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Research Article

Embracing Sustainability in Green Supplier Evaluation: A Novel Integrated Multi-Criteria Decision-Making Framework

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Abstract: Nowadays, industrial production is a critical issue for companies as public consciousness is rising because of environmental impacts. Like most other industries, the ready-made garment (RMG) industry faces immense pressure to be more competitive in this increasingly competitive market and proactively reduce waste and ecological footprint impacts. Besides, suppliers' environmental performance and image have far more effect on a corporation's environmental sustainability than the corporation's internal environmental efforts. Moreover, there is a shortage of environmental consciousness in emerging economies; thus, green supply chain practices are lagging. Therefore, the green supplier evaluation criteria should be identified and focused on during sustainable procurement. This study analyses quantitative and qualitative factors and explores the relationship between green supplier preference principles using the combination of the Fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) method and the Fuzzy Technique for Order Performance by Similarity to Ideal Solution (TOPSIS). Initially, the supplier's green performance was measured by identifying the criteria from relevant literature. After that, the Fuzzy DEMATEL technique measures the related criteria weights, and the Fuzzy TOPSIS method utilizes these criteria weights to rank suppliers among alternative suppliers. The findings will guide policymakers to improve supplier quality, increase profitability through improved brand recognition, and attract consumers who prioritize environmentally friendly products.

***Keywords*:** green supply chain, green supplier evaluation, sustainability, fuzzy decision-making, Fuzzy DEMATEL, Fuzzy TOPSIS

MSC: 03E75

1. Introduction

In today's globalized and fiercely competitive business landscape, effective supply chain management (SCM) is crucial in ensuring the success and sustainability of organizations. In conventional SCM, the primary emphasis was maximizing profit and minimizing costs. However, in sustainable SCM, organizations must adopt a broader perspective by incorporating environmental and social considerations into the design and optimization of their supply chains. Therefore, sustainability has become a top priority in today's globalized business environment, motivating businesses

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to review their supply chain procedures and incorporate green initiatives into their daily operations, especially when identifying and selecting environmentally responsible suppliers. As environmental concerns become popular and regulations become enforced, there is a growing emphasis on evaluating suppliers' performance based on price and quality and their sustainability performance. This shift is driven by government regulations and a growing awareness among individuals to safeguard the environment [1]. Due to the rising environmental concerns and demands for responsible company conduct, there is a growing need for frameworks that comprehensively examine and incorporate sustainability factors in supplier evaluation processes. Furthermore, to remain competitive and ensure long-term survival, firms can no longer afford to ignore environmental issues [2]. SCM contains several procedures that transform raw materials into manufactured goods, including procurement, production planning, production process, distribution, and shipment of products and services [3]. The choice of suppliers is a crucial element of procurement decisions that nearly every company faces. In business operations, companies must rely on suppliers to improve product quality, minimize costs or improve particular parts of their businesses [4]. Therefore, supplier selection is vital to every company's SCM system. The key goal of conventional supplier selection is to optimize the needs of companies. In recent years, however, there has been a growing, evident, and unrecognizable trend for businesses to make more of an effort to choose proper suppliers by implementing government regulations and improving environmental consciousness [5]. The selection of green suppliers will minimize pollutant generation from the source and would directly impact the environmental performance of companies by greening suppliers [6]. On the other hand, selecting a green supplier provider will offer the company economic and competitive benefits, which are very important to the company's growth [7]. It indicates that there is growing global attention to environmental management concerns, and organizations are facing increasing pressure to implement sustainable practices across their supply chains [8].

The ready-made garment (RMG) sector has also been undergoing extensive development since it became part of the 21st century, as fashion is an increasingly important place in life [9]. RMG products have continuously been modified, and RMG waste is rampant due to the enormous number of products sold and the relentless search for new products [10]. In particular, several dangerous chemicals are also produced, and the environmental risk is much greater. Therefore, choosing green suppliers has become essential for RMG growth [11].

Green Supply Chain Management (GSCM) provides global opportunities among industries and research communities [12]. However, RMG and its supply chains face one of the challenges of decoupling economic development from a proportional deterioration of the environment due to a range of pressures, including ever-strict environmental regulation, consumer perception, and the consequent change in attitudes to buying greener products [13]. Tackling those mentioned issues will be an important challenge. RMGs should not only concentrate on greening intra-organizational supply chain operations (e.g., domestic greening, transportation, and warehouse operations) but also on inter-organizational aspects that need to extend beyond their corporate borders and examine their supplier's performance [14]. Selecting an optimal green supplier enables businesses to achieve sustainable development, maximizes resource utilization, and mitigates the adverse impact of environmental issues, which aligns with the objective of promoting green development [15]. Therefore, selecting green suppliers aims to address the crucial landmark of eco-friendly supply chain growth and management. In today's highly competitive business environment, cost-effectiveness and quality alone are insufficient in traditional suppliers' procurement processes and methods. As a result, additional factors, including lead time, responsiveness, warranties, and more, have emerged as crucial requirements [16, 17]. Additionally, choosing green suppliers requires incorporating environmental criteria, including environmental certifications and green packaging [18, 19]. Though organizations are implementing GSCM, sometimes applying GSCM is a legal necessity in developed countries. However, in emerging economies, adopting green supply chain practices is still in its early stages. Literature and expert opinion suggest that green ideas are not well-known in the Bangladeshi industry [10]. Very few criteria and models are available to select green suppliers for RMG industries in developing countries; moreover, few researches have been initiated to define and suggest any integrated model [20, 21]. However, it is always important to identify the green criteria and select the best suppliers according to the selected. Hence, this research focuses on addressing quite a few research queries:

RQ (1) What are the significant criteria for selecting a green supplier?

RQ (2) How do the contextual relationships among the criteria interact?

RQ (3) How can policymakers help to rank the best green suppliers among the alternatives?

The particular research focuses on the following objectives:

(a) To find the most significant criteria for selecting the green suppliers of an RMG industry.
(b) To find the correlation between the criteria to implement a green supply chain.
(c) To assist policymakers in improving supplier quality by ranking and selecting suppliers based on green criteria.

This study proposes an integrated Multi-Criteria Decision Making (MCDM) method that includes Fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) and Fuzzy Technique for Order Performance by Similarity to Ideal Solution (TOPSIS). The Fuzzy DEMATEL methodology reveals the connections between criteria and prioritizes the criteria based on the weights of each criterion. Once Fuzzy DEMATEL has determined the criteria weights, Fuzzy TOPSIS has been employed to select the best supplier.

The paper is prepared according to the following: Section 2 explains literature studies on GSCM, Fuzzy DEMATEL, and Fuzzy TOPSIS. Section 3 provides a detailed description of the hybrid methodology of Fuzzy DEMATEL and Fuzzy TOPSIS. Section 4 discusses data collection, describes how the proposed framework will be accomplished, and analyzes the findings and results. The managerial and empirical significance of this study is demonstrated in Section 5. Finally, the research limitations and future directions are shown in Section 6.

2. Literature review

GSCM is providing opportunities and growing in popularity among industries and research communities globally. As business organizations outsource many of their goods and activities, green suppliers are vital in helping businesses sustain their competitive advantages [22]. GSCM has quickly become an essential strategy for being environmentally sustainable for many businesses [6]. Adopting GSCM practices will help industries save enormous operating resources, minimize costs, increase productivity, and decrease toxic waste production [23]. Thus, it will guarantee the establishment of an effective waste management system, recognized as one of the essential components of environmentally-friendly practices [24].

Because of the awareness of environmental and sustainability issues, customers are inquiring about the companies regarding how green the manufacturing and supply chain process is. Environmental regulation and concern have grown over the last decade, resulting in more significant consideration for green-supplier selection [25]. It has become essential for organizations to achieve sustainable targets [26]. Suppliers' assessment and decision-making are generally focused on a wide variety of quantitative and qualitative criteria. Given the growing global trends in environmental sustainability policies and practices, many recent studies on suppliers take a set of traditional and environmental requirements into account to address the problems of green suppliers [27]. The most common parameters in traditional supplier selection literature are the standard of service, quality, and price. Over the last few years, green supplier selection techniques have increased in numbers. Quan et al. [28] proposed a methodology for green supplier selection for a chemical process industry using a comprehensive weighted grey incidence decision-making approach. The study considered both economic and environmental criteria, including cost, quality, delivery, service, technique capability, pollution control, green product, and environmental management, as the main factors of the green supplier selection process, according to previous research. Basu et al. [29] discussed a mathematical model for supplier selection. Their study provided insights into a buyer's sourcing strategy when suppliers can reduce their unit costs through production learning coupled with investments in process improvements. Dobos and Vörösmarty [30] proposed a Data Envelopment Analysis (DEA) methodology for green supplier selection that can handle both management and green criteria as well as inventory-related costs. Bai et al. [31] proposed a green supplier segmentation model to evaluate suppliers based on their environmental capabilities and willingness using VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje) and fuzzy C-means. Guo et al. [32] and also Hussain and Al-Aomar [33] identified quality, cost, delivery, technology level, capability of green research and development (R&D), service, and environmental competency for green supplier selection. Liu et al. [34] introduced innovativeness technology, price, reuse and recycle rate, green design, and respect for policy as some criteria for selecting green suppliers. Büyüközkan and Göçer [35] proposed an integrated methodology combining the intuitionistic fuzzy analytic hierarchy process (IFAHP) and intuitionistic fuzzy axiomatic design (IFAD) principles method for selecting a suitable supplier. Their study indicated that price dependence on purchase orders, cost comparison with the market, compliance with the contract terms, and financial stability and strength are the cost criteria for selecting the supplier. Sevkli et al. [36] developed a novel model called Data Envelopment Analytic Hierarchy Process (DEAHP) to facilitate the supplier selection process. Their study identified six key criteria for evaluating potential suppliers, including performance assessment, human resources, quality system, manufacturing, business, and information technology. The study of Cole and Aitken [37] focused on supplier selection in the context of socially sustainable SCM. Their study showed that suppliers must demonstrate their commitment to sustainability by implementing the improvements detailed in corrective action reports.

Though organizations are implementing GSCM, sometimes applying GSCM is a legal necessity in developed countries. However, in emerging economies, adopting green supply chain practices is still in its early stages. Although implementing the green supply chain has many benefits, it is not broadly adopted in the textile industry of emerging economies, perhaps at an early stage of GSCM adoption [38]. Literature and expert opinion suggest that green ideas are not well-known in the Bangladeshi industry. 51% of companies in Bangladesh adopt GSCM, while over 48% of organizations do not use GSCM [39]. In Bangladesh's RMG sector, several studies on green practices have been conducted. Sarkar et al. [9] presented a synopsis of Bangladesh's RMG industries' green business strategy. Sarkar et al. [10] assessed green business approaches in the RMG sector of Bangladesh and offered a formal framework to address the factors that influence the use of green business practices. Islam et al. [40] proposed the essential GSCM characteristics from the perspective of the Bangladeshi leather industry. Thus, supplier evaluation considering green aspects in Bangladesh's RMG sector remains a significant field of research.

Very few criteria and models are available to select green suppliers for RMG industries in developing countries; moreover, there is insufficient research to define and suggest an integrated model. This study identifies the crucial criteria for selecting green suppliers through extant literature in the context of emerging economies.

Pareto analysis is a method used to classify tasks that have a disproportionate effect on the majority of instances. Lei et al. [41] proposed a Pareto-based TOPSIS method for developing supplier selection with probabilistic linguistic information. Gani et al. [42] used the Pareto method to determine and prioritize the crucial environmental protection metrics in the manufacturing sector.

With the DEMATEL method, complicated and interwoven problems can be approached. It clarifies interdependence and improves the relationship of variables [43]. DEMATEL makes it easier to discover how each criterion affects other criteria and discover the casual relationship between criteria [44]. The DEMATEL approach divides the variables into cause-and-effect categories and uses a causal relationship diagram to identify their relationships [45]. This approach builds and visualizes the relationships between sub-criteria and criteria in MCDM [46]. The crucial success factors for implementing a green supply chain in the electronics industry of Bangladesh were identified and ranked by Banik et al. [47] using the DEMATEL method.

Lo et al. [48] presented a synthetical approach for green supplier selection by combining the best-worst method (BWM) and the modified TOPSIS method. Haeri and Rezaei [22] proposed a model to select green suppliers by using the grey-based BWM. Gupta et al. [49] evaluated green suppliers in the fuzzy environment. In their study, several methods were integrated to rank the green suppliers. Rouyendegh et al. [5] presented the Intuitionistic Fuzzy TOPSIS method for selecting green suppliers. Qu et al. [50] presented Fuzzy approaches of TOPSIS and ÉLimination et Choix Traduisant la REalité (ELECTRE) for evaluating green suppliers in the Chinese Internet company. Gao et al. [51] developed a decision-making framework based on group consensus to assist in selecting the best green supplier for electronics manufacturing. Kilic and Yalcin [21] proposed an integrated Intuitionistic Fuzzy Technique for Order Preference by Similarity to Ideal Solution (IF-TOPSIS) and a modified two-phase fuzzy goal programming model to rank the green suppliers in the air filter industry. Shojaei and Bolvardizadeh [52] proposed a rough MCDM model for selecting green suppliers in the Iranian university construction project.

The recent development of integrated approaches is an ongoing trend from the above circumstances, but studies that produced or implemented integrated strategies are limited. However, over the past few decades, MCDM has seen tremendous utilization. It has dramatically increased its position in various fields of application, particularly by developing new approaches and improving traditional methods. Table 1 presents a comprehensive literature review, summarizing the key findings and insights from various scholarly sources.

An integrated model can help decision-makers to manage information such as the stakeholders' expectations, intertwined or conflicting requirements, and unpredictable environments. In this research, an integrated model is developed using weights obtained from Fuzzy DEMATEL embedded in Fuzzy TOPSIS, which results in the supplier's ranking for developing GSCM. This research's main strength is its reliability, as "fuzzy" has been utilized to attain accurate results. Prior research has employed triangular fuzzy numbers to address the uncertainty or imprecision in quantitative values; consequently, this study employs them as well [53, 54]. Moreover, the combo of DEMATEL and TOPSIS can identify correct green suppliers as DEMATEL deals with connections between the criteria connected with the suppliers, primarily how they affect each other, which increases the chance of getting the right weighted criteria; later, these are utilized in TOPSIS to narrow down the ranking.

Table 1. Existing literature studies on green supplier selection

Author's	Focus area	Method applied	Application area	Findings
Gupta et al. [49]	Environmental and conventional criteria	Fuzzy-TOPSIS, Fuzzy-MABAC, and Fuzzy-WASPAS with Fuzzy-AHP	Automotive industry	Environment management system, pollution control, quality, and green image have been ranked as the top four green supplier selection criteria.
Çalık [55]	Environmental criteria based on Industry 4.0 components	Pythagorean Fuzzy AHP and Fuzzy TOPSIS	Machinery company	Production, delivery and quality were the most important factors from the Industry 4.0 window for green supplier selection.
Ecer [56]	Environmental criteria	Interval type-2 fuzzy AHP (IT2FAHP)	Home appliance manufacturer	Cleaner production, energy/material saving, green package, remanufacturing, and environmental management system were the most important factors for selecting green suppliers.
Jain & Singh [57]	Economic, environmental and social dimensions	Fuzzy Kano	Iron and steel industry	Quality and delivery criteria are classified as high must be criteria in the economic realm. Environmental and energy management system in the environmental dimension and health and safety, human rights and social responsibility criteria in the social dimension are classified as high must be criteria.
Hoseini et al. [58]	Economic, environmental and social perspectives	Fuzzy best-worst method and fuzzy inference system (FBWM-FIS)	Construction industry	Cost, quality, pollution control, hazardous wastes, and workers' contract were the most effective ones compared to the other criteria in this study.
Luthra et al. [59]	Economic, environmental and social dimensions	AHP and VIKOR	Automobile industry	Environmental costs, quality of product, price of product, occupational health and safety systems, and environmental competencies were identified as the top five sustainable supplier selection criteria.
Gegovska et al. [60]	Environmental issues	Fuzzy AHP, Fuzzy TOPSIS, and Fuzzy ELECTRE	Manufacturing industry	In this study, five different suppliers were compared to identify the best green supplier.
Nguyen et al. [61]	Environmental and conventional dimensions	Fuzzy analytical hierarchy process (FAHP) and Fuzzy VIKOR	Manufacturing industry	Quantity discount, solid waste generation, order fulfillment rate, logistics cost, and purchasing cost are the most critical criteria.
Puška & Stojanović [62]	Ecological and economic perspectives	Fuzzy MABAC, MARCOS, and CRADIS	Agri-food industry	Environmental management system and partnership relations are the most significant criteria for selecting a green supplier.
Rahardjo et al. [63]	Economic, environmental and social dimensions	DEMATEL-based on ANP (DANP) with VIKOR	Electronic manufacturing industry	The findings reveal the ranking to select the best sustainable supplier.
Verdecho et al. [64]	Business, environmental, social and collaboration perspectives	AHP	Automotive industry	The most important attributes for assessing supplier sustainability are cost, quality, delivery time, trust, information shared, process controls, health and safety (H&S) problems.
Jiang et al. [65]	Economic and environmental dimensions	DEMATEL-based analytical network process (DANP)	Automotive industry	Technology, delivery time, environmental management system and pollution control are the key factors to select a green supplier.
This study	Green and sustainable criteria for supplier selection	Pareto-based Fuzzy DEMATEL and Fuzzy TOPSIS	RMG industry	Responsiveness, stock management, certificates related to the environment, internal control process, green packaging, waste management and recycling, technology level are the major criteria for selecting a green supplier.

3. Methodology

This study aims to evaluate green suppliers for the RMG industry. The proposed research structure is illustrated in Figure 1.

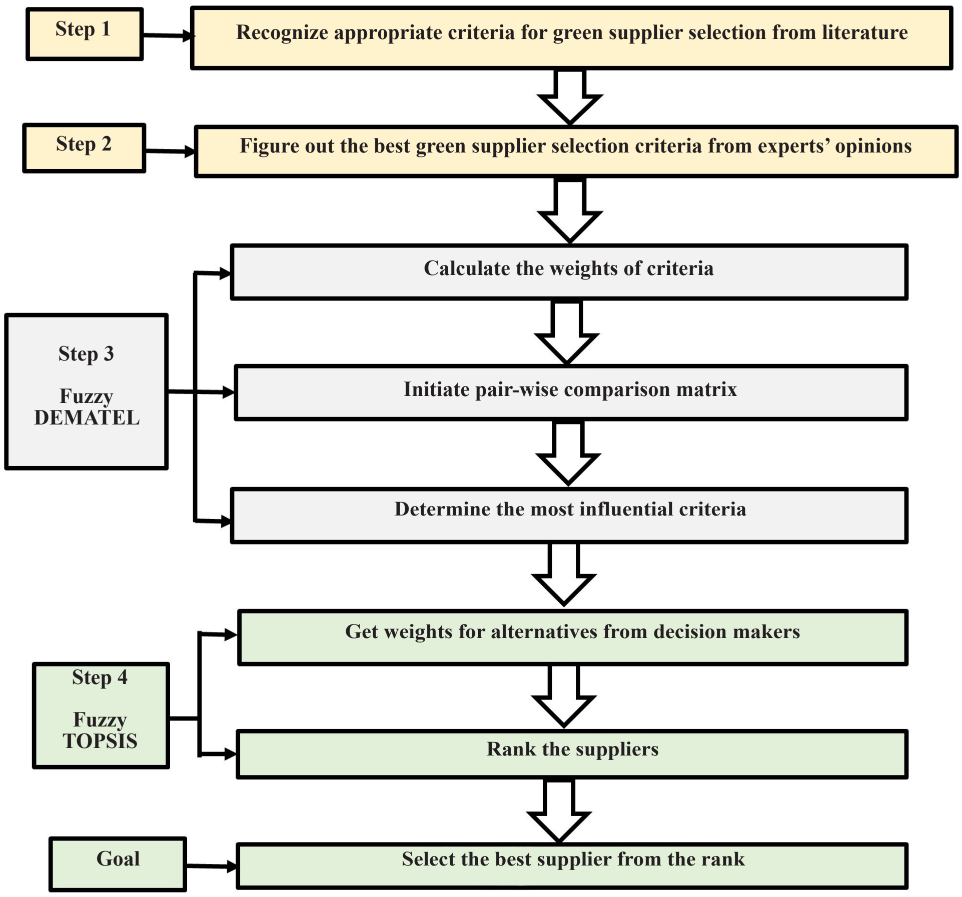

Figure 1. Structure of the framework

The step-by-step procedure of the integrated framework is illustrated below.

Step 1: The green suppliers' selection criteria in the context of the RMG industry based on the extant literature reviews are identified as listed in Table 2.

Table 2. Identification of green criteria for adoption of green supplier selection

Green criteria	Criteria code	Relevant literature
Inspection methods and plans	F1	[60]
Quality related certificates	F2	[28]
Corrective actions	F3	[37]
Warranties and claim policies	F4	[16]
Process improvement	F5	[29]
Price-performance value	F6	[22]
Quantity discount	F7	[61]
Logistic cost	F8	[30]
Product cost	F9	[28]
Compliance with sectoral price behavior	F10	[64]
Responsiveness	F11	[17]
Service innovation	F12	[62]
Willingness	F13	[31]
Stock management	F14	[60]
Flexibility in service	F15	[28]
Restriction on the use of hazardous substances	F16	[59]
Environment-related certificates	F17	[18]
Internal control process	F18	[65]
Green packaging	F19	[19]
Waste management and recycling	F20	[24]
Resource consumption	F21	[25]
Environmental management system	F22	[8]
Capacity of design	F23	[36]
Capability of R&D	F24	[32]
Capability of preventing pollution	F25	[28]
Technology level	F26	[33]
The rights of the employee	F27	[58]
The rights of stakeholders	F28	[57]
Respect for the policy	F29	[34]
Contract terms	F30	[35]

Step 2: The most relevant criteria are selected with industry professionals' support through Pareto analysis shown in Table 3. Here, 30 experts were chosen; their profiles are listed in Table A1. The most significant criteria were identified using Pareto analysis. Appropriate responses (i.e., score on all criteria using a 10-point Likert scale) were demanded by the experts shown in Table A2, where 0 indicates the least important on the Likert scale, and 10 shows highly important.

Table 3. Most important criteria according to experts' opinions

Green criteria	Criteria code
Process improvement	GC1
Quality related certificates	GC2
Warranties and claim policies	GC3
Price performance value	GC4
Compliance with sectoral price behavior	GC5
Logistic cost	GC6
Responsiveness	GC7
Stock management	GC8
Willingness	GC9
Restriction on the use of hazardous substances	GC10
Environment related certificates	GC11
Internal control process	GC12
Green packaging	GC13
Waste management and recycling	GC14
Technology level	GC15
Capability of R&D	GC16
Capability of preventing pollution	GC17
The rights of the employee	GC18
The rights of stakeholders	GC19
Respect for the policy	GC20

Step 3: Designing the fuzzy linguistic scale for criterion evaluations. Through this step, relationships within attributes must be established through pair-wise comparison assessment, using three expert opinions from Table A1. As shown in Table A3, the fuzzy linguistic scale must be configured initially to compare the relationships.

Step 4: A direct relationship matrix between the criteria is defined in the first step in fuzzy DEMATEL to decide the significance of one criterion over another. The matrix is created with the help of a fuzzy linguistic scale. Table A4 is developed where the criteria are put in row-column cells. The point is then given to those criteria by following the expert opinions to find the importance of one criterion over another. Three experts were chosen from Table A1 to identify influences between pairs and compare paths within the appropriate criteria, which is a $n \times m$ matrix, $\hat{A}$ as shown in Equation (1), in which $\hat{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ is referred to as the degree to which the criterion i affects the criterion j for experts.

$$\hat{A} = \begin{matrix} A_1 \\ A_i \\ A_n \end{matrix} \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{1j} & \tilde{x}_{1m} \\ \vdots & \vdots & \vdots \\ \tilde{x}_{n1} & \tilde{x}_{11} & \tilde{x}_{nm} \end{bmatrix} \tag{1}$$

Fuzzy numbers are recommended as an appropriate way to express linguistic variables. The fuzzy triangular numbers are the most widely utilized [66]. They are characterized by a triangular membership function, where the highest degree of membership is at the central value and gradually decreases towards the lower and upper bounds. To handle imprecise or unclear information, fuzzy logic and fuzzy set theory utilize fuzzy triangular numbers extensively [67, 68].

Step 5: This step involves transforming the fuzzy triangular numbers into the initial direct-relation matrix. Fuzzy linguistic variables are used in this research to obtain a comparison matrix from the three expert's opinions. Let, $\hat{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ is denoted as the degree to which one criterion affects another criterion. The Converting Fuzzy data into Crisp Scores (CFCS) method involves a five-step algorithm as follows:

Step 5.1: The fuzzy numbers are normalized first using Equations (2) to (4).

$$xu_{ij}^{n} = (u_{ij}^{n} - minl_{ij}^{n}) / \Delta_{min}^{max} \tag{2}$$

$$xm_{ij}^{n} = (m_{ij}^{n} - minl_{ij}^{n}) / \Delta_{min}^{max} \tag{3}$$

$$xl_{ij}^{n} = (l_{ij}^{n} - minl_{ij}^{n}) / \Delta_{min}^{max} \tag{4}$$

where $\Delta_{min}^{max} = maxu_{ij}^{n} - minl_{ij}^{n}$

Step 5.2: The calculation of right (*rs*) and left (*ls*) normalized values is done using Equations (5) and (6).

$$xrs_{ij}^{n} = xu_{ij}^{n} / (1 + xu_{ij}^{n} - xm_{ij}^{n}) \tag{5}$$

$$xls_{ij}^{n} = xm_{ij}^{n} / (1 + xm_{ij}^{n} - xl_{ij}^{n}) \tag{6}$$

Step 5.3: The calculation of total normalized crisp values is done using Equation (7).

$$x_{ij}^{n} = \left[xls_{ij}^{n}(1 - xls_{ij}^{n}) + xrs_{ij}^{n} \times xrs_{ij}^{n} \right] / \left[1 - xls_{ij}^{n} + xrs_{ij}^{n} \right] \tag{7}$$

Step 5.4: The computation of crisp values is done using Equation (8).

$$z_{ij}^{n} = min_{ij}^{n} + x_{ij}^{n} \times \Delta_{min}^{max} \tag{8}$$

Step 5.5: The integration of crisps values is done using Equation (9).

$$z_{ij} = \frac{1}{p}(z_{ij}^{1} + z_{ij}^{2} + \ldots + z_{ij}^{p}) \tag{9}$$

Step 6: Acquire a normalized direct-relation matrix. All major diagonal elements in the generalized direct relationship matrix generated should be between 0 and 1, as shown in Table A4. This step is done using Equations (10) and (11).

$$K = 1 / max_{1 \le i \le n} \sum_{j=1}^{n} z_{ij} \tag{10}$$

$$X = K \times \hat{A} \tag{11}$$

Step 7: The total-relationship matrix *T*, as shown in Table A5, can be attained using Equation (12), which denotes *I* as the identity matrix.

$$T = X\left(I - X\right)^{-1} \tag{12}$$

where X = Total relationship matrix.

Step 8: Calculate the weightage W_i for different criteria is done using Equations (13) to (16). The sum of rows and column numbers is denoted separately vector R_i and vector C_i.

$$T = [m_{ij}]_{n\times n},\ i, j = 1, 2, \dots, n \tag{13}$$

$$R_i = \left[\sum_{j=1}^{n} m_{ij}\right]_{n\times 1} = [t_i]_{n\times 1} \tag{14}$$

$$C_i = \left[\sum_{j=1}^{n} m_{ij}\right]_{1\times n} = [t_j]_{1\times n} \tag{15}$$

$$W_i = (R_i + C_i)_k \Big/ \sum_{k=1}^{n} (R_i + C_i)_k,\ i, k = 1, 2, \dots, n \tag{16}$$

Step 9: The Fuzzy TOPSIS is an MCDM approach used to solve uncertainty problems. For this technique, the three decision-makers use linguistic variables D_r ($r = 1, \dots, k$) to assess the alternatives score. $\tilde{w}_i$ denotes the ith criterion weightage, C_j ($j = 1, \dots, m$) given by the rth decision-maker in Fuzzy DEMATEL. $\tilde{x}_{ij}^r$ here denotes ith alternative rating, A_i ($i = 1, \dots, n$), regarding the criteria j, assumed by the rth decision-maker.

Aggregate the alternatives ratings given by k decision-makers are done using Equation (17).

$$\tilde{x}_{ij} = \frac{1}{k}\left[\tilde{x}_{ij}^1 + \tilde{x}_{ij}^2 + \dots + \tilde{x}_{ij}^k\right] \tag{17}$$

Step 10: Fuzzy decision matrix of the alternatives ($\tilde{D}$) assemble in Equation (18).

$$\tilde{D} = \begin{matrix} A_1 \\ A_i \\ A_n \end{matrix} \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{1j} & \tilde{x}_{1m} \\ \vdots & \vdots & \vdots \\ \tilde{x}_{n1} & \tilde{x}_{11} & \tilde{x}_{nm} \end{bmatrix} \tag{18}$$

Step 11: At this stage, three decision-makers give ratings of alternative suppliers. Then express their ratings in Fuzzy Numbers. After applying linear scale transformation, the Fuzzy decision matrix of the alternatives ($\tilde{D}$) is normalized, expressed in $\tilde{R}$ [69] using Equations (19) to (21).

$$\tilde{R} = \left[\tilde{r}_{ij}\right]_{m*n} \tag{19}$$

$$\tilde{r}_{ij} = \left(\frac{l_{ij}}{u_j^+}, \frac{m_{ij}}{u_j^+}, \frac{u_{ij}}{u_j^+}\right) \text{where } u_j^+ = \max u_{ij} \text{ (benefit criteria)} \tag{20}$$

$$\tilde{r}_{ij} = \left(\frac{l_j^-,}{u_{ij}}, \frac{l_j^-}{u_{ij}}, \frac{l_j^-}{u_{ij}}\right) \text{ where } l_j^- = \min l_{ij} \text{ (cost criteria)} \tag{21}$$

Step 12: The weighted normalized decision matrix $\tilde{V}$ using Equations (22) and (23). It is calculated by multiplying the evaluation criteria weightage obtained from Fuzzy DEMATEL, $\tilde{w}_i$ by the elements $\tilde{r}_{ij}$ of the normalized fuzzy decision matrix.

$$\tilde{V} = \left[\tilde{v}_{ij}\right]_{m*n} \tag{22}$$

$$\tilde{v}_{ij} = \tilde{r}_{ij} * \tilde{w}_i \tag{23}$$

where $\tilde{v}_j^-$ is the fuzzy weight of the jth criterion.

Step 13: Identification of the Fuzzy Positive Ideal Solution (FPIS, S^+) and the Fuzzy Negative Ideal Solution (FNIS, S^-) is done using Equations (24) and (25), respectively.

$$S^+ = (\tilde{v}_1^+, \tilde{v}_2^+, \ldots.., \tilde{v}_j^+) = \{(max_i v_{ij} \mid i = 1, 2, \ldots, m), j = 1, 2, \ldots, n\} \tag{24}$$

$$S^- = (\tilde{v}_1^-, \tilde{v}_2^-, \ldots.., \tilde{v}_j^-) = \{(\min_i v_{ij} \mid i = 1, 2, \ldots, m), j = 1, 2, \ldots, n\} \tag{25}$$

where $\tilde{v}_j^- = (1, 1, 1)$ and $\tilde{v}_j^- = (0, 0, 0)$, $j = 1, 2, ..., n$.

Step 14: The distances of every alternative from the FPIS point and FNIS point have been calculated using Equations (26) and (27), respectively.

$$d_i^+ = \sum_{j=1}^{n} d(\tilde{v}_{ij} - \tilde{v}_j^+), i = 1, 2, \ldots, m \tag{26}$$

$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij} - \tilde{v}_j^-), i = 1, 2, \ldots, m \tag{27}$$

For triangular fuzzy numbers, Equation (28) is used, which can be expressed as

$$d(\tilde{a}_1, \tilde{a}_2) = \sqrt{\frac{1}{3}[(l_1 - l_2)^2 + \frac{1}{3}(m_1 - m_2)^2 + \frac{1}{3}(u_1 - u_2)^2]} \tag{28}$$

Step 15: The closeness coefficient (CC_i) of every alternative has been computed using Equation (29).

$$CC_i = \frac{d_i^+}{d_i^+ + d_i^-}; i = 1, 2, \ldots, m \tag{29}$$

Step 16: After getting the closeness coefficient, the alternatives have been ranked. The alternative with the highest CC_i value will be the best choice.

Step 17: In Figure 3, the causal diagram is obtained using the central degree of the position as the horizontal axis ($R_i + C_i$) and the vertical axis ($R_i - C_i$) known as the degree of relation. A threshold value is defined to transform the critical evaluation criteria from the total relationship matrix. The degree of central position ($R_i + C_i$) represents both dispatched and received influences. Moreover, if $(R_i + C_i) > 0$, the evaluation criterion i diffuses the impact more than it receives on other evaluation criteria. In the other scenario, if $(R_i - C_i) > 0$, the evaluation criterion i derives more influence than it has been dispatched from other evaluation criteria.

4. Case study

GSCM implementation is complex due to the contradictory quality of the goals. Companies aim to achieve significant benefits while simultaneously reducing adverse environmental effects. However, there is often a dispute regarding whether to invest heavily in sustainable practices in the long-term or prioritize immediate financial gains. Adaptation of GSCM may extend trade contributions. A practical case study of a ready-made clothing factory (Utah Fashions Ltd.) is provided here to illustrate how decision-making helps with the designed integrated approach that incorporates Fuzzy DEMATEL and Fuzzy TOPSIS.

4.1 *Company profile*

The planned methodology is conducted in a realistic real-world scenario. The chosen company trades with the assembly of ready-made clothes. The embellishment capability of this company is 45,000 items per day. The case firm profile is shown in Table 4. The new manufacturing unit was designed with the most imaginative and compliant variables in mind. The new segment will boost production strength and raise in-house production capacity by near about 15 percent. It was apparent from a discussion with the management that the corporation needs a framework to integrate GSCM to enhance its organizational performance. Several explanations indicate their complementary view of GSCM being implemented at their factory. The demand from consumers is one of the crucial reasons for this. Customers keep pressuring them to encourage ecological harmony and ecological waste management. Besides, they advise the administration to have a streamlined manufacturing process and enhance quality standards. Corporate Social Responsibility (CSR) is the ultimate case for consumers today. The merchandiser must regularly consult with the CSR assembly house. They receive orders from many employers, especially when management decides to obey GSCM, and can add to the nation's growth by earning a fair amount of money.

Therefore, the goals of this study are synergized with the purpose of the selected organization. To this end, a systematic approach for seeing the comparative importance of selected parameters for selecting green suppliers relevant to the implementation of GSCM was carried out.

Table 4. Profile of business case

Industry name	Established	Product	Company year (Fiscal year 2019-20)
Utah Fashions Ltd.	2005	Knit woven	Number of employees: 3180

4.2 *Data collection*

The necessary information needed for this research was obtained from industry professionals. Unfortunately, no consensus is reached in the literature on the number of specialists needed to develop an MCDM case. For instance, fourteen consultants' views were taken to design a Fuzzy-TOPSIS problem [70], and four specialists were considered to model a Grey-DEMATEL analysis [71]. However, due to time limitations and convenience, this analysis included three data collection experts from Table A1. The data assortment method is carried out as delineated here in two steps. The first step identifies and finalizes the appropriate green supplier selection criteria. After that, the suppliers' ranking according to their effectiveness as green suppliers is done. These steps are dispensed by taking input from experts to build a combined method of Fuzzy DEMATEL and Fuzzy TOPSIS.

4.2.1 *Identification of major criteria for green supplier selection*

Figure 2 illustrates the Pareto diagram of green supplier selection criteria. The experts assessed all criteria found in the literature, as indicated in Table 2. The cumulative percentage and highest mean value score for all criteria were computed after collecting expert responses. The 20 (comprising 80%) most important criteria among 30 were finalized, as shown in Table 3, which will boost green suppliers' selection based on the percentage score.

The most appropriate and applicable parameters were chosen with the help of industry professionals utilizing Pareto analysis, as shown in Table 3.

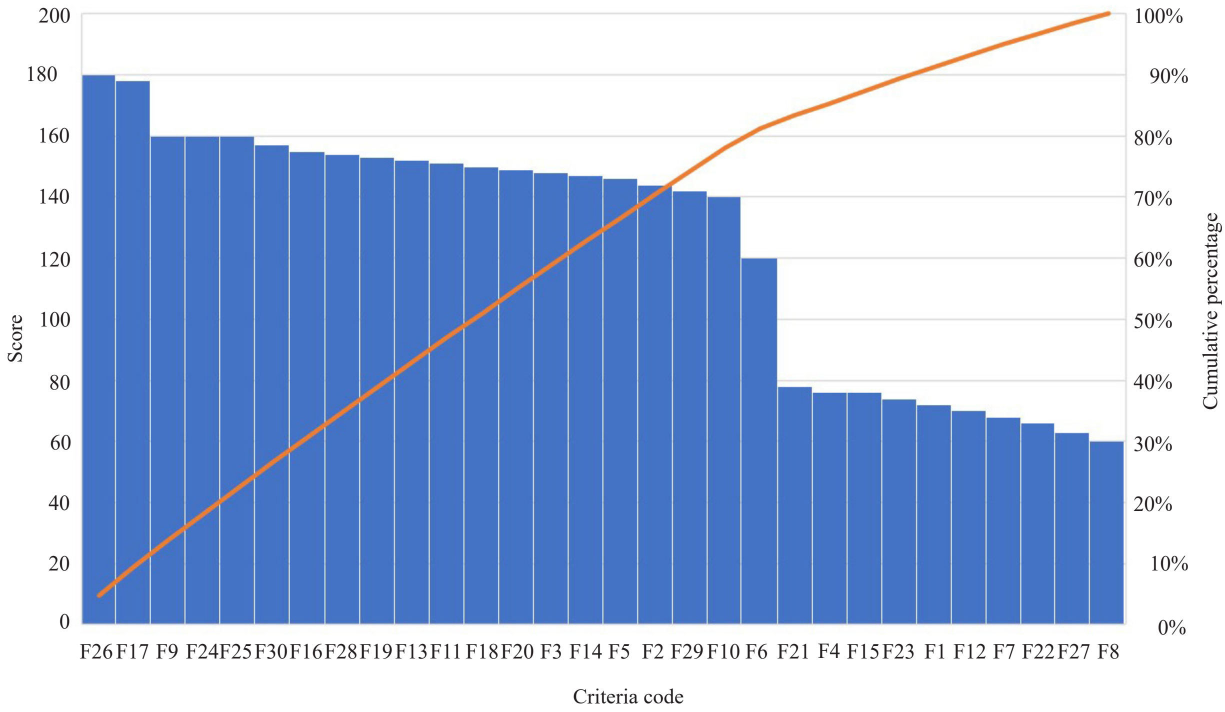

Figure 2. Pareto analysis for identifying the most important green criteria

4.2.2 *Implication of Fuzzy DEMATEL*

A direct relation matrix among the criteria is set up in Table A2 to determine the importance of one criterion over another in Fuzzy DEMATEL. A calculation is done to find the criterion's value over another criterion arranged in row and column cells. The point is then given to those criteria by following the expert opinions according to the scale shown in Table A3.

A normalized direct-relation matrix is acquired after transforming the fuzzy triangular numbers into the initial direct-relation matrix, as shown in Table A4. After the normalized direct-relationship matrix is obtained, the total-relationship matrix, as shown in Table A5, is acquired using Equation (12).

Using the Fuzzy DEMATEL method, Table 5 reveals that the maximum 0.061825 was achieved by GC14 (waste management and recycling).

Table 5. Weightage W_i for different criteria

Criteria	Weightage	Criteria	Weightage	Criteria	Weightage	Criteria	Weightage
GC 1	0.051506	GC 6	0.032999	GC 11	0.051606	GC 16	0.050061
GC 2	0.053993	GC 7	0.051241	GC 12	0.055869	GC 17	0.058365
GC 3	0.044001	GC 8	0.038282	GC 13	0.055259	GC 18	0.041996
GC 4	0.049296	GC 9	0.060672	GC 14	0.061825	GC 19	0.034563
GC 5	0.047054	GC 10	0.052045	GC 15	0.059967	GC 20	0.049401

4.2.3 *Implication of Fuzzy TOPSIS*

The weighted normalized decision matrix shown in Table A6 is developed by multiplying the weights obtained from Fuzzy DEMATEL by the normalized Fuzzy TOPSIS decision matrix elements. The calculation of every alternative's distance from a fuzzy positive ideal solution point and a fuzzy negative ideal solution point using Equations (26) to (28) are shown in Table 6.

Table 6. The distances of every alternative from the fuzzy negative ideal solution (d_i^-) and fuzzy positive ideal solution (d_i^+)

Green supplier	d_i^-	d_i^+
GS 1	0.486	0.071
GS 2	0.292	0.268
GS 3	0.271	0.288
GS 4	0.201	0.355
GS 5	0.353	0.207

Now, the closeness coefficient is calculated using Equation (29), and the suppliers shall be numbered in the descending order of the closeness coefficient value, and finally, the suppliers' ranking is shown in Table 7.

Table 7. Alternative suppliers ranking according to Fuzzy TOPSIS

Suppliers	CC_i	Rank
GS 1	1.486	1
GS 2	1.292	3
GS 3	1.271	4
GS 4	1.201	5
GS 5	1.353	2

The final result is summarized as Supplier 1 > Supplier 5 > Supplier 2 > Supplier 3 > Supplier 4.

4.3 *Result analysis*

In this segment, the results are described. This research uses Fuzzy DEMATEL to assess the weights of parameters. Three decision-makers were selected to provide decisions based on a fuzzy linguistic scale to form an interrelationship matrix among criteria. Weights of criteria are acquired by incorporating their decisions in the Fuzzy DEMATEL method. Criteria weights are demonstrated in Table 5. From the mentioned table, it is identified that waste management and recycling criteria have got the maximum weightage.

Table A5 contains the total relationship matrix and, based on this matrix, the impact (R_i) and received (C_i) are determined. The value of ($R_i + C_i$) provides the degree of importance (prominence), and ($R_i - C_i$) provides the net effect (relation), which are shown in Table 8.

Table 8. Result of Fuzzy DEMATEL

Criteria	R_i	C_i	$R_i + C_i$	$R_i - C_i$	Category
GC 1	2.097959	2.746065	4.84402418	-0.64811	Effect group
GC 2	2.638202	2.599332	5.237533625	0.03887	Cause group
GC 3	2.161888	2.503641	4.665528844	-0.34175	Effect group
GC 4	2.30652	2.476949	4.783468784	-0.17043	Effect group
GC 5	2.426495	2.638757	5.065251404	-0.21226	Effect group
GC 6	1.701161	1.978623	3.679783829	-0.27746	Effect group
GC 7	2.803242	2.58143	5.384672749	0.221812	Cause group
GC 8	2.047651	2.024085	4.071735872	0.023566	Cause group
GC 9	2.862193	2.88025	5.742443277	-0.01806	Effect group
GC 10	2.266952	2.895952	5.162904072	-0.62900	Effect group
GC 11	2.54843	2.440411	4.988840697	0.108019	Cause group
GC 12	2.846614	2.806439	5.653053094	0.040174	Cause group
GC 13	2.913747	2.30214	5.215886517	0.611606	Cause group
GC 14	3.55257	2.599026	6.151596042	0.953543	Cause group
GC 15	3.207466	2.736549	5.944015285	0.470916	Cause group
GC 16	2.742043	2.093187	4.835230285	0.648856	Cause group
GC 17	3.226415	2.489342	5.71575696	0.737073	Cause group
GC 18	1.876398	2.460306	4.336704106	-0.58391	Effect group
GC 19	1.513858	2.196766	3.710624429	-0.68291	Effect group
GC 20	2.276573	2.567127	4.843700204	-0.29055	Effect group

The feedback received from the experts for success factors is seen in the type of a visual appeal chart by splitting the variables into two to distinguish better cause and effect varying quadrants. The causal relationship diagram of the supplier selection criteria is shown in Figure 3. The diagram compares the values ($R_i + C_i$) and ($R_i - C_i$) found in Table 8. The factors with a positive net effect are categorized as cause factors, and those with a negative net effect are categorized as effect factors. In the cause-and-effect diagram, shown in Figure 3, factors at the top are cause factors and factors at the bottom are effect factors. Criteria with the most weightage are also at the top of the causal relationship diagram. After analysis of both Figure 3 and Table 8, it can be said that responsiveness (GC7), capability of preventing pollution (GC17), stock management (GC8), environment related certificates (GC11), internal control process (GC12), green packaging (GC13), waste management and recycling (GC14), technology level (GC15), capability of preventing pollution (GC17), etc., are the most impactful cause grouped criteria. These aspects have a more significant effect;

therefore, more focus should be implemented to improve them to strengthen the aspects. Process improvement (GC1), warranties and claim policies (GC3), price performance value (GC4), compliance with sectoral price behavior (GC5), restriction on the use of hazardous substances (GC10), etc., are effect groups. Such criteria also need further attention from managers because the causal group variables can greatly influence them.

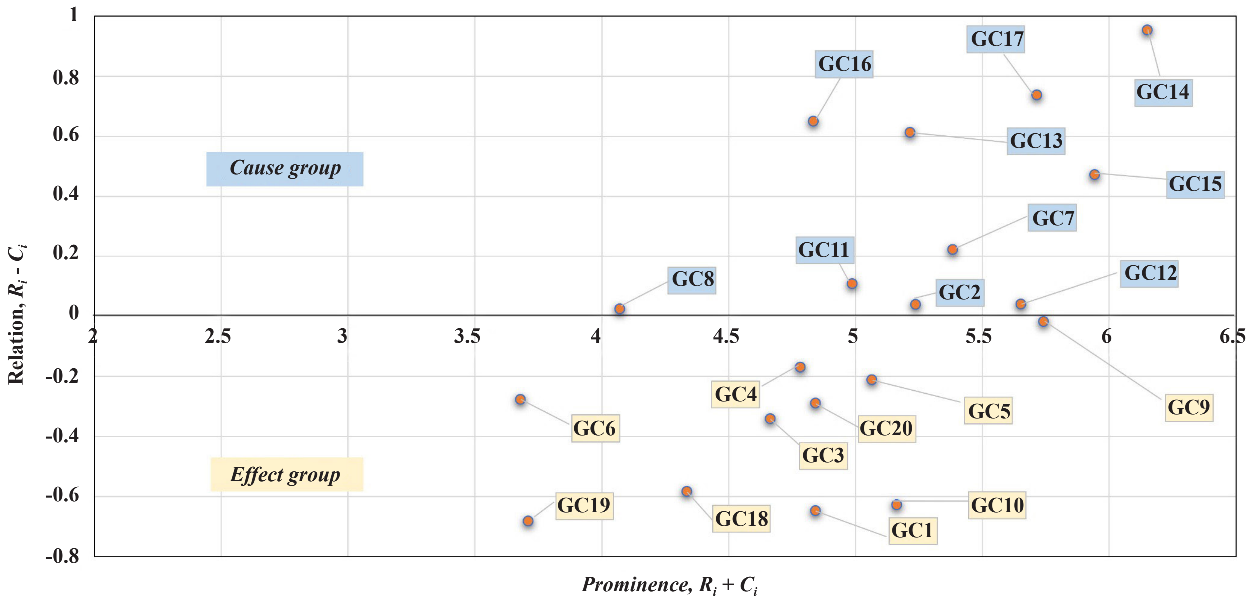

Figure 3. Causal relationship diagram

The waste management and recycling criterion (GC14) has the maximum weightage and is also at cause group effect. These aspects are then incorporated into the system of Fuzzy TOPSIS. The decision-makers give the suppliers' performance ratings for each criterion in the Fuzzy TOPSIS MCDM technique. According to the available Fuzzy TOPSIS result in Table 7, supplier 1 is the best alternative in green supplier selection for the firm.

Based on Fuzzy TOPSIS, the ranking of the suppliers is as follows.

Supplier 1 > Supplier 5 > Supplier 2 > Supplier 3 > Supplier 4

5. Managerial and empirical significance

In order to select the most suitable green supplier, it is crucial to consider numerous criteria while minimizing costs. This study narrows down those criteria, which ultimately benefit the industrial managers to have their desired products from the right green supplier.

5.1 *Managerial significance*

When implementing GSCM, it can be challenging for managers to consider all the selection criteria for a specific provider. Therefore, it becomes crucial to determine the priority among the criteria. Among these criteria, waste management and recycling (GC14) holds paramount importance, and managers should focus on this aspect. By prioritizing this criterion, managers can ensure sustainable practices and minimize environmental impact throughout the supply chain. Also, managers should consider the supplier's capability to prevent pollution (GC17) as a critical criterion. Suppliers who strongly commit to pollution prevention practices can significantly contribute to achieving environmental sustainability goals. By partnering with suppliers that prioritize pollution prevention, managers can mitigate risks associated with environmental contamination and strengthen their overall sustainability performance. The level of technology adoption (GC15) is another significant criterion managers should carefully assess when selecting green suppliers. Suppliers who embrace advanced technologies demonstrate a proactive approach to improving environmental performance. These technologies can enable efficient resource utilization, reduce emissions, and enhance sustainability outcomes. Therefore, managers should prioritize suppliers who embrace and invest in advanced technology solutions for their operations. Another essential criterion is the supplier's commitment to green packaging (GC13). Green packaging plays a crucial role in reducing waste and minimizing the environmental footprint of products throughout their lifecycle. Managers should seek suppliers prioritizing sustainable packaging materials, such as biodegradable or recyclable, and utilize packaging designs that optimize space and reduce material consumption. By selecting suppliers that prioritize green packaging, managers can contribute to waste reduction goals and enhance the overall sustainability profile of their supply chain. Ultimately, if managers prioritize these criteria, such as waste management and recycling, capability of preventing pollution, technology level, and green packaging, they can make informed decisions when selecting green suppliers. By incorporating these criteria into their supplier selection process, managers can ensure the successful implementation of GSCM, minimize environmental impacts, and contribute to long-term sustainability goals.

5.2 *Empirical and global significance*

Some of the most important criteria found in this study, which have significant empirical and global significance for the implementation of GSCM within the Bangladeshi RMG sector, include waste management and recycling, the ability to prevent pollution, technology level, and green packaging. The study's findings effectively offer useful data about choosing eco-friendly vendors for GSCM implementation in the Bangladeshi RMG industry. Managers can address the pressing issue of waste generation and advance sustainable practices throughout the supply chain by prioritizing waste management and recycling (GC14). This empirical data can help factory managers optimize GSCM activities inside the RMG supply chains, resulting in better environmental performance and waste management procedures.

On a global scale, this research has implications for integrating GSCM practices within the Bangladeshi RMG sector, which operates in an increasingly globalized economy. The pressure put on Bangladesh's textile industry by foreign investors to adopt environmentally friendly practices exemplifies the importance of GSCM on a global scale. Managers can proactively address environmental problems and lessen the ecological effects linked to RMG manufacturing by considering the capability of preventing pollution criterion (GC17). This global push for GSCM promotes sustainable practices to reduce risks on the financial and social fronts as well as to limit negative environmental effects. The technology level criterion (GC15) holds substantial global significance as well. Green suppliers' adoption of cutting-edge technologies encourages resource efficiency, lowers emissions, and improves sustainability outcomes. Managers in the Bangladeshi RMG industry can align their operations with global sustainability trends by adopting cutting-edge technology solutions, demonstrating a commitment to environmental responsibility, and luring in international investors who prioritize sustainability. Another factor with empirical support and broad significance is green packaging (GC13). Managers can minimize waste and lower the environmental impact of RMG products by concentrating on sustainable packaging materials and designs. Green packaging initiatives help the world's efforts to reduce waste and conserve resources. Additionally, it promotes a favorable business image and draws customers who respect ecologically responsible products. This global preference for greener products aligns with the sustainable development objectives of many nations and promotes the expansion of sustainable enterprises worldwide.

In conclusion, the criteria of waste management and recycling, capability of preventing pollution, technology level, and green packaging have both empirical and global significance for implementing GSCM within the Bangladeshi RMG sector. Managers may increase environmental performance, satisfy global sustainability objectives, and boost their brand image while recruiting environmentally conscious customers by giving these factors priority. This study promotes the adoption of GSCM methods, promoting a more environmentally conscious and sustainable global economy.

6. Conclusions, limitations, and future work

Green supply chain practices, particularly selecting a supplier based on green criteria, are still in their infancy in emerging economies. This study offers a comprehensive framework for evaluating suppliers' environmental performance and sustainability contributions using a novel integrated technique that combines the Fuzzy DEMATEL with the Fuzzy TOPSIS within the context of Bangladesh. Initially, a thorough literature review identified thirty green supplier selection criteria. Following that, the most critical criteria for choosing a green supplier were determined using experts' feedback and Pareto analysis. Fuzzy DEMATEL weighted these criteria, and Fuzzy TOPSIS ranked the suppliers to select the best green supplier. According to the findings of this study, the major factors are responsiveness (GC7), stock management (GC8), certificates related to the environment (GC11), internal control process (GC12), green packaging (GC13), waste management and recycling (GC14), technology level (GC15).

The model developed in this paper contributes significantly by considering the most relevant criteria for evaluating green suppliers. A case study is conducted within a ready-made clothing industry in Bangladesh to analyze and rank their suppliers to validate the framework's efficacy. The research also involves a thorough analysis encompassing quantitative and qualitative data, assuring supplier comparability. Additionally, this integrated strategy offers a systematic and robust technique that assists company managers in understanding the importance of sustainability in the procurement process and equips them to assess suppliers accordingly, especially in the ready-made garment industry. Consequently, stakeholders such as investors and suppliers within this industry may find merit in the suggested methodology to enhance their profitability and brand reputation by adopting sustainable practices.

This study, like others, has several shortcomings that could be addressed in subsequent studies. As the study focuses on specific industry types, it may not consider other green criteria depending on the industry and the geographical context. Furthermore, there is a possibility of introducing judgmental bias as the techniques heavily rely on these experts' subjective opinions and judgments, leading to results that may not accurately represent reality. Future research could enhance expert diversity by including a wider range of experts from several relevant fields to mitigate judgmental bias. Additionally, the interrelationships among these criteria should also be investigated in future research. These relationships can be investigated by integrating fuzzy or grey-based total interpretive structural modeling (TISM) and fuzzy MICMAC (Matrice d'impacts croisés multiplication appliquée á un classment), which can explore the interrelationships among the factors and cluster them based on their driving and dependence power. Other methods, such as Bayesian BWM for quantifying uncertainty and making more robust inferences about preferences and rankings, and ELECTRE for effective handling of multiple criteria and qualitative data, can be employed. Lastly, conducting sensitivity analysis would be valuable in assessing the robustness of the results by evaluating the impact of variations in input data.

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Conflict of interest

The authors declare no competing financial interest.

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Appendix

Table A1. Industry experts

Experts	Companies	Affiliation
Expert 1	X Industries Ltd.	Head of Supply Chain Management
Expert 2	X Industries Ltd.	In-Charge, Sourcing & Procurement
Expert 3	X Industries Ltd.	In-Charge, Planning & Inventory
Expert 4	X Industries Ltd.	In-Charge, Logistics & Distribution
Expert 5	X Industries Ltd.	Manager, Distribution
Expert 6	X Industries Ltd.	Assistant Manager, Sourcing
Expert 7	X Industries Ltd.	Assistant Manager, Commercial
Expert 8	X Industries Ltd.	Executive, Commercial & Logistics
Expert 9	X Industries Ltd.	Executive, Supply Chain Management
Expert 10	X Industries Ltd.	Head of Supply Chain Management
Expert 11	Y Industries Ltd.	Head of Supply Chain Management
Expert 12	Y Industries Ltd.	In-Charge, Sourcing & Procurement
Expert 13	Y Industries Ltd.	In-Charge, Planning & Inventory
Expert 14	Y Industries Ltd.	In-Charge, Logistics & Distribution
Expert 15	Y Industries Ltd.	Manager, Distribution
Expert 16	Y Industries Ltd.	Assistant Manager, Sourcing
Expert 17	Y Industries Ltd.	Assistant Manager, Commercial
Expert 18	Y Industries Ltd.	Executive, Commercial & Logistics
Expert 19	Y Industries Ltd.	Executive, Supply Chain Management
Expert 20	Y Industries Ltd.	Head of Supply Chain Management
Expert 21	Z Industries Ltd.	Head of Supply Chain Management
Expert 22	Z Industries Ltd.	In-Charge, Sourcing & Procurement
Expert 23	Z Industries Ltd.	In-Charge, Planning & Inventory
Expert 24	Z Industries Ltd.	In-Charge, Logistics & Distribution
Expert 25	Z Industries Ltd.	Manager, Distribution
Expert 26	Z Industries Ltd.	Assistant Manager, Sourcing
Expert 27	Z Industries Ltd.	Assistant Manager, Commercial
Expert 28	Z Industries Ltd.	Executive, Supply Chain Management
Expert 29	Z Industries Ltd.	Executive, Commercial & Logistics
Expert 30	Z Industries Ltd.	Head of Supply Chain Management

Table A2. Fuzzy linguistic scale for direct-relation matrix

Lingusitic terms	Triangular fuzzy numbers
No influence (N)	(0, 0, 0.25)
Very low influence (VL)	(0, 0.25, 0.50)
Low influence (L)	(0.25, 0.50, 0.75)
High influence (H)	(0.50, 0.75, 1.00)
Very high influence (VH)	(0.75, 1.00, 1.00)

Table A3. Experts' feedback on most important criteria for green supplier selection

Experts	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15
E1	0	7	7	5	7	7	7	2	7	7	7	5	4	6	2
E2	5	7	5	5	7	7	7	2	5	8	8	5	4	6	0
E3	5	7	5	5	7	7	2	2	5	8	6	5	4	6	0
E4	5	7	5	5	7	7	2	2	5	8	7	5	4	6	2
E5	5	2	5	5	8	7	2	2	5	8	4	5	4	6	2
E6	5	2	5	3	8	3	2	2	5	2	4	3	4	6	4
E7	7	2	5	3	8	3	2	2	5	2	4	3	7	4	4
E8	7	2	2	3	8	3	2	2	2	2	5	3	5	4	4
E9	7	2	2	3	8	3	2	2	2	2	5	3	5	4	4
E10	7	8	8	3	8	3	2	2	8	2	5	3	5	4	4
E11	0	2	2	3	2	3	2	2	2	2	5	3	5	5	3
E12	0	2	2	3	2	3	0	0	2	2	4	3	5	5	3
E13	0	2	2	3	2	3	0	0	2	2	4	3	5	5	3
E14	4	2	2	3	2	3	0	4	2	2	4	3	5	5	0
E15	4	2	2	3	2	3	0	4	2	7	4	1	5	4	4
E16	4	8	8	3	2	3	0	4	8	7	5	1	5	4	2
E17	4	9	3	3	2	3	0	4	3	7	5	1	5	4	5
E18	3	9	3	3	2	3	4	4	10	7	5	1	5	6	5
E19	1	5	5	1	2	3	4	4	10	7	6	1	5	6	2
E20	0	5	5	1	2	3	4	4	10	7	6	1	8	3	2
E21	0	8	8	1	7	3	4	4	8	7	6	1	6	3	2
E22	2	5	5	2	7	3	4	4	5	7	5	2	5	3	5
E23	0	7	7	2	5	3	4	4	7	7	5	2	5	3	6
E24	0	8	7	2	5	5	4	4	9	3	5	2	5	3	1
E25	1	5	7	1	5	5	4	4	7	3	5	2	5	8	2
E26	0	5	7	1	5	5	2	2	7	3	5	2	7	5	2
E27	0	5	7	1	5	6	4	0	7	3	5	2	7	3	2
E28	0	3	7	1	3	5	4	0	7	3	6	2	8	8	2
E29	0	3	4	0	3	4	0	0	3	2	5	1	5	4	1
E30	0	2	1	0	2	1	0	0	2	3	1	0	2	4	0

	F16	F17	F18	F19	F20	F21	F22	F23	F24	F25	F26	F27	F28	F29	F30
E1	5	7	5	7	6	3	3	3	8	4	7	4	9	7	6
E2	5	7	5	4	4	3	3	3	8	8	8	4	7	5	6
E3	5	7	5	4	4	3	3	3	6	8	7	0	7	5	6
E4	5	7	8	4	6	3	3	2	6	8	6	4	4	5	5
E5	5	7	5	4	4	3	3	3	6	8	5	2	4	5	6
E6	5	8	5	4	4	3	3	2	7	8	5	4	4	5	8
E7	6	7	5	4	4	3	3	3	6	8	7	3	4	5	4
E8	6	7	8	4	6	3	3	2	6	8	3	4	4	5	6
E9	6	7	4	4	6	3	3	3	4	4	7	2	4	3	4
E10	6	7	8	4	6	5	3	2	4	4	4	1	4	3	4
E11	6	6	4	4	6	7	3	3	4	4	8	1	4	3	4
E12	6	8	4	4	6	3	3	1	4	2	2	1	4	3	3
E13	6	6	8	4	6	3	3	3	4	3	6	1	7	3	9
E14	5	5	4	9	6	3	3	1	4	4	6	1	7	3	9
E15	5	6	4	9	6	2	2	3	4	4	7	1	7	3	9
E16	5	8	5	9	6	0	0	4	4	2	7	1	9	8	4
E17	8	6	4	8	6	2	2	0	4	7	5	1	9	8	5
E18	5	6	4	8	6	4	4	3	4	7	3	1	4	7	5
E19	5	6	4	5	3	4	4	0	4	7	3	5	5	8	5
E20	8	5	4	5	3	4	4	3	4	7	3	2	5	4	4
E21	5	5	4	5	3	4	4	3	4	7	8	4	5	4	5
E22	5	5	4	5	5	4	4	3	4	7	8	4	5	4	5
E23	5	5	4	5	3	3	3	3	4	9	8	3	5	4	5
E24	5	1	4	5	3	1	1	3	4	9	8	4	5	4	5
E25	5	5	4	5	3	0	0	3	9	3	8	4	5	4	5
E26	5	5	4	5	7	0	0	3	9	3	8	2	4	4	6
E27	6	5	9	5	7	1	1	3	9	3	8	3	4	4	7
E28	6	6	7	9	6	1	1	3	9	3	8	1	4	8	6
E29	5	4	4	3	4	1	1	2	5	1	3	2	5	5	3
E30	0	4	3	3	3	0	0	1	4	2	3	2	4	4	2

Table A4. The normalized direct-relation matrix

Criteria	GC1	GC2	GC3	GC4	GC5	GC6	GC7	GC8	GC9	GC10
GC 1	0.0024	0.0193	0.0193	0.0475	0.0193	0.0024	0.0475	00.0024	0.0531	0.0362
GC 2	0.0419	0.0024	0.0250	0.0475	0.0475	0.0428	0.0419	0.0245	0.0419	0.0531
GC 3	0.0545	0.0545	0.0024	0.0362	0.0531	0.0200	0.0193	0.0349	0.0362	0.0362
GC 4	0.0362	0.0362	0.0362	0.0024	0.0700	0.0372	0.0362	0.0506	0.0531	0.0419
GC 5	0.0193	0.0250	0.0419	0.0362	0.0024	0.0541	0.0531	0.0506	0.0362	0.0588
GC 6	0.0531	0.0024	0.0024	0.0193	0.0700	0.0024	0.0531	0.0700	0.0419	0.0024
GC 7	0.0362	0.0193	0.0531	0.0193	0.0588	0.0707	0.0024	0.0506	0.0588	0.0193
GC 8	0.0193	0.0362	0.0531	0.0024	0.0475	0.0485	0.0700	0.0024	0.0531	0.0024
GC 9	0.0362	0.0700	0.0193	0.0362	0.0193	0.0024	0.0362	0.0024	0.0024	0.0700
GC 10	0.0700	0.0362	0.0362	0.0531	0.0193	0.0312	0.0024	0.0405	0.0531	0.0024
GC 11	0.0362	0.0531	0.0531	0.0362	0.0024	0.0024	0.0193	0.0450	0.0362	0.0531
GC 12	0.0531	0.0700	0.0362	0.0531	0.0531	0.0541	0.0362	0.0349	0.0419	0.0588
GC 13	0.0362	0.0588	0.0024	0.0362	0.0362	0.0372	0.0193	0.0024	0.0700	0.0700
GC 14	0.0644	0.0700	0.0475	0.0475	0.0024	0.0200	0.0475	0.0349	0.0531	0.0531
GC 15	0.0531	0.0531	0.0531	0.0531	0.0700	0.0024	0.0362	0.0188	0.0531	0.0475
GC 16	0.0700	0.0362	0.0362	0.0700	0.0588	0.0372	0.0531	0.0024	0.0024	0.0531
GC 17	0.0362	0.0362	0.0531	0.0531	0.0531	0.0541	0.0475	0.0349	0.0362	0.0700
GC 18	0.0024	0.0024	0.0362	0.0419	0.0362	0.0200	0.0193	0.0405	0.0419	0.0362
GC 19	0.0193	0.0193	0.0531	0.0024	0.0193	0.0256	0.0362	0.0349	0.0193	0.0024
GC 20	0.0419	0.0306	0.0531	0.0024	0.0250	0.0024	0.0700	0.0024	0.0362	0.0475
	GC11	GC12	GC13	GC14	GC15	GC16	GC17	GC18	GC19	GC20
GC 1	0.0362	0.0362	0.0193	0.0475	0.0700	0.0024	0.0588	0.0024	0.0362	0.0024
GC 2	0.0531	0.0193	0.0700	0.0362	0.0531	0.0475	0.0024	0.0362	0.0024	0.0588
GC 3	0.0362	0.0475	0.0193	0.0137	0.0193	0.0362	0.0024	0.0419	0.0531	0.0193
GC 4	0.0306	0.0362	0.0250	0.0531	0.0362	0.0024	0.0362	0.0024	0.0193	0.0024
GC 5	0.0024	0.0419	0.0193	0.0419	0.0419	0.0250	0.0193	0.0024	0.0700	0.0644
GC 6	0.0362	0.0024	0.0024	0.0024	0.0193	0.0024	0.0193	0.0531	0.0531	0.0024
GC 7	0.0531	0.0531	0.0419	0.0362	0.0362	0.0250	0.0531	0.0362	0.0362	0.0475
GC 8	0.0362	0.0362	0.0362	0.0024	0.0193	0.0362	0.0024	0.0531	0.0362	0.0024
GC 9	0.0531	0.0531	0.0700	0.0531	0.0700	0.0193	0.0475	0.0700	0.0024	0.0531
GC 10	0.0193	0.0193	0.0193	0.0362	0.0193	0.0024	0.0644	0.0419	0.0362	0.0531
GC 11	0.0024	0.0700	0.0700	0.0193	0.0362	0.0193	0.0531	0.0362	0.0193	0.0531
GC 12	0.0531	0.0024	0.0193	0.0531	0.0700	0.0193	0.0362	0.0024	0.0419	0.0193
GC 13	0.0700	0.0475	0.0024	0.0475	0.0588	0.0700	0.0531	0.0531	0.0193	0.0193
GC 14	0.0475	0.0700	0.0700	0.0193	0.0700	0.0531	0.0700	0.0531	0.0362	0.0700
GC 15	0.0531	0.0531	0.0193	0.0700	0.0024	0.0362	0.0531	0.0700	0.0531	0.0644
GC 16	0.0193	0.0700	0.0531	0.0531	0.0475	0.0024	0.0531	0.0024	0.0024	0.0362
GC 17	0.0475	0.0531	0.0644	0.0531	0.0531	0.0531	0.0024	0.0545	0.0024	0.0588
GC 18	0.0024	0.0531	0.0193	0.0362	0.0024	0.0475	0.0024	0.0024	0.0475	0.0531
GC 19	0.0024	0.0362	0.0024	0.0354	0.0024	0.0475	0.0024	0.0362	0.0024	0.0362
GC 20	0.0362	0.0024	0.0081	0.0193	0.0419	0.0531	0.0644	0.0531	0.0531	0.0024

Table A5. The total-relation matrix

Criteria	GC1	GC2	GC3	GC4	GC5	GC6	GC7	GC8	GC9	GC10
GC 1	0.0870	0.1018	0.0969	0.1231	0.0988	0.0625	0.1221	0.0646	0.1400	0.1259
GC 2	0.1464	0.1022	0.1185	0.1410	0.1457	0.1148	0.1380	0.0997	0.1518	0.1635
GC 3	0.1368	0.1326	0.0801	0.1125	0.1325	0.0815	0.0996	0.0970	0.1242	0.1247
GC 4	0.1268	0.1238	0.1184	0.0850	0.1543	0.1034	0.1215	0.1180	0.1488	0.1374
GC 5	0.1167	0.1148	0.1295	0.1183	0.0957	0.1222	0.1433	0.1208	0.1359	0.1537
GC 6	0.1126	0.0628	0.0662	0.0759	0.1311	0.0522	0.1164	0.1194	0.1113	0.0699
GC 7	0.1454	0.1248	0.1520	0.1180	0.1632	0.1475	0.1082	0.1318	0.1726	0.1364
GC 8	0.0983	0.1105	0.1237	0.0752	0.1253	0.1071	0.1426	0.0638	0.1355	0.0871
GC 9	0.1502	0.1774	0.1228	0.1418	0.1265	0.0831	0.1383	0.0845	0.1242	0.1926
GC 10	0.1554	0.1197	0.1168	0.1314	0.1041	0.0928	0.0889	0.1043	0.1460	0.0977
GC 11	0.1371	0.1502	0.1427	0.1279	0.1004	0.0758	0.1124	0.1150	0.1428	0.1610
GC 12	0.1655	0.1748	0.1382	0.1537	0.1595	0.1326	0.1412	0.1188	0.1600	0.1751
GC 13	0.1533	0.1680	0.1080	0.1449	0.1447	0.1175	0.1257	0.0872	0.1874	0.1939
GC 14	0.2044	0.2033	0.1743	0.1758	0.1387	0.1197	0.1770	0.1339	0.1999	0.2035
GC 15	0.1776	0.1726	0.1693	0.1671	0.1859	0.0936	0.1542	0.1119	0.1836	0.1828
GC 16	0.1789	0.1395	0.1335	0.1684	0.1630	0.1168	0.1532	0.0843	0.1201	0.1687
GC 17	0.1652	0.1573	0.1668	0.1683	0.1748	0.1442	0.1650	0.1286	0.1708	0.2038
GC 18	0.0782	0.0744	0.1037	0.1059	0.1064	0.0742	0.0903	0.0939	0.1169	0.1125
GC 19	0.0795	0.0752	0.1064	0.0563	0.0776	0.0692	0.0933	0.0780	0.0804	0.0644
GC 20	0.1308	0.1136	0.1358	0.0862	0.1105	0.0678	0.1502	0.0688	0.1280	0.1413

	GC11	GC12	GC13	GC14	GC15	GC16	GC17	GC18	GC19	GC20
GC 1	0.1120	0.1230	0.0920	0.1291	0.1529	0.0661	0.1355	0.0798	0.1000	0.0848
GC 2	0.1452	0.1261	0.1548	0.1349	0.1566	0.1248	0.1026	0.1293	0.0876	0.1546
GC 3	0.1091	0.1326	0.0898	0.0950	0.1043	0.0988	0.0785	0.1137	0.1201	0.0985
GC 4	0.1124	0.1289	0.1029	0.1378	0.1282	0.0713	0.1179	0.0862	0.0934	0.0900
GC 5	0.0883	0.1355	0.0961	0.1298	0.1342	0.0973	0.1061	0.0913	0.1466	0.1504
GC 6	0.0915	0.0730	0.0579	0.0650	0.0831	0.0529	0.0761	0.1108	0.1077	0.0655
GC 7	0.1503	0.1644	0.1330	0.1385	0.1460	0.1093	0.1505	0.1365	0.1259	0.1490
GC 8	0.1069	0.1192	0.1028	0.0782	0.0984	0.0967	0.0728	0.1234	0.1013	0.0788
GC 9	0.1550	0.1680	0.1651	0.1624	0.1831	0.1082	0.1535	0.1706	0.0926	0.1622
GC 10	0.0991	0.1095	0.0946	0.1203	0.1097	0.0716	0.1427	0.1222	0.1062	0.1338
GC 11	0.0955	0.1695	0.1527	0.1159	0.1379	0.0983	0.1435	0.1269	0.0981	0.1447
GC 12	0.1525	0.1169	0.1150	0.1587	0.1805	0.1028	0.1382	0.1052	0.1310	0.1262
GC 13	0.1704	0.1660	0.1039	0.1592	0.1747	0.1539	0.1601	0.1547	0.1081	0.1322
GC 14	0.1748	0.2117	0.1876	0.1548	0.2108	0.1608	0.1983	0.1787	0.1450	0.1998
GC 15	0.1623	0.1823	0.1271	0.1893	0.1305	0.1333	0.1672	0.1792	0.1533	0.1844
GC 16	0.1185	0.1773	0.1414	0.1574	0.1588	0.0830	0.1544	0.0971	0.0914	0.1360
GC 17	0.1603	0.1815	0.1685	0.1725	0.1793	0.1480	0.1213	0.1669	0.1072	0.1763
GC 18	0.0672	0.1262	0.0791	0.1050	0.0765	0.1025	0.0701	0.0676	0.1067	0.1191
GC 19	0.0554	0.0967	0.0523	0.0894	0.0621	0.0924	0.0555	0.0877	0.0522	0.0900
GC 20	0.1137	0.0981	0.0854	0.1059	0.1288	0.1212	0.1443	0.1326	0.1224	0.0910

Table A6. Weighted normalized decision matrix

Supplier	GC1			GC2			GC3			GC4			GC5			GC6			GC7		
	l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
GS 1	0.040	0.047	0.048	0.044	0.051	0.052	0.020	0.030	0.039	0.029	0.039	0.048	0.035	0.046	0.051	0.037	0.024	0.018	0.038	0.048	0.054
GS 2	0.016	0.024	0.034	0.037	0.047	0.052	0.022	0.030	0.036	0.015	0.026	0.036	0.003	0.012	0.022	0.027	0.019	0.015	0.005	0.016	0.027
GS 3	0.036	0.045	0.048	0.030	0.040	0.049	0.039	0.045	0.047	0.029	0.039	0.048	0.032	0.042	0.049	0.019	0.015	0.013	0.016	0.027	0.038
GS 4	0.024	0.034	0.044	0.002	0.009	0.019	0.003	0.011	0.020	0.002	0.009	0.019	0.035	0.046	0.051	0.031	0.021	0.017	0.004	0.013	0.023
GS 5	0.024	0.031	0.037	0.033	0.044	0.051	0.036	0.044	0.047	0.005	0.015	0.026	0.022	0.032	0.042	0.037	0.024	0.018	0.016	0.027	0.038
	GC8			GC9			GC10			GC11			GC12			GC13			GC14		
GS 1	0.037	0.041	0.041	0.040	0.052	0.057	0.033	0.043	0.050	0.038	0.047	0.050	0.057	0.057	0.057	0.043	0.050	0.052	0.047	0.057	0.061
GS 2	0.028	0.037	0.041	0.006	0.017	0.029	0.036	0.046	0.052	0.002	0.008	0.018	0.057	0.057	0.057	0.030	0.040	0.047	0.040	0.053	0.061
GS 3	0.020	0.028	0.037	0.021	0.033	0.044	0.002	0.009	0.019	0.008	0.015	0.025	0.057	0.057	0.057	0.030	0.040	0.049	0.033	0.049	0.061
GS 4	0.012	0.020	0.028	0.021	0.033	0.044	0.040	0.048	0.052	0.002	0.007	0.015	0.057	0.057	0.057	0.009	0.019	0.030	0.039	0.050	0.061
GS 5	0.012	0.020	0.028	0.036	0.048	0.055	0.021	0.029	0.038	0.012	0.022	0.032	0.057	0.057	0.057	0.036	0.045	0.050	0.026	0.044	0.061
	GC15			GC16			GC17			GC18			GC19			GC20					
GS 1	0.038	0.050	0.057	0.023	0.031	0.037	0.034	0.046	0.054	0.036	0.042	0.043	0.024	0.032	0.037	0.008	0.015	0.025			
GS 2	0.046	0.055	0.059	0.037	0.045	0.048	0.017	0.029	0.040	0.027	0.036	0.042	0.020	0.028	0.036	0.008	0.018	0.028			
GS 3	0.002	0.011	0.023	0.003	0.011	0.021	0.000	0.006	0.017	0.030	0.039	0.043	0.020	0.028	0.033	0.032	0.042	0.048			
GS 4	0.015	0.029	0.039	0.040	0.047	0.048	0.040	0.051	0.057	0.004	0.009	0.016	0.017	0.025	0.032	0.002	0.008	0.018			
GS 5	0.033	0.046	0.059	0.010	0.018	0.027	0.034	0.046	0.054	0.033	0.040	0.043	0.023	0.030	0.037	0.032	0.042	0.048			