i=1}^{n} w^T_i \begin{bmatrix} (\mu^L_{1jk}-\mu^L_{1*k})^2+(\mu^U_{1jk}-\mu^U_{1*k})^2+(v^L_{1jk}-v^L_{1*k})^2+ \\ (v^U_{1jk}-v^U_{1*k})^2+(\pi^L_{1jk}-\pi^L_{1*k})^2+(\pi^U_{1jk}-\pi^U_{1*k})^2 \end{bmatrix}} \quad (15)$$

$$D^{-k}_j = \sqrt{\frac{1}{2}\sum_{i=1}^{n} w^T_i \begin{bmatrix} (\mu^L_{1jk}-\mu^L_{1-k})^2+(\mu^U_{1jk}-\mu^U_{1-k})^2+(v^L_{1jk}-v^L_{1-k})^2+ \\ (v^U_{1jk}-v^U_{1-k})^2+(\pi^L_{1jk}-\pi^L_{1-k})^2+(\pi^U_{1jk}-\pi^U_{1-k})^2 \end{bmatrix}} \quad (16)$$

Step 15. Aggregate the separation measures D^{*k}_j and D^{-k}_j by using Equation 17 and Equation 18 where λ_k is the weight of expert k. Then, obtain the closeness coefficients for alternatives by using Equation 19.

$$D^*_j = \sum_{k=1}^{K} \lambda_k D^{*k}_j \quad (17)$$

$$D^-_j = \sum_{k=1}^{K} \lambda_k D^{-k}_j \quad (18)$$

$$U_j = \frac{D_j^{-k}}{(D_j^{-k} + D_j^{*k})} \tag{19}$$

Step 16. Rank the alternatives taking into account the closeness coefficient values.

3. Results and Discussion

3.1.Case Study: Green Supplier Selection in Textile Industry

To show the application of the integrated model, a GSS problem for the textile industry is solved with this model. The data (expert's evaluations) are collected from a textile firm that wants to supply raw materials from a green supplier. There are four suppliers as candidates and evaluations of alternatives are procured by three experts in the company's procurement team. The selection of the proper green supplier depends upon a number of economic and environmental factors. Criteria used in the evaluation of candidates are determined considering literature reviews and expert opinions. A total of 12 sub-criteria are determined and these sub-criteria are grouped under two main criteria as economic performance and environmental performance. The hierarchical framework of the sub-criterions under each main criterion visualize in Fig. 1 and the explanations of main-criteria and sub-criteria are listed in Table 5.

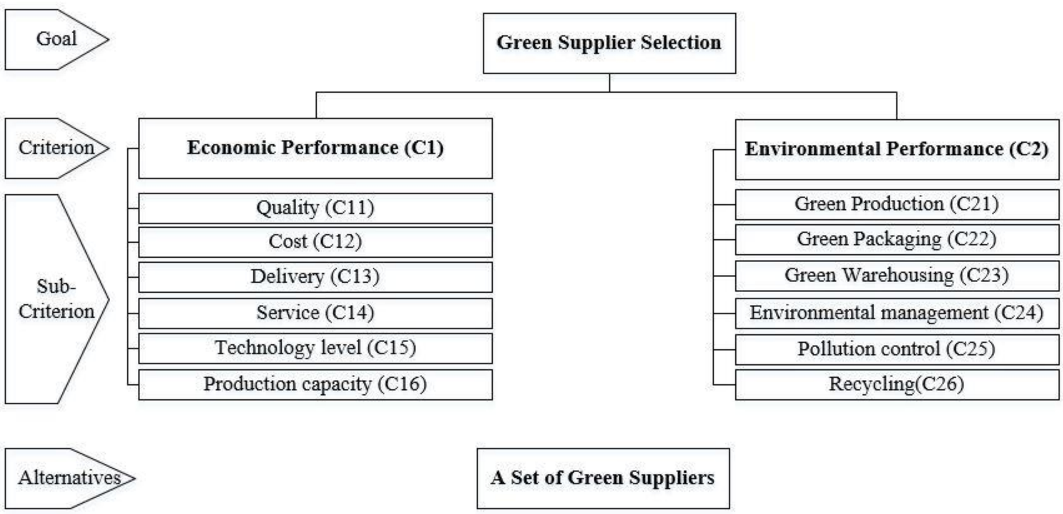

Figure 1. Criterion list for GSS.

Table 5. Explanations of main criteria and sub-criteria.

Main criteria Sub-criteria	Explanations
Economic Performance (C1): The factors which demonstrate the effort of the supplier in economic performance.	
Quality (C11)	The rate of acceptable material determined in the quality control process, the acquisition of quality assurance, the application of process improvement activities, importance given to the quality processes in organization and management.
Cost (12)	Consistency of supplier's offered unit variable and fixed transportation costs with industry average
Delivery (C13)	Compliance with due date, delivery date and predetermined order quantities.
Service (C14)	The ability to schedule and modify orders, compliance of stock management system of supplier with manufacture line, ability to overcome conflicts
Technology level (C15)	Technology capacity to help the new product or process development and to ensure upgraded or new products to the company, technology development to satisfy current and future demands of the company.
Production capacity (C16)	The maximum production, which can be produced with the help of available resources.
Environmental Performance (C2): The factors which demonstrate the effort of the supplier in environmental performance.	
Green production (C21)	The level of the establishment of environmentally-friendly processes within the production area.
Green packaging (C22)	The level of limiting the packaging waste created and of using sustainable materials (such as recyclable or biodegradable packaging elements) in packaging.
Green warehousing (C23)	The level of implementing environmentally friendly processes with the purpose of minimizing GHG emissions, energy cost, and energy consumption of a warehouse.
Environment management (C24)	Following new developments and legislation related to the environment. Compliance of processes with legislation. Having environmental certificates such as ISO 14000.
Pollution control (C25)	The level of the control in producing pollution such as air pollution, wastewater, use of harmful materials, solid wastes, energy consumption, etc.
Recycling (C26)	The process of collecting and processing materials to be discarded as garbage and transforming them into new products.

First of all, the linguistic terms in Table 2 are used to describe the importance of experts. The linguistic terms assigned to three experts are {High, Low, Medium High} respectively. Then these linguistic terms convert to IVIF sets to calculate the weights of experts. The corresponding numerical intervals are ([0.65,0.70], [0.15,0.20]), ([0.15,0.20], [0.65,0.70]), and ([0.55,0.60], [0.25,0.30]). The weights for three experts, λ_1, λ_2 and λ_3 are calculated using Equation 2. The weights of three experts are obtained as $\lambda_1 = 0.394$, $\lambda_2 = 0.274$ and $\lambda_3 = 0.332$ respectively as in Table 6.

PCMs are filled taking into account experts' opinions for the main criteria and sub-criteria. The evaluations of the experts are given in Table 7 and Table 8. Then, these linguistic PCMs are converted to IVIF PCMs using Table 4. The consistency of the each PCM is checked using the multiplicative consistency analysis proposed by Liao et al. (2014). The iterative steps are repeated until inconsistent matrices turn into consistent by considering the maximum number of iteration N=5, threshold τ=0.10, and the iteration step σ=0.20. The consistency ratios obtained from each iterative step (p) are illustrated in Figure 2. After the consistency of each IVIF PCM is provided to be under 0.10, the aggregated IVIF PCMs are obtained.

Table 6. Weights of experts.

	Expert 1	Expert 2	Expert 3
Linguistic variables	Very Important	Medium	Important
IVIFVs	([0.80,0.95], [0.00,0.05])	([0.45,0.55], [0.30,0.45])	([0.65,0.75], [0.15,0.20])
Weights	0.394	0.274	0.332

Table 7. PCM of main criteria.

Expert 1	C1	C2	Expert 2	C1	C2	Expert 3	C1	C2
C1	EE	ML	C1	EE	AE	C1	EE	L
C2	MH	EE	C2	AE	EE	C2	H	EE

Table 8. PCMs of sub-criteria by experts.

Economic Performance Sub-Criteria							Environmental Performance Sub-Criteria						
Expert 1	C11	C12	C13	C14	C15	C16	Expert 1	C21	C22	C23	C24	C25	C26
C11	EE	H	MH	VH	H	H	C21	EE	H	VH	ML	ML	L
C12	L	EE	L	MH	ML	ML	C22	L	EE	H	ML	ML	VL
C13	ML	H	EE	VH	H	H	C23	VL	L	EE	VL	ML	VL
C14	VL	ML	VL	EE	L	ML	C24	MH	MH	VH	EE	VH	MH
C15	L	MH	L	H	EE	ML	C25	MH	MH	MH	VL	EE	ML
C16	L	MH	L	MH	MH	EE	C26	H	VH	VH	ML	MH	EE
Expert 2	C11	C12	C13	C14	C15	C16	Expert 2	C21	C22	C23	C24	C25	C26
C11	EE	AE	MH	H	H	MH	C21	EE	MH	H	L	ML	ML
C12	AE	EE	H	MH	MH	MH	C22	ML	EE	VH	VL	L	L
C13	ML	L	EE	H	MH	AE	C23	L	VL	EE	AL	L	VL
C14	L	ML	L	EE	ML	MH	C24	H	VH	AH	EE	H	H
C15	L	ML	ML	MH	EE	L	C25	MH	H	H	L	EE	MH
C16	ML	ML	AE	ML	H	EE	C26	MH	H	VH	L	ML	EE
Expert 3	C11	C12	C13	C14	C15	C16	Expert 3	C21	C22	C23	C24	C25	C26
C11	EE	AE	MH	VH	H	VH	C21	EE	AE	H	L	L	L
C12	AE	EE	ML	MH	H	H	C22	AE	EE	VH	VL	L	VL
C13	ML	MH	EE	H	VH	VH	C23	L	VL	EE	VL	L	AL
C14	VL	ML	L	EE	MH	AE	C24	H	VH	VH	EE	MH	ML
C15	L	L	VL	ML	EE	AE	C25	H	H	H	ML	EE	ML
C16	VL	L	VL	AE	AE	EE	C26	H	VH	AH	MH	MH	EE

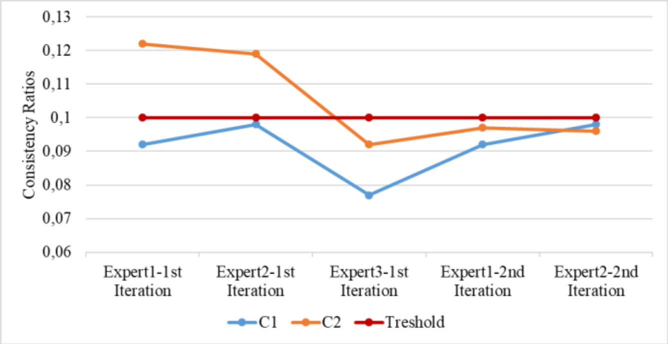

Figure 2. Consistency ratio charts.

The aggregated IVIF PCMs are created using Equation 1 as demonstrated in Tables 9, 10, and 11. To show the calculation of the values in aggregated IVIF PCMs, an example calculation is given in below. For example, the value ([0.52,0.57], [0.27,0.33]) that is remarked in bold numbers in Table 10 illustrates the importance of C13 (Delivery) according to C12 (Cost) and it is obtained as in Equation 20.

$$IVIFWA(C_{13}-C_{12}) = \left(\begin{bmatrix} \left(1-\left((1-0.65)^{0.394} x (1-0.15)^{0.274} x (1-0.55)^{0.332}\right)\right), \\ \left(1-\left((1-0.70)^{0.394} x (1-0.20)^{0.274} x (1-0.60)^{0.332}\right)\right) \end{bmatrix}, \begin{bmatrix} \left((0.15)^{0.394} x (0.65)^{0.274} x (0.25)^{0.332}\right), \\ \left((0.20)^{0.394} x (0.70)^{0.274} x (0.30)^{0.332}\right) \end{bmatrix} \right) = ([0.52, 0.57],[0.27, 0.33]) \quad (20)$$

The score judgment matrices and the interval multiplicative matrices are calculated using Equation 6 and Equation 7. As an example of the calculations, the score judgement and interval multiplicative for the value ([0.52,0.57], [0.27,0.33]) that shows the importance of C13 (Delivery) according to C12 (Cost) are calculated as below:

$$\tilde{s}_{C_{13},C_{12}} = \left[(0.515-0.323),(0.568-0.266,)\right] = [0.192, 0.302] \quad (21)$$

$$\tilde{a}_{C_{13},C_{12}} = \left[10^{0.192}, 10^{0.302}\right] = [1.556, 2.004] \quad (22)$$

Table 9. Aggregated comparison matrix for main criteria.

	C1	C2
C1	([0.50,0.50],[0.50,0.50])	([0.55,0,60],[0.25,0.30])
C2	([0.54,0.60],[0.24,0.29])	([0.50,0.50],[0.50,0.50])

Table 10. Aggregated comparison matrix for sub-criteria of Economic Performance.

	C11	C12	C13
C11	([0.50,0.50],[0.50,0.50])	([0.52,0.57],[0.26,0.33])	([0.55,0.60],[0.25,0.30])
C12	([0.28,0.37],[0.49,0.54])	([0.50,0.50],[0.50,0.50])	([0.37,0.42],[0.42,0.48])
C13	([0.25,0.30],[0.55,0.60])	**([0.52,0.57],[0.27,0.33])**	([0.50,0.50],[0.50,0.50])
C14	([0.12,0.17],[0.73,0.78])	([0.25,0.3],[0.55,0.60])	([0.14,0.19],[0.69,0.74])
C15	([0.15,0.20],[0.65,0.70])	([0.37,0.42],[0.43,0.49])	([0.17,0.22],[0.66,0.71])
C16	([0.17,0.22],[0.66,0.71])	([0.37,0.42],[0.43,0.49])	([0.20,0.27],[0.60,0.65])
	C14	**C15**	**C16**
C11	([0.73,0.78],[0.12,0.17])	([0.65,0.70],[0.15,0.20])	([0.67,0.72],[0.16,0.21])
C12	([0.55,0.60],[0.25,0.30])	([0.50,0.55],[0.29,0.35])	([0.50,0.55],[0.29,0.35])
C13	([0.70,0.75],[0.13,0.18])	([0.67,0.72],[0.16,0.21])	([0.64,0.70],[0.17,0.23])
C14	([0.50,0.50],[0.50,0.50])	([0.34,0.39],[0.46,0.51])	([0.40,0.45],[0.39,0.46])
C15	([0.52,0.57],[0.27,0.33])	([0.50,0.50],[0.50,0.50])	([0.28,0.33],[0.50,0.57])
C16	([0.42,0.49],[0.37,0.42])	([0.53,0.59],[0.26,0.31])	([0.50,0.50],[0.50,0.50])

Table 12 shows the priority vector of the interval multiplicative matrix obtained by using Equation 8. Then, the possibility degree matrices are calculated as in Tables 13, 14, and 15 by using Equation 9. As an illustration of calculations, the value 0.865 which is remarked in bold number in Table 14 is computed as in Equation 23.

$$P(\tilde{w}_{C_{12}} \geq \tilde{w}_{C_{16}}) = \frac{\min\left(\left(0.191-0.123+0.139-0.90\right), \max\left(0,\left(0.191-0.90\right)\right)\right)}{\left(0.191-0.123\right)+\left(0.139-0.90\right)} = 0.865 \quad (23)$$

The prioritized values for the criteria are determined using Equation 10. For example, $w_{C_{25}} = 0.828$ is calculated as in Equation 24. The normalized weights vector w_i^T are calculated by normalizing the prioritized values and given in Tables 12, 13, and 14.

$$w_{C_{25}} = \frac{1}{6}\left[\left(0.586+0.845+1.0+0+0.5+0.035\right)+\frac{6}{2}-1\right] = 0.828 \quad (24)$$

According to the weights of the main criteria presented in Table 16, Environmental Performance (C2) is the main criterion for GSS, more important than Economic Performance (C1). Environmental management system (C24) is the most important sub-criterion among all 12 sub-criteria. The three criteria that follow this criterion are Quality (C11), Recycling (C26), and Delivery (C13). Then, the weights of the criteria are calculated, and linguistic decision matrices are created by using the experts' evaluations of the alternatives according to each criterion. Table 17 gives the linguistic decision matrices. After then, the linguistic terms are converted to IVIF values taking into account the scale in Table 4 to calculate the IVIF decision matrices for each expert.

Table 11. Aggregated comparison matrix for Environmental Performance sub-criteria.

	C21	C22	C23
C21	([0.50,0.50],[0.50,0.50])	([0.56,0.61],[0.23,0.30])	([0.71,0.76],[0.11,0.16])
C22	([0.25,0.32],[0.53,0.58])	([0.50,0.50],[0.50,0.50])	([0.72,0.77],[0.12,0.17])
C23	([0.12,0.17],[0.70,0.76])	([0.13,0.18],[0.71,0.76])	([0.50,0.50],[0.50,0.50])
C24	([0.58,0.65],[0.19,0.25])	([0.65,0.72],[0.15,0.21])	([0.77,0.82],[0.09,0.14])
C25	([0.54,0.60],[0.23,0.29])	([0.56,0.63],[0.20,0.26])	([0.58,0.65],[0.18,0.25])
C26	([0.60,0.66],[0.18,0.24])	([0.69,0.75],[0.12,0.18])	([0.75,0.80],[0.09,0.14])
	C24	**C25**	**C26**
C21	([0.20,0.26],[0.57,0.64])	([0.24,0.30],[0.53,0.59])	([0.18,0.24],[0.59,0.65])
C22	([0.16,0.22],[0.63,0.70])	([0.21,0.28],[0.55,0.61])	([0.13,0.18],[0.68,0.75])
C23	([0.09,0.14],[0.77,0.82])	([0.19,0.26],[0.57,0.64])	([0.09,0.15],[0.74,0.80])
C24	([0.50,0.50],[0.50,0.50])	([0.67,0.72],[0.16,0.21])	([0.51,0.57],[0.26,0.32])
C25	([0.17,0.22],[0.66,0.71])	([0.50,0.50],[0.50,0.50])	([0.35,0.40],[0.45,0.50])
C26	([0.33,0.39],[0.45,0.51])	([0.49,0.54],[0.32,0.37])	([0.50,0.50],[0.50,0.50])

Table 12. Priority vector.

Main criteria	Priority
C1	([0.424, 0,583])
C2	([0.424, 0,596])
Economic Performance sub-criteria	**Priority**
C11	([0.243, 0,379])
C12	([0.123, 0,191])
C13	([0.208, 0,325])
C14	([0.061, 0,092])
C15	([0.078, 0,119])
C16	([0.090, 0,139])
Environmental Performance sub-criteria	**Priority**
C21	([0.116, 0,185])
C22	([0.092, 0,144])
C23	([0.034, 0,050])
C24	([0.228, 0,370])
C25	([0.124, 0,202])
C26	([0.195, 0,317])

Table 13. Possibility degree matrix and weights of the main criteria.

	C1	C2	w_i	w_i^T
C1	0.500	0.482	0.982	0.491
C2	0.518	0.500	1.018	0.509

Table 14. Possibility degree matrix and weights of the Economic Performance sub-criteria.

	C11	C12	C13	C14	C15	C16	w_i	w_i^T
C11	0.500	1.000	0.674	1.000	1.000	1.000	1.196	0.239
C12	0.000	0.500	0.000	1.000	1.000	**0.865**	0.894	0.179
C13	0.326	1.000	0.500	1.000	1.000	1.000	1.138	0.228
C14	0.000	0.000	0.000	0.500	0.194	0.031	0.454	0.091
C15	0.000	0.000	0.000	0.806	0.500	0.327	0.605	0.121
C16	0.000	0.135	0.000	0.969	0.673	0.500	0.713	0.143

Table 15. Possibility degree matrix and weights of the Environmental Performance sub-criteria.

	C21	C22	C23	C24	C25	C26	w_i	w_i^T
C21	0.500	0.769	1.000	0.000	0.414	0.000	0.781	0.156
C22	0.231	0.500	1.000	0.000	0.155	0.000	0.648	0.130
C23	0.000	0.000	0.500	0.000	0.000	0.000	0.417	0.083
C24	1.000	1.000	1.000	0.500	1.000	0.662	1.194	0.239
C25	0.586	0.845	1.000	0.000	0.500	0.035	0.828	0.166
C26	1.000	1.000	1.000	0.338	0.965	0.500	1.134	0.227

The fuzzy PIS $I\tilde{S}_k^+$ and fuzzy NIS $I\tilde{S}_k^-$ are obtained for each criterion. Then the separation measure between the *jth* alternative and $I\tilde{S}_k^+$ for kth expert (D_j^{*k}) is calculated using Equation 15. Similarly, (D_j^{-k}) is calculated using Equation 16 and the separation measures calculated from all three experts are listed in Table 18. Separation measures are aggregated using Equation 17 and Equation 18 considering weights of experts Then, the closeness coefficient U_j of each alternative is obtained by using Equation 19 and these values are listed in Table 19. When comparing alternatives, it is accepted that the alternative with a higher closeness coefficient is a better alternative than other alternatives. So, candidate GS2 that has a highest closeness coefficient with 0.805 should be preferred. The rank of the candidates is as follows: GS2>GS3>GS1>GS4.

Table 16. Global weights of sub-criteria.

Criteria	Weight	Sub-criteria	Local Weight	Global Weight
C1	0,491	C11	0,239	0,117
		C12	0,179	0,088
		C13	0,228	0,111
		C14	0,091	0,045
		C15	0,121	0,059
		C16	0,143	0,070
C2	0,509	C21	0,156	0,080
		C22	0,130	0,066
		C23	0,083	0,043
		C24	0,239	0,122
		C25	0,166	0,084
		C26	0,227	0,116

Table 17. Alternative evaluations.

		C11	C12	C13	C14	C15	C16	C21	C22	C23	C24	C25	C26
Expert 1	GS1	MH	H	MH	AE	L	H	H	AH	MH	H	H	AE
	GS2	AH	VH	VH	L	VH	AH	VH	VH	MH	VH	AH	H
	GS3	MH	H	H	L	VH	MH	VH	VH	AE	H	AE	AE
	GS4	AE	ML	L	MH	VL	VL	MH	AE	AE	VH	L	MH
Expert 2	GS1	H	VH	AE	L	ML	MH	H	AH	H	MH	H	ML
	GS2	H	AH	H	VL	AH	VH	VH	AH	MH	AH	VH	MH
	GS3	VH	ML	H	ML	MH	VH	AH	H	AE	H	MH	H
	GS4	H	L	VL	H	VL	L	MH	ML	AE	VH	ML	VH
Expert 3	GS1	H	VH	H	MH	L	VH	H	VH	MH	MH	H	H
	GS2	VH	AH	VH	VL	VH	VH	VH	VH	MH	VH	VH	MH
	GS3	AH	AE	VH	L	AH	MH	VH	MH	MH	MH	L	L
	GS4	H	L	L	H	VL	AL	MH	ML	AE	H	L	MH

Table 18. Final separation measures from all experts.

	GS1	GS2	GS3	GS4
D_j^{*1}	0.111	0.055	0.104	0.318
D_j^{-1}	0.157	0.292	0.147	0.095
D_j^{*2}	0.165	0.079	0.030	0.298
D_j^{-2}	0.187	0.272	0.169	0.164
D_j^{*3}	0.098	0.073	0.165	0.324
D_j^{-3}	0.204	0.266	0.155	0.120

Table 19. Aggregated and closeness coefficients.

	GS1	GS2	GS3	GS4
D_j^*	0.121	0.067	0.104	0.315
D_j^-	0.181	0.278	0.156	0.122
U_j	0.598	0.805	0.600	0.280

4. Sensitivity Analyses

A sensitivity analysis is performed to analyse the effects of the changes weights of the criteria on the GSS for the textile industry. One-at-a-time sensitivity analysis is performed and analyses results are presented in Fig. 3. In this figure, the colours blue, orange, gray, and yellow indicate the alternatives GS1, GS2, GS3, and GS4 respectively. The X-axis indicates the weight of criterion, while Y-axis indicates the closeness coefficients of alternatives. In sensitivity analysis, the value of a certain weight of criterion is changed while the other weights of criteria are proportionally fixed. The sum of the weights equals 1 in each case. Using these new weights of criteria, the closeness coefficients of alternatives are recalculated.

It is seen from the graphics in Fig. 3 that in most cases the choice of the GS2 alternative appears to be more appropriate. In case of the change the weights of criteria whose quality (C11), technology level (C15), production capacity (C16), green production (C21), green warehousing (C23), environmental management (C24), pollution control (C25), recycling (C26), the G2 alternative is still the most suitable alternative. However, although it is rare, in some cases it is appropriate to choose GS1 and GS4 alternatives. GS1 is chosen when weight of the criterion service (C14) is bigger than approximately 0.30, and GS4 is chosen when weight of the criterion service (C14) is bigger than approximately 0.55. When the weights of the criteria cost (C12) and delivery (C13) are equal to 1, the closeness coefficients of all candidates are equal.

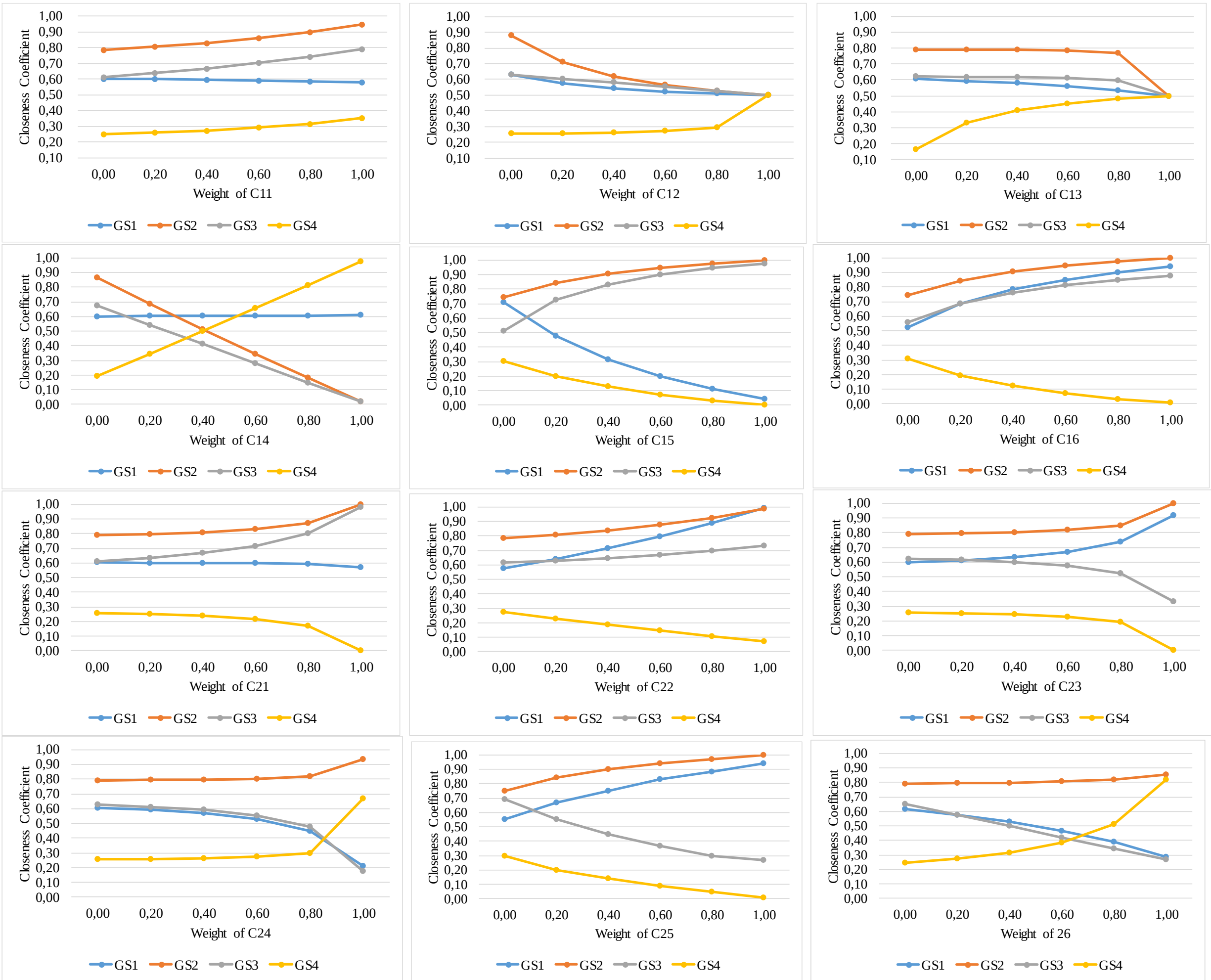

Figure 3. Results of sensitivity analyses.

5. Conclusion

The selection of the best GS in the textile industry is a difficult MCDM problem because various conflicting criteria are considered. While each of the green suppliers can ensure several advantages and at the same time may cause some risks and costs. So, the opinions of the experts regarding the criteria should be carefully evaluated, since the criteria weights affect the ranking of the alternatives. Most of the criteria used to assess the alternative are properly evaluated by linguistic terms. Imprecise information of the decision-making process where linguistic terms are used and hesitancies of experts' enhancement the difficulties of the MCDM problem. Since IVIF sets are used in the MCDM approach proposed by integrating AHP and TOPSIS methods, this model produces an effective and practical evaluation for problems with vagueness and hesitation. The hesitancy of experts is handled by the IVIF sets by both calculating the weights of criteria by PCMs using AHP and ranking the candidate green suppliers using the TOPSIS method. This integrated model can be practically applied not only to GSS for the textile industry but also to MCDM problems in different fields. For further research, it is suggested that other extended versions of fuzzy sets, such as Neutrosophic sets or spherical fuzzy sets to be used for the same problem.

Statement of Research and Publication Ethics

The author declares that this study complies with Research and Publication Ethics.

References

Abdullah, L., and Najib, L. (2014). A new preference scale of intuitionistic fuzzy analytic hierarchy process in multi-criteria decision making problems. *Journal of Intelligent & Fuzzy Systems, 26*(2), 1039-1049. doi:10.3233/Ifs-130796

Acar, A. Z., Onden, I., and Gurel, O. (2016). Evaluation of the Parameters of the Green Supplier Selection Decision in Textile Industry. *Fibres & Textiles in Eastern Europe, 24*(5), 8-14. doi:10.5604/12303666.1215520

Amindoust, A., and Saghafinia, A. (2017). Textile supplier selection in sustainable supply chain using a modular fuzzy inference system model. *Journal of the Textile Institute, 108*(7), 1250-1258. doi:10.1080/00405000.2016.1238130

Atanassov, K., and Gargov, G. (1989). Interval Valued Intuitionistic Fuzzy-Sets. *Fuzzy Sets and Systems, 31*(3), 343-349. doi:Doi 10.1016/0165-0114(89)90205-4

Banaeian, N., Mobli, H., Fahimnia, B., Nielsen, I. E., and Omid, M. (2018). Green supplier selection using fuzzy group decision making methods: A case study from the agri-food industry. *Computers & Operations Research, 89*, 337-347. doi:10.1016/j.cor.2016.02.015

Boran, F. E., Genc, S., Kurt, M., and Akay, D. (2009). A multi-criteria intuitionistic fuzzy group decision making for supplier selection with TOPSIS method. *Expert Systems with Applications, 36*(8), 11363-11368. doi:10.1016/j.eswa.2009.03.039

Celik, E., Yucesan, M., andGul, M. (2021). Green supplier selection for textile industry: a case study using BWM-TODIM integration under interval type-2 fuzzy sets. *Environmental Science and Pollution Research*, 1-25. doi:10.1007/s11356-021-13832-7

Chen, S. M., Yang, M. W., Yang, S. W., Sheu, T. W., andLiau, C. J. (2012). Multicriteria fuzzy decision making based on interval-valued intuitionistic fuzzy sets. *Expert Systems with Applications*, *39*(15), 12085-12091. doi:10.1016/j.eswa.2012.04.021

Chen, T. Y., Wang, H. P., andLu, Y. Y. (2011). A multicriteria group decision-making approach based on interval-valued intuitionistic fuzzy sets: A comparative perspective. *Expert Systems with Applications, 38*(6), 7647-7658. doi:10.1016/j.eswa.2010.12.096

Ecer, B., Aktas, A., andKabak, M. (2019). Green supplier selection of a textile manufacturer: a hybrid approach based on AHP and VIKOR. *MANAS Journal of Engineering*, *7*(2), 126-135.

Ecer, F. (2020). Multi-criteria decision making for green supplier selection using interval type-2 fuzzy AHP: a case study of a home appliance manufacturer. *Operational Research*, 1-35. doi:10.1007/s12351-020-00552-y

Gören, H. G., andŞenocak, A. A. (2018). Macbeth Based Taguchi Loss Functions Approach for Green Supplier Selection: A Case Study in Textile Industry. *Journal of Textile & Apparel*, *28*(2), 90-97.

Guarnieri, P., andTrojan, F. (2019). Decision making on supplier selection based on social, ethical, and environmental criteria: A study in the textile industry. *Resources Conservation and Recycling*, *141*, 347-361. doi:10.1016/j.resconrec.2018.10.023

Guo, Z. X., Liu, H. T., Zhang, D. Q., andYang, J. (2017). Green Supplier Evaluation and Selection in Apparel Manufacturing Using a Fuzzy Multi-Criteria Decision-Making Approach. *Sustainability*, *9*(4), 650. doi:10.3390/su9040650

Javad, M. O. M., andJavad, A. O. M. (2020). Green supplier selection for the steel industry using BWM and fuzzy TOPSIS: A case study of Khouzestan steel company. *Sustainable Futures, 2*, 100012.

Kahraman, C., Oztaysi, B., andOnar, S. C. (2020). An Integrated Intuitionistic Fuzzy AHP and TOPSIS Approach to Evaluation of Outsource Manufacturers. *Journal of Intelligent Systems*, *29*(1), 283-297. doi:10.1515/jisys-2017-0363

Kokoc, M., and Ersoz, S. (2021). New Ranking Functions for Interval-Valued Intuitionistic Fuzzy Sets and Their Application to Multi-Criteria Decision-Making Problem. *Cybernetics and Information Technologies*, *21*(1), 3-18. doi:10.2478/cait-2021-0001.

Kokoc, M., and Ersoz, S. (2021). A Literature Review Of Interval-Valued Intuitionistic Fuzzy Multi-Criteria Decision-Making Methodologies. *Operations Research and Decisions, 31(4), 89-116.* doi: 10.37190/ord210405.

Liao, H. C., Xu, Z. S., andXia, M. M. (2014). Multiplicative consistency of interval-valued intuitionistic fuzzy preference relation. *Journal of Intelligent & Fuzzy Systems*, *27*(6), 2969-2985. doi:10.3233/Ifs-141256

Mishra, A. R., Rani, P., Mardani, A., Pardasani, K. R., Govindan, K., andAlrasheedi, M. (2020). Healthcare evaluation in hazardous waste recycling using novel interval-valued intuitionistic fuzzy information based on complex proportional assessment method. *Computers & Industrial Engineering*, *139*, 106140. doi:10.1016/j.cie.2019.106140

Onar, S. C., Oztaysi, B., Otay, I., andKahraman, C. (2015). Multi-expert wind energy technology selection using interval-valued intuitionistic fuzzy sets. *Energy*, *90*, 274-285. doi:10.1016/j.energy.2015.06.086

Oztaysi, B., Onar, S. C., Kahraman, C., andYavuz, M. (2017). Multi-criteria alternative-fuel technology selection using interval-valued intuitionistic fuzzy sets. *Transportation Research Part D-Transport and Environment*, *53*, 128-148. doi:10.1016/j.trd.2017.04.003

Tooranloo, H. S., andIranpour, A. (2017). Supplier selection and evaluation using interval-valued intuitionistic fuzzy AHP method. *International journal of procurement management*, *10*(5), 539-554.

Ulutas, A., Topal, A., andBakhat, R. (2019). An Application of Fuzzy Integrated Model in Green Supplier Selection. *Mathematical Problems in Engineering*, *2019*. doi:10.1155/2019/4256359

Wu, J., Huang, H. B., andCao, Q. W. (2013). Research on AHP with interval-valued intuitionistic fuzzy sets and its application in multi-criteria decision making problems. *Applied Mathematical Modelling*, *37*(24), 9898-9906. doi:10.1016/j.apm.2013.05.035

Xu, Z. S. (2007). Methods for aggregating interval-valued intuitionistic fuzzy information and their application to decision making. *Control Decision*, *22*(2), 215-219.

Yang, Y., andWang, Y. (2020). Supplier Selection for the Adoption of Green Innovation in Sustainable Supply Chain Management Practices: A Case of the Chinese Textile Manufacturing Industry. *Processes*, *8*(6), 717. doi:10.3390/pr8060717