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Greening the pillars of pharmaceuticals: Sustainable supplier selection in emerging economies

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A B S T R A C T

The pharmaceutical industry is vital for global health, supplying necessary medicines, yet its conventional supply chain has notable environmental and social impacts. Amid a growing sustainability focus across sectors, the pharmaceutical industry must also adopt sustainable practices throughout its supply chain. This includes lessening its ecological impact, curbing waste, and endorsing social responsibility. Assessing a supplier's environmental performance, or "green performance," is of great interest. This involves gauging their eco-friendly actions like energy efficiency, waste management, and carbon footprint reduction. Metrics cover certifications, resource conservation, and responsible sourcing. In a study within a renowned Bangladeshi pharmaceutical firm, a key drugs manufacturer, seven criteria were used to evaluate suppliers' green performance. For this multi-criteria decision-making (MCDM) task, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was applied, considering a fuzzy environment. It ranked alternative suppliers via a widely used approach using linguistic terms expressed as Triangular Fuzzy Numbers (TFN). Important weights were determined via the Center of Area (COA) method. The study revealed supplier 4 as the top performer in green performance among five alternatives. This study introduces an innovative strategy for manufacturing decision-makers to choose the most suitable green supplier. It's anticipated to aid decision-makers in emerging economy pharmaceutical industries, facilitating the efficient evaluation of economically viable and environmentally sustainable suppliers for the long term.

1. Introduction

The intricate coordination of pharmaceutical product production, distribution, and delivery to end consumers takes place within a multilayered nexus made up of a wide range of stakeholders, including people, groups, and businesses, which is referred to as the pharmaceutical supply chain collectively. The pharmaceutical industry has seen significant development and upheaval in recent years, because of advances in technology, globalization, and shifting consumer needs. But these advancements also bring with them new difficulties and complications in the pharmaceutical supply chain. The preservation and traceability of pharmaceutical products have received increasing attention in recent years. The hazards of counterfeit medicine treatments to patient health have grown significantly, and they are now a significant issue. The COVID-19 pandemic has brought to light the pharmaceutical supply chain's vulnerabilities. Worldwide transportation disruptions, an increase in the demand for certain pharmaceuticals, and delivery chain bottlenecks have all brought attention to the need for more resilience and flexibility. For organizations to be successful and provide high-quality products with efficient supply chains, it is essential to evaluate suppliers' performance.

Supply Chain Environmental Management (SCEM), also known as Green Supply Chain Management (GSCM), is a widely accepted practice by the business world that entails keeping an eye on suppliers' environmental performance. Conscious business practices, however, are attracting more and more attention. Businesses are thinking more and more about incorporating ecological practices into their policy designs (Ashraf et al., 2020). Due to its significant impact on supply chain performance and firm competitiveness, academics are becoming more and more interested in investigating supplier perfor-

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mance evaluation (Chang et al., 2011). Aspects of the green supply chain such eco-design, green distribution, eco-purchasing, eco-manufacturing, and eco-reverse logistics have an influence on the sustainability of pharmaceutical manufacture (Al-Awamleh et al., 2022). Due to the increasing awareness and understanding of environmental concerns throughout the world, the pharmaceutical industry has also been compelled to utilize GSCM. Upgrades to facilities are necessary for pharmaceutical businesses in particular in order to develop and execute GSCM through the Green Manufacturing Process. Businesses are pushed to implement environmentally conscious supply chain practices as a result of increasing governmental and international demand to protect ecological integrity. The broad adoption of these environmentally conscious practices is plain to see in the industrial sectors of industrialized countries. Multiple industrialized economies are under pressure to adopt environmentally friendly industrial practices. There is also a worldwide research initiative focusing on a wide range of supply chain sustainability aspects, all with the goal of enhancing environmental sustainability.

Due to the simultaneous examination of several criteria and objectives, the Multicriteria choice Making technique (MCDM) is an essential instrument for solving choice problems. By using a weighting procedure inside the present choices via pairwise comparisons, multicriteria decision making approaches based on linguistic evaluations aid in producing the optimal choice decision (Kabir and Hasin, 2011). Evaluation of a supplier taking into account environmental and economic implications is regarded as a significant multi-criteria decision-making (MCDM) challenge. Undertaking the fact that the suppliers effectively incorporated green criteria, MCDM approaches are successful in treating the issue (Remadi & Frikha, 2020). A multi-criterion, intricate supply chain challenge is supplier selection. To choose the most favorable option from a group of selected alternatives, MCDM methods—which are widely used in supplier selection—evaluate the alternatives based on many features. (Rashidi and Cullinane, 2019).

Both organic and inorganic chemicals are essential to the pharmaceutical production process and have a key function to play. It is crucial to always have a sustainability mindset, especially when choosing suppliers, in order to reduce the harmful impacts of these chemicals and ensure proper disposal of the hazardous and chemically active waste created by pharmaceutical enterprises. There has been a noticeable lack of research on sustainable supplier selection using Multiple Criteria Decision Making (MCDM) methods within this industry, despite the significant growth of the pharmaceutical sector in Bangladesh and the presence of about 257 licensed pharmaceutical companies currently in operation. To make up this void, this study tried to answer the stated research questions (RQs):

RQ1: What pertinent assessment factors must be considered while evaluating the performance of suppliers by Bangladeshi pharmaceutical companies?

RQ2: What weight does each of the chosen assessment criteria provide to the performance of green suppliers?

2. Literature review

For this research, a well-organized literature review on sustainable supplier performance evaluation and MCDM approaches was conducted. Given that Bangladesh's pharmaceutical sector has never been the subject of study in this field, it is challenging to find adequate standards for this business. So, a thorough literature review was used to conduct the study. Here, a review of the literature on MCDM methods is provided before a review of the literature on criterion selection.

Given its significant influence on the quality and timeliness of the goods and services they offer, supplier assessment is today's top priority for any manufacturing or service organization (Rahman et al., 2022). The traditional methods of selecting a supplier frequently depend on the advertised price, which frequently overlooks significant direct and indirect costs related to the quality, delivery, and service costs of acquired products. Nevertheless, uncertainty always exists because the future cannot be predicted with absolute certainty (Badi and Ballem, 2018).

The best green supplier might be chosen using a cutting-edge group decision-making method built on features of Industry 4.0. AHP and TOPSIS processes are combined in a Pythagorean fuzzy environment by Çalık (2021). The Pythagorean Fuzzy AHP interval-valued approach has been used in this specific situation to get the criteria weights. Pythagorean Fuzzy TOPSIS is then used to rank and evaluate the different suppliers, making it easier to choose the best one based on supplier distances. Rahman et al. (2022) developed a MCDM model to find sustainable suppliers for textile dying, which consumes the most chemicals in Bangladesh. They created an integrated approach that utilized the SWARA-WASPAS method to find sustainable suppliers. The complete approach proposed by Abdel-Baset et al. (2019) was used to identify sustainable suppliers in the import sector.

Their objective was to calculate key measurements for the import field and provide a fair and reliable forecast. Summarized studies are presented in Table 1.

In this study, the assessment and ranking of providers were accomplished through the implementation of the TOPSIS approach within a fuzzy framework. At the heart of TOPSIS lies the fundamental principle that the optimal choice should be the one closest to the ideal solution while simultaneously being farthest from the anti-ideal solution (Opricovic and Tzeng, 2004). The Centre of Area (COA) approach was employed to calculate the weight of the criterion. Experts in COA can indicate the importance of each criterion in respect to other, more weighted considerations.

Environmental parameters must be incorporated into traditional supplier selection practices for organizations wishing to develop green supply chain management.

Table 1
Summary of Studies on Supplier's Performance Evaluation

Author (Year)	Focused Industry	Method
Çalık (2021)	Industry 4.0	Pythagorean fuzzy AHP and fuzzy TOPSIS
Rahman et al. (2022)	Textile Dyeing	SWARA-WASPAS integrated method
Thanh and Lan (2022)	Food-processing industry	Hybrid SWOC-FAHP-WASPAS
Abdel-Baset et al. (2019)	Importing Field	Integrated neuromorphic ANP and VIKOR
Tian et al. (2018)	Agri-food industry	Intuitionistic Fuzzy TOPSIS and Best-Worst
Pamucar et al. (2022)	Health sector	MACBETH
Remadi and Frikha (2020)	Pharmaceuticals	Intuitionistic Fuzzy Set FlowSort

Green manufacturing has become a crucial concern for practically every company due to the increased global awareness of environmental preservation, and it will ultimately decide a factory's long-term viability. To assess whether suppliers are qualified to work with the company, a performance evaluation methodology for green suppliers is thus required (Lee et al., 2009). As consumers' knowledge of the environment grows, manufacturers are starting to take it into account when evaluating and choosing suppliers (Guo et al., 2017).

Table 2
Criteria Used in Recent Studies

	Material Cost	Transportation Cost	Payment Terms	QMS	Quality Assurance	Process Improvement	Lead Time	Responsiveness	Flexibility	On Time	Green Design	Green Purchasing	Green Packaging	EMS	Waste Management	Recycle	Pollution Control	Emission Control	Management Commitment
Puška and Stoja-nović (2022)	✓			✓		✓	✓					✓		✓		✓		✓	✓
Salimian et al. (2022)	✓			✓						✓				✓			✓		✓
Çalık (2021)					✓				✓	✓	✓			✓			✓		
Remadi and Frikha (2020)	✓			✓						✓		✓				✓			✓
Baset et al. (2019)	✓	✓									✓		✓		✓				

3. Methodology and Data Collection

3.1 Fuzzy set

A mathematical idea known as fuzzy set theory enables the representation and manipulation of ambiguity and uncertainty in data. L. A. Zadeh introduced Fuzzy set (FS) theory, was developed on the presumption that phonetic phrases from the fuzzy set, rather than numbers, are the primary components of human perception and judgement. The degree of an element in FS theory can take any value between 0 and 1, where 0 represents total non-membership and 1 represents entire membership. Numerous applications, such as artificial intelligence, control systems, decision-making, and pattern recognition, employ fuzzy sets.

Definition 1. (Fuzzy number): In the context of this study, Fuzzy Numbers (FNs) are used to assess the suppliers to Green Supply Chain Management (GSCM) implementation. FNs are a type of Fuzzy Set (FS) that are easy to understand and use for decision makers. A standard representation of a Triangular Fuzzy Number (TFN) takes the form (l, m, u), where l represents the lower limit, m is the most probable value, and u stands for the upper limit. Figure 1 illustrates that a TFN exhibits linear illustration on both its left and right sides. The mathematical expression for the membership function of a TFN can be defined as Eq. (1).

$$\mu(z/M) = \begin{cases} 0, & z \leq l \\ \dfrac{z-l}{m-l}, & l \leq z \leq m \\ \dfrac{u-z}{u-m}, & m \leq z \leq u \\ 0, & z \geq u \end{cases} \tag{1}$$

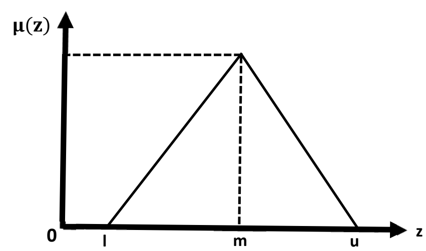

Fig. 1. Triangular Fuzzy Distribution

The easiest way to determine a fuzzy number is to compare the left and right representations of each membership level as shown in Eq. (2):

$$\overline{M} = \overline{M}^{l(y)}, \overline{M}^{r(y)} = (l + (m - l)y, u + (m - u)y), y \in [0,1] \tag{2}$$

Definition 2: Let A(l, m, u)and B(o, p, q) are two TFNs (see Figure 2). Fuzzy numbers A and B's distance from each other is calculated as:

$$d(\mathrm{A}, \mathrm{B}) = \sqrt{\frac{1}{3}[(l - o)^2 + (m - p)^2 + (u - q)^2]}$$

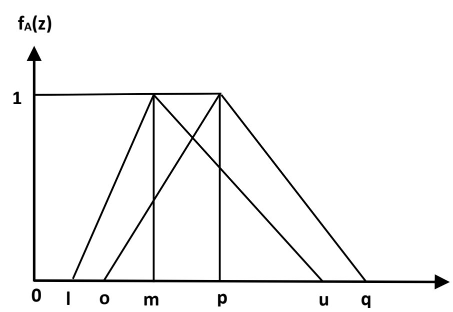

Fig. 2. Two Triangular Fuzzy Numbers

Definition 3: Suppose there are K evaluators in a group of decision-makers. A positive TFN may be used to indicate the fuzzy rating of the evaluator D_k, where k can be denoted by the values 1, 2,..., K R_k (k = 1, 2, ..., K) along with membership function $FR_k(z)$. The combined fuzzy rating or aggregated fuzzy value may thus be described as follows:

R = (l, m, u)

Here,

k= 1,2, 3, ...k

$$l = \min_k\{l_k\}, \quad m = 1/k\sum_{k=1}^{b} m_k, \quad u = \max_k\{u_k\}_k. \tag{3}$$

3.2 Center of Area (COA) Method for Defuzzufied Value Calculation

To obtain a precise, non-fuzzy number for each criterion, the information in the fuzzy decision matrices is defuzzified. The value that best captures the ideal non-fuzzy performance (BNP) was determined in the context of this study using a sophisticated defuzzification approach. There are, in general, three main methods for calculating BNP: the mean of maximum (MOM), the center of area (COA), and the alpha-cut approach. The COA technique stands out among them as a particularly tasteful and useful option for actual applications. Notably, the COA approach adds an added layer of speed and convenience to the process by eliminating the need for assessors to participate in complex procedural evaluations. COA methods of TFN performance score $\overline{h}_{ai} = (lh_{ai}, mh_{ai}, uh_{ai})$ may be used to determine the 'BNP' value, and the supplied equation is utilized to do so. The 'BNP' value can be expressed as,

$$\text{BNP}: x_{ai} = lh_{ai} + \frac{(uh_{ai} - lh_{ai}) + (mh_{ai} - lh_{ai})}{3}, \forall a \quad (4)$$

3.3 TOPSIS Method

A well-known multi-criteria decision-making (MCDM) technique called Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is used to rank solutions only based on a few criteria. It involves a scientific procedure where options are contrasted with the best-case scenario and the worst-case scenario. To establish how near or far off each alternative is from the ideal solution and the worst-case scenario, TOPSIS computes their similarity. The technique makes a thorough evaluation by considering both the excellent and bad components of each criterion. The fundamental rule is that the alternative that is ultimately picked should be the one that is closest to the perfect solution and the furthest from the opposite of the ideal solution. (Opricovic and Tzeng, 2004).

Steps of TOPSIS are retrieved from Papathanasiou et al. (2018).

Step 1: Determine the normalized decision matrix. The calculation of the normalized value, denoted as r_{ij} is performed as follows:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad \text{where, i = 1, 2, ..., m and j = 1, 2, ..., n.} \quad (5)$$

Step 2: Calculate the weighted normalized decision matrix. The weighted normalized value V_{ij} is calculated as follows:

$$V_{ij} = r_{ij} * W_j \quad \text{where, i = 1, 2,….., m and j = 1, 2, ..., n.} \quad (6)$$

W_j is the weight of the j^{th} criterion or attribute and $\sum_{j=1}^{n} W_j = 1$.

Step 3: Calculate the ideal (A^*) and negative ideal (A^-) solutions which will be used in next step.

$$A^* = \{(\max_i V_{ij} \mid j \in C_b), (\min_i V_{ij} \mid j \in C_c)\} = \{V_j^* \mid j = 1, 2, ..., m\} \quad (7)$$

$$A^- = \{(\min_i V_{ij} \mid j \in C_b), (\max_i V_{ij} \mid j \in C_c)\} = \{V_j^- \mid j = 1, 2, ..., m\} \quad (8)$$

Step 4: Compute the separation metrics employing the m-dimensional Euclidean distance. The separation metrics for each option from both the positive ideal solution and the negative ideal solution are outlined below:

$$S_i^* = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^*)^2} \quad (9)$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^-)^2} \quad (10)$$

Step 5: Compute the relative closeness to the ideal solution. The relative closeness of the alternative A_i concerning A* is defined in the subsequent manner:

$$RC_i^* = \frac{S_i^-}{S_i^* + S_i^-}, i = 1,2,...,m \quad (11)$$

Step 6: Rank the alternatives in order.

3.4 Data collection

In this study Alternative Suppliers are detonated as A1, A2…...A5 (Total five alternative suppliers), Experts are denoted as E1, E2, E3, E4 (Total four experts who gave importance rating), Decision Makers are denoted as D1, D2, D3 (Total three decision Makers who rate the alternative supplier's performance).

Table 3
Information about Expert and Decision Maker

Expert/Decision Maker	Designation
E1	Head of Supply Chain
E2	Executive
E3	Production & Development Engineer
E4	Researcher
D1	Senior Officer
D2	Senior Assistant Manager
D3	Senior Assistant Manager

Two types of scale have been used for this study. Scale shown in Table 4 is for Experts who gave the importance for the selected criteria and scale shown in Table 5 used by Decision Makers for performance rating purpose. In Table 6 selected criteria for green supplier's performance evaluation in pharmaceutical company is presented.

Table 4
Scale for Experts to Give Importance Rating

Linguistic Variables	Triangular Fuzzy Numbers
Very Low (VL)	(0,0,0.1)
Low (L)	(0.1,0.2,0.3)
Medium Low (ML)	(0.2,0.3,0.4)
Medium(M)	(0.4,0.5,0.6)
Medium High (MH)	(0.6,0.7,0.8)
High(H)	(0.7,0.8,0.9)
Very High	(0.8,0.9,1)

Table 5
Scale for Decision Makers to Give Performance Rating

Linguistic Variables	Triangular Fuzzy Numbers
Very Poor (VP)	(0,0.1,0.2)
Poor (P)	(0.1,0.2,0.3)
Medium Poor (MP)	(0.2,0.3,0.4)
Medium(M)	(0.3,0.4,0.5)
Medium Good (MG)	(0.5,0.6,0.7)
Good(G)	(0.6,0.7,0.8)
Very Good (VG)	(0.7,0.8,0.9)
Excellent	(0.8,0.9,1)

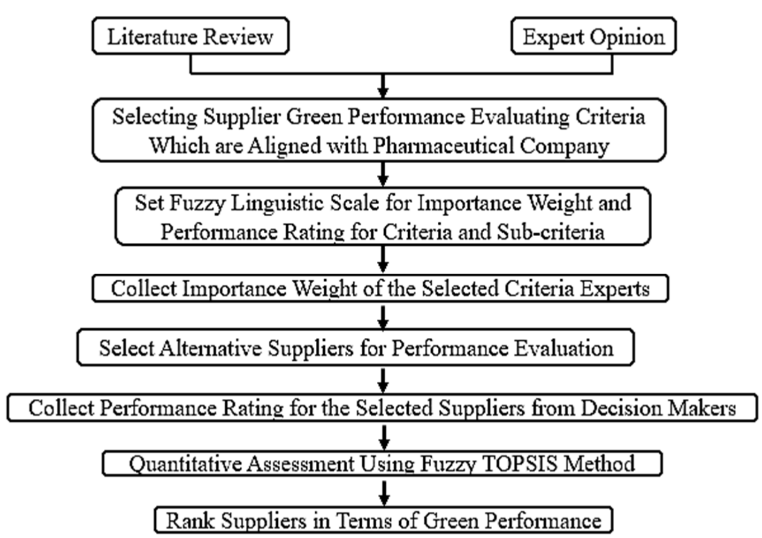

Fig. 3. Proposed Methodology

Evaluating a company entails examining its economic viability, devotion to quality, timely delivery, good after-sales service, eco-friendly practices, environmental responsibility, and strategic alliances, all of which contribute to its overall success.

Table 6
Selected Criteria for this Study

	Criteria
C1	Economic Factors
C2	Quality Concern
C3	Delivery
C4	After Sales Service
C5	Green Management
C6	Environment Management
C7	Strategic Alliance

Table 7
Expert's Importance Rating

Criteria	E-1	E-2	E-3	E-4
C1	H	H	H	VH
C2	VH	M	H	MH
C3	H	ML	VH	MH
C4	VH	MH	MH	MH
C5	MH	MH	H	M
C6	H	MH	H	M
C7	VH	ML	L	M

Table 7 presents the expert's importance rating for each criterion. Experts gave ratings using Table 4. Linguistic Values were changed by TFN for quantitative analysis which is shown in Table 10. Decision Makers used Table 5 linguistic scale for performance rating, shown in Table 8. Table 9 presents the TFNs for the linguistic value.

Table 8
Decision Maker's Performance Rating

	C1	C2	C3	C4	C5	C6	C7
			From D1				
A1	G	M	G	G	VP	M	M
A2	G	VG	VG	VG	VP	G	VG
A3	M	M	VP	P	VP	M	MP
A4	G	G	VG	VG	VP	MG	VG
A5	M	MG	MP	M	VP	M	G
			From D2				
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
A1	M	M	MG	G	P	M	VG
A2	G	MG	MG	G	P	M	VG
A3	P	M	M	M	P	P	M
A4	VG	G	VG	G	P	M	E
A5	M	MG	M	G	P	P	G
			From D3				
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
A1	G	M	MG	P	VP	MP	G
A2	VG	G	G	VG	VP	MP	VG
A3	M	MP	P	P	VP	P	P
A4	G	VG	VG	VG	VP	P	G
A5	VG	G	MG	M	VP	MP	G

Table 9
TFN for Decision Maker's Opinion

	C1	C2	C3	C4	C5	C6	C7
				From D1			
A1	(0.6,0.7,0.8)	(0.3,0.4,0.5)	(0.6,0.7,0.8)	(0.6,0.7,0.8)	(0,0.1,0.2)	(0.3,0.4,0.5)	(0.3,0.4,0.5)
A2	(0.6,0.7,0.8)	(0.7,0.8,0.9)	(0.7,0.8,0.9)	(0.7,0.8,0.9)	(0,0.1,0.2)	(0.6,0.7,0.8)	(0.7,0.8,0.9)
A3	(0.3,0.4,0.5)	(0.3,0.4,0.5)	(0,0.1,0.2)	(0.1,0.2,0.3)	(0,0.1,0.2)	(0.3,0.4,0.5)	(0.2,0.3,0.4)
A4	(0.6,0.7,0.8)	(0.6,0.7,0.8)	(0.7,0.8,0.9)	(0.7,0.8,0.9)	(0,0.1,0.2)	(0.5,0.6,0.7)	(0.7,0.8,0.9)
A5	(0.3,0.4,0.5)	(0.5,0.6,0.7)	(0.2,0.3,0.4)	(0.3,0.4,0.5)	(0,0.1,0.2)	(0.3,0.4,0.5)	(0.6,0.7,0.8)
				From D2			
A1	(0.3,0.4,0.5)	(0.3,0.4,0.5)	(0.5,0.6,0.7)	(0.6,0.7,0.8)	(0.1,0.2,0.3)	(0.3,0.4,0.5)	(0.7,0.8,0.9)
A2	(0.6,0.7,0.8)	(0.5,0.6,0.7)	(0.5,0.6,0.7)	(0.6,0.7,0.8)	(0.1,0.2,0.3)	(0.3,0.4,0.5)	(0.7,0.8,0.9)
A3	(0.1,0.2,0.3)	(0.3,0.4,0.5)	(0.3,0.4,0.5)	(0.3,0.4,0.5)	(0.1,0.2,0.3)	(0.1,0.2,0.3)	(0.3,0.4,0.5)
A4	(0.7,0.8,0.9)	(0.6,0.7,0.8)	(0.7,0.8,0.9)	(0.6,0.7,0.8)	(0.1,0.2,0.3)	(0.3,0.4,0.5)	(0.8,0.9,1)
A5	(0.3,0.4,0.5)	(0.5,0.6,0.7)	(0.3,0.4,0.5)	(0.6,0.7,0.8)	(0.1,0.2,0.3)	(0.1,0.2,0.3)	(0.6,0.7,0.8)
				From D3			
A1	(0.6,0.7,0.8)	(0.3,0.4,0.5)	(0.5,0.6,0.7)	(0.1,0.2,0.3)	(0,0.1,0.2)	(0.2,0.3,0.4)	(0.6,0.7,0.8)
A2	(0.7,0.8,0.9)	(0.6,0.7,0.8)	(0.6,0.7,0.8)	(0.7,0.8,0.9)	(0,0.1,0.2)	(0.2,0.3,0.4)	(0.7,0.8,0.9)
A3	(0.3,0.4,0.5)	(0.2,0.3,0.4)	(0.1,0.2,0.3)	(0.1,0.2,0.3)	(0,0.1,0.2)	(0.1,0.2,0.3)	(0.1,0.2,0.3)
A4	(0.6,0.7,0.8)	(0.7,0.8,0.9)	(0.7,0.8,0.9)	(0.7,0.8,0.9)	(0,0.1,0.2)	(0.1,0.2,0.3)	(0.6,0.7,0.8)
A5	(0.7,0.8,0.9)	(0.6,0.7,0.8)	(0.5,0.6,0.7)	(0.3,0.4,0.5)	(0,0.1,0.2)	(0.2,0.3,0.4)	(0.6,0.7,0.8)

4. Calculation

i. Table 10 presents the aggregated TFN and defuzzified values of importance rating. Defuzzified values are represented as "Weight" of the criteria. Aggregated values are determined by using Eq. (3) and Weight is determined by using Equation 4.

ii. Table 11 presents the performance scores of alternatives. Decision maker's rating was firstly aggregated and then de-fuzzified using Eq. (3) and Eq. (4), respectively.

iii. Table 12 presents Weighted Normalized Decision Matrix and Ideal Solutions. Weighted Normalized Decision Matrix was determined using Equation 6 and Ideal Solutions were determined using Eq. (7) and Eq. (8).

iv. Eq. (9) and Eq. (10) was used to determine separation measures, listed in Table 13.

v. Eq. (11) was used to determine closeness ratios which are listed in Table 14.

Table 10
Weight for Each Criterion from Expert's Rating

	E-1	E-2	E-3	E-4	Aggregated	Weight
C1	(0.7,0.8,0.9)	(0.7,0.8,0.9)	(0.7,0.8,0.9)	(0.8,0.9,1)	(0.7,0.825,1)	0.84167
C2	(0.8,0.9,1)	(0.4,0.5,0.6)	(0.7,0.8,0.9)	(0.6,0.7,0.8)	(0.4,0.725,1)	0.70833
C3	(0.7,0.8,0.9)	(0.2,0.3,0.4)	(0.8,0.9,1)	(0.6,0.7,0.8)	(0.2,0.675,1)	0.62500
C4	(0.8,0.9,1)	(0.6,0.7,0.8)	(0.6,0.7,0.8)	(0.6,0.7,0.8)	(0.6,0.75,1)	0.78333
C5	(0.6,0.7,0.8)	(0.6,0.7,0.8)	(0.7,0.8,0.9)	(0.4,0.5,0.6)	(0.4,0.675,0.9)	0.65833
C6	(0.7,0.8,0.9)	(0.6,0.7,0.8)	(0.7,0.8,0.9)	(0.4,0.5,0.6)	(0.4,0.7,0.9)	0.66667
C7	(0.8,0.9,1)	(0.2,0.3,0.4)	(0.1,0.2,0.3)	(0.4,0.5,0.6)	(0.1,0.475,1)	0.52500

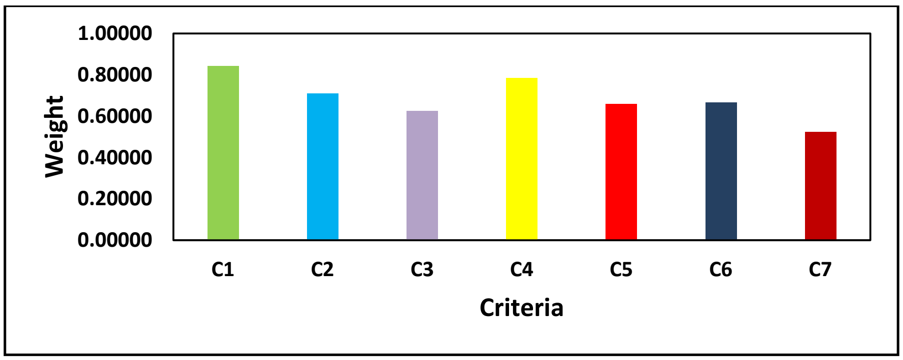

Fig. 4. Weight of Different Criteria

Table 11
Performance Score of Each Alternative

	A1	A2	A3	A4	A5
C1	0.7	0.7444	0.3111	0.6556	0.6
C2	0.4889	0.6556	0.3556	0.7444	0.655556
C3	0.6111	0.7000	0.2444	0.7556	0.444444
C4	0.4778	0.7556	0.2889	0.7556	0.533333
C5	0.1444	0.2889	0.2000	0.2444	0.144444
C6	0.4444	0.6444	0.3111	0.8000	0.555556
C7	0.6111	0.7667	0.3889	0.8000	0.7

Table 12
Values of Weighted Normalized Decision Matrix and Ideal Solutions

	V1	V2	V3	V4	V5	A^*	A^-
C1	0.31649	0.336584	0.140662	0.296395	0.271277	0.336584	0.140662
C2	0.186024	0.249441	0.13529	0.283264	0.249441	0.283264	0.13529
C3	0.205174	0.235017	0.082068	0.253669	0.149217	0.253669	0.082068
C4	0.201045	0.317932	0.121562	0.317932	0.224423	0.317932	0.121562
C5	0.051082	0.102164	0.070729	0.086446	0.051082	0.102164	0.051082
C6	0.159165	0.230789	0.111415	0.286497	0.198956	0.286497	0.111415
C7	0.172346	0.216216	0.109675	0.225616	0.197414	0.225616	0.109675

Table 13
Values of Separation Measures

	S1*	S2*	S3*	S4*	S5*	$S1^-$	$S2^-$	$S3^-$	$S4^-$	$S5^-$
C1	0.000404	0	0.038385	0.001615	0.004265	0.080286	0.096267	0.002284	0.065755	0.049629
C2	0.009456	0.001144	0.021896	0	0.001144	0.015459	0.045301	0.002865	0.067623	0.045301
C3	0.002352	0.000348	0.029447	0	0.01091	0.044773	0.064674	0.001253	0.078965	0.017294
C4	0.013663	0	0.038561	0	0.008744	0.026352	0.107184	0.00251	0.107184	0.03816
C5	0.002609	0	0.000988	0.000247	0.002609	0.022326	0.122443	0.051318	0.083074	0.022326
C6	0.016213	0.003103	0.030654	0	0.007663	0.014084	0.04938	0.002465	0.091656	0.031046
C7	0.002838	0	0.013442	0	0.000795	0.010936	0.025316	0.000711	0.029171	0.018424

Table 14
Values of Relative Closeness to the Ideal Solution

	A1	A2	A3	A4	A5
RC	0.679781	0.912594	0.376846	0.943711	0.712624

5. Results and discussion

Performance evaluation of green suppliers by placing the values of RC in Table 14 in ascending order, the Fuzzy TOPSIS method's use inside Bangladesh's pharmaceutical business produced the following ranking: A4>A2>A1>A5>A3.

Supplier A4 emerged as the top performer, displaying the highest stage of environmental sustainability practices and demonstrating a sturdy dedication to green tasks. This supplier validated wonderful overall performance in areas consisting of waste management, quality control, carbon footprint discount, and compliance with environmental policies. Following intently at the back of, Supplier A2 secured the second one position inside the ranking. This supplier showcased commendable efforts in enforcing inexperienced practices, especially in the regions of sustainable sourcing, waste control, and pricing. Supplier A1 attained the third function inside the evaluation, showing great performance in numerous environmental sustainability factors.

Notable strengths included strategic alliance with its partners for sustainability, Environment Management programs, and the implementation of environmentally friendly manufacturing processes. Supplier A5 secured the fourth role, demonstrating a moderate degree of green practices. While this dealer showcased a commitment to environmentally accountable operations, there remains room for improvement in terms of waste discount strategies and ordinary aid performance. Finally, Supplier A3 acquired the 5th function inside the ranking. Although this dealer established some green initiatives, there may be great scope for enhancement, especially in areas such as pollutants prevention, eco-design, and eco-labeling practices.

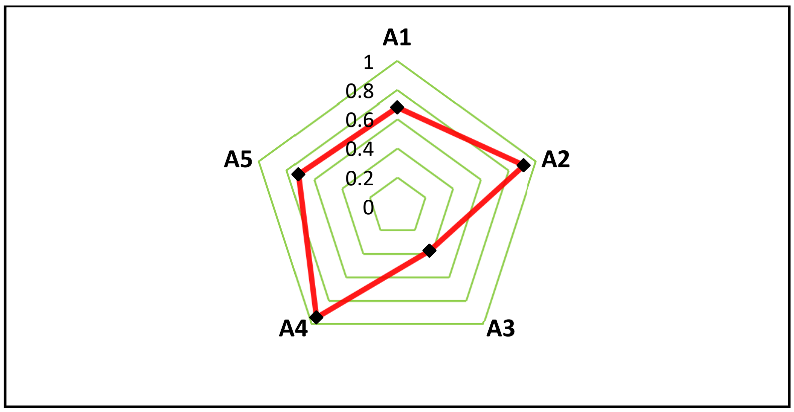

Fig. 5. Radar Chart Showing the RC Values of Different Supplier

In order to undertake a thorough investigation of green supplier performance in the pharmaceutical business in Bangladesh, this paper employed the fuzzy method (Fuzzy TOPSIS) approach for order prioritization by similarity of model solutions. The survey's major goal was to find and rank suppliers according to their environmental sustainability practices, and it concentrated on seven carefully chosen factors.

This research offers a significant contribution to the pharmaceutical sector in Bangladesh by furnishing decision-makers with vital information for identifying and nurturing partnerships with suppliers aligned with their sustainability objectives. By collaborating with high-performing environmentally-conscious manufacturers, pharmaceutical companies can not only reduce their ecological impact but also bolster their corporate image and competitive edge. Nonetheless, it's important to acknowledge the limitations of the Fuzzy TOPSIS-based analysis presented in this study. Future research endeavors may consider integrating additional criteria for conducting more comprehensive evaluations of green supplier performance. Additionally, longitudinal studies that track supplier progress over time can offer a more dynamic perspective on environmental practices within the pharmaceutical supply chain. Ultimately, this study aims to aid decision-makers within the Bangladeshi pharmaceutical industry through a systematic assessment of suppliers based on sustainability criteria. Furthermore, these findings will promote a deeper understanding of the significance of sustainability encompassing economic, environmental, and social dimensions within the pharmaceutical sector and related industries.

This study is aware of several restrictions. Seven criteria were identified after a thorough literature search and guidance from experts; however, they might not fully account for all pertinent elements. Future research could explore the incorporation of other relevant criteria to provide sound analysis. Furthermore, the present study contained responses from a small number of experts and decision-makers, which may introduce conceptual bias. To reduce this bias, future research could expand the range of experts and decision-makers involved, providing a more diverse and representative perspective. Other MCDM methods with integrated approach may be used to check the ranking's stability and reliability. Moreover, this study primarily concentrated on the pharmaceutical industry within Bangladesh. It is worth considering that results may vary in countries with different economic, social, and environmental contexts. Therefore, further research could explore these variations in diverse settings to gain a more comprehensive understanding of the subject. Similar studies can be done in the future, concentrating more on disruptive situations.

In conclusion, the promotion of green practices in the pharmaceutical industry is crucial for achieving sustainable development and environmental protection. By choosing environmentally conscious suppliers and fostering collaborative relationships with high-performance green suppliers, Bangladeshi businesses can play an important role in sourcing practices in promoting environmental sustainability, contributing to a greener future for the region and the planet as a whole.

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