ISSN: 2093-5374 / E-ISSN: 2093-5382

Ranking the Barriers to Green Supply Chain Management Using Fuzzy-TOPSIS in Manufacturing Industries in India

Dr. Sunil Dhull[1*], Dr. Anju Bhandari Gandhi[2], Dr. Stuti Mehla[3], Dr. Upasana Lakhina[4], Jaya Rani[5], and Geeta Rani[6]

[1*]Department of Mechanical Engineering, Panipat Institute of Engineering and Technology, Panipat, India. sunildhull12@rediffmail.com, https://orcid.org/0000-0003-0668-3765

[2]Department of Computer Science and Engineering, Panipat Institute of Engineering and Technology, Panipat, India. anjugandhi.cse@piet.co.in, https://orcid.org/0000-0002-4178-3035

[3]Department of Computer Science and Engineering, Panipat Institute of Engineering and Technology, Panipat, India. stuti21mehla@gmail.com, https://orcid.org/0000-0003-0220-8860

[4]Department of Computer Science and Engineering, Panipat Institute of Engineering and Technology, Panipat, India. drupasana.cse@piet.co.in, https://orcid.org/0000-0002-1946-373X

[5]Department of Computer Science and Engineering, Panipat Institute of Engineering and Technology, Panipat, India. jayapannu11@gmail.com, https://orcid.org/0009-0002-1902-1138

[6]Department of Computer Science and Engineering, Panipat Institute of Engineering and Technology, Samalkha, Panipat, Haryana, India. vermageeta1802@gmail.com, https://orcid.org/0009-0009-2165-7531

Received: August 19, 2025; Revised: October 03, 2025; Accepted: November 06, 2025; Published: December 15, 2025

Abstract

In the 21st century, environmental degradation is a primary concern. Green Supply Chain Management (GSCM) acts as a decisive industrial instrument, mitigating the environmental deterioration stemming from supply chain operations. To implement GSCM effectively, manufacturing industries need to recognize these barriers and eliminate them in the early phases of the implementation process. For effective implementation of GSCM practices manufacturing industries must have to move beyond simply recognizing barriers to strategically prioritizing those that pose the utmost impediment. Acknowledging the necessity to conquer obstacles to GSCM in manufacturing, this research systematically identifies barriers with intensive review of existing literature and insights from industrial experts. The fuzzy-TOPSIS methodology is then applied to focus on these barriers, integrating the major four perspectives: government, industry, environment, and the general public to offer a comprehensive understanding. The study's findings demonstrate that the paramount barrier to GSCM execution in the Indian manufacturing environment is "no/low return from investment". This is followed in significance by the "lack of government support". The barriers deemed least critical are "unwillingness to share trade information" and "deficient coordination between internal departments". The implications of these rankings can be further explored to develop targeted strategies. The managers, policymakers, and decision-makers can

Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications (JoWUA), volume: 16, number: 4 (December), pp. 247-268. DOI: *10.58346/JOWUA.2025.I4.014*

*Corresponding author: Department of Mechanical Engineering, Panipat Institute of Engineering and Technology, Panipat, India.

address these barriers on the basis of their merit for successful adoption of GSCM techniques at an early stage.

Keywords: Green Supply Chain Management (GSCM), Fuzzy-TOPSIS, Manufacturing Industries (India), Barriers to GSCM Implementation, Sustainability and Environmental Management.

1 Introduction

Supply chain professionals in the 21st century are concerned about the environmental degradation resulting from global supply chain activities. India is a developing country and one of the most populations in the world. India needs a significant amount of resources to meet the demands of its large population. To meet this demand, Indian manufacturing industries require a large number of natural resources. Therefore, it is the responsibility of supply chain professionals to optimize the use of these natural resources; taking into account environmental concerns each phase of supply chain. This helps in decreasing the carbon footprint of the country and sustainable development goals. However, the primary goal of the manufacturing industries in India; is to cut the cost. The environmental degradation stemming from manufacturing activities is regularly overlooked by these industries. This oversight has contributed to the considerable environmental strain experienced in India over the past 50 years, manifested in the swift depletion of natural resources and a sharp rise in pollution. The use of hazardous materials and emissions from manufacturing industries are major contributors to environmental degradation. Manufacturing activities in every phase have a substantial economic impact on the nation and necessitate serious attention from India's policymakers, industry experts, and citizens.

These barriers significantly impede the effective implementation of Green Supply Chain Management (GSCM) practices in Indian manufacturing industries. Experts from industry and academia are looking for solutions to these barriers. These solutions will assist Indian manufacturing industries in addressing environmental issues. The industries can only address environmental problems by implementing GSCM practices. The success or failure of implementing GSCM practices depends on identifying barriers. The aim of this research is to identify key GSCM barriers that restrain the adoption of GSCM practices in Indian manufacturing industries. Prioritizing GSCM barriers will enable manufacturing industries to proactively address these challenges, thereby facilitating the eminent election of GSCM practices.

This study used government, industry, environment, and public, option to rank the barriers. These barriers extensively persuade to the successful execution of GSCM practices. These perspectives both compel and motivate the manufacturing industry to reduce ecological hazards. The ranking of barriers is a Multi-Criteria Decision Making (MCDM) industrial problem that deals with ambiguous data. Fuzzy set theory in combination with the decision-making tool is a widely adopted technique to solve industrial problems in a vague and uncertain environment. The TOPSIS methodology uses a fuzzy concept to rank the barriers. The results show that GSCM's most critical barrier is "no/low return on investment." “Insufficient coordination between different departments” is the least important barrier.

2 Literature Review

Since the late 1960s, the problem of global environmental degradation has emerged. The past century is known as the “Club of Rome." Since then, the issue of global environmental pollution has become more complex and inescapable. Moreover, the concentration of contaminating substances in the earth's air, water, and soil is steadily rising. The alarming level of environmental problems can be attributed to countries' economic growth and the intensification of manufacturing, particularly in developing countries, to meet society's demands. These developing countries usually have no or very slack environmental laws.

On the other hand, growing environmental awareness worldwide encourages industries to apply GSCM practices and encourage the government to enforce strict environmental regulations. This has resulted in significant changes in the global manufacturing environment. The GSCM approach aids the manufacturing sectors in mitigating environmental deterioration, a consequence of their production processes. The manufacturing industries have a very detrimental effect on atmosphere (Govindan et al., 2014). Furthermore, they observe that the implementation of GSCM, particularly in India, encounters additional challenges compared to the developed world.

As manufacturing industries gain a deeper understanding of GSCM's importance, the critical role of their willingness to adopt these practices becomes evident. Without this commitment, successful implementation is infeasible. A range of barriers, exhibiting variability across different industries, pose obstacles to GSCM integration. Conquering the challenges stipulates a joint effort from experts and industry players to thoroughly identify and understand these impediments to pave the way for effective GSCM implementation.

- Khan et al., 2023 identified important barriers in their research from 1994 to 2016, suggesting that by eliminating these barriers, Indian industries could consider implementing cleaner production techniques. (Mathiyazhagan et al., 2017) investigated the barriers hindering Green Supply Chain Management (GSCM) implementation within the Indian automotive sector. Their study involved gathering expert opinions using the Delphi technique, followed by model validation through the application of the LISREL software package. (Kaur et al., 2018) used the DEMATEL methodology to investigate the barriers to GSCM operations in Canadian electronic goods manufacturing industries. This research categorized barriers into three types: knowledge barriers, commitment barriers, and product design-related barriers. (Bhatia & Srivastava, 2018) identified two leading barriers to GSCM: a shortage of channels to accumulate end used products and consumers' reluctance to return the products. This research also highlighted that policymakers should boost the concept of re-manufacturing in India.

Several studies have investigated barriers to Green Supply Chain Management (GSCM) across various industries. Using the Interpretive Structural Modeling (ISM) technique, (Soda et al., 2017) identified sixteen GSCM barriers in the power industry, highlighting lack of government support and insufficient investments as the most critical. Similarly, authors examined sixteen barriers in the Indian oil and gas sector, concluding that a lack of management commitment, leadership, knowledge, and training represented the most significant impediments. (Yang & Zhang, 2017) identified thirteen barriers, pinpointing insufficient information about buyer's requirements as the top-ranked obstacle. In their analysis, (Bhatia & Srivastava, 2018) found cost and complexity to be the most significant barriers. (Zaman et al., 2024) explored barriers in Indian industry, linking them to both Supply Chain Management (SCM) and Sustainable Supply Chain Management (SSCM) enactments, identifying a total of thirteen barriers. (Luthra et al., 2014) contributed to the understanding of GSCM by conducting a literature review that differentiated GSCM from traditional SCM. Furthermore, authors analyzed GSCM practices and demonstrated that their adoption can enhance environmental, economic, social, and operational performance. Focusing on the Indian automobile industry, (Balon et al., 2016) identified thirteen barriers to GSCM and categorized them into dependent (six barriers), linkage (three barriers), and driver (five barriers) types.

Massoud et al., 2010 identified ISO 14001 as a hindrance to GSCM in the Lebanese industry. (Dhull & Narwal, 2018) prioritize the main motivating factors using a fuzzy-TOPSIS methodology, investigated the common association between barriers. These barriers did not focus on a specific sector. In their research, (Dhull & Narwal, 2018) identified the barriers associated with global supply chain management (GSCM) and compiled a list of these barriers specific to the manufacturing industry. (Kaur et al., 2018) considered the various GSCM barriers and ranked them using PARETO analysis. Reviewed the barriers to the Bangladesh textile industry and identified a lack of customer demand and government support as two important barriers used the GRA-DEMATEL-ANP approach to barriers in the manufacturing industry and found that factors associated with customers, markets, managers, and business partners are the most significant barriers. In their research, Oliveira et al. (2018) found that while about 40% of the study focused on the benefits of GSCM employment, about 10% focused on the challenges associated with GSCM. According to (Chen et al., 2025), the most prominent barriers to GSCM implementation include a dearth of financial resources, deficiencies in regulatory frameworks, inadequate technological innovation, and limited organizational commitment. (Abosuliman et al., 2025; Ahluwalia et al., 2024), indentified financial barrier as most critical barrier of GSCM. As a result, their research suggests that their efforts to overcome the barriers to GSCM practice adoption could serve as a potential focus for future studies. Therefore, it is crucial to study the barriers associated with GSCM in both developing and developed countries, and assist these nations in removing these barriers.

Existing literature on GSCM barriers is sparse, with few studies prioritizing them, particularly within the Indian context. A significant gap exists in understanding the importance of these barriers in manufacturing sector. Furthermore, research identifying the importance of these barriers within specific country or sector contexts remains notably absent. This paper aims to bridge these identified research challenges.

3 Research Methodology

The literature survey identifies the barriers. Professionals in GSCM further discuss the barriers identified from the literature survey using a questionnaire. We select experts from the GSCM domain, representing government, industry, and academia. The questionnaire incorporated the suggestions provided by these experts. Professionals from academia and industries involved in GSCM further revised this questionnaire to enhance its ease of understanding and clarity. The present research uses the industry, environment, government, and public perspectives to rank barriers to GSCM. We select experts from these criteria who possess over ten years of experience in GSCM. The government department, which handles industrial policies at the director's level, provides the government perspective. Experts in the industry, responsible for managing industrial policies, provide the industry perspective. Officers in the environmental department, responsible for the industry's environmental policies, gather the environmental perspective, while non-government organizations (NGOs) dedicated to environmental protection provide the public perspective.

The objective of this literature review is to investigate the key barriers hindering the successful implementation of GSCM practices. This research provides a roadmap for industries to strategically address these obstacles prior to GSCM adoption, thereby reducing costs and accelerating implementation. Furthermore, this initiative supports the prevention of environmental degradation within industrial supply chains. The methodology for identifying these GSCM barriers included a thorough literature review, surveys, expert consultations, and engaging in brainstorming sessions with relevant policymakers. Table 1 presents the barriers ranked according to their importance in the Indian manufacturing environment.

Table 1: List of barriers

S. No.	Barriers of GSCM	Research
1	Lack of knowledge, necessary tools & management skills (B1)	Kareem et al., 2025; Schöggl et al., 2024; Agarwal et al., 2024; Rola, 2017; Dhull & Narwal, 2016; Parmar & Shah, 2016a; Parmar & Shah, 2016b
2	Shortage of management(B2)	Chen et al., 2025; Schöggl et al., 2024; Agarwal et al., 2024; Pathak et al., 2024; Hebaz, & Oulfarsi, 2021; Menon, & Ravi, 2022; Jalali et al., 2022
3	Slack government legislation(B3)	Kareem et al., 2025; Chen et al., 2025; Panigrahi et al., 2025; Pathak et al., 2024; Parmar & Shah, 2016; Govindan et al., 2014; Singh et al., 2012
4	Lack of awareness in companies(B4)	Schöggl et al., 2024; Modha & Sumant, 2017; Parmar & Shah, 2016; Balasubramanian, 2012; Azhar & Talib, 2015; Bag & Anand, 2014; Singh et al., 2012;
5	Insufficient coordination between different departments (B5)	Schöggl et al., 2024; Menon & Ravi, 2022; Jalali, et al., 2022; Parmar & Shah, 2016; Singh et al., 2012
6	Inability to adopt adequate environmental treatment measures (B6)	Do et al., 2024; Panigrahi et al., 2025; Khan et al., 2023; Menon & Ravi, 2022; Parmar & Shah, 2016
7	Lack of government support(B7)	Gagandeep et al., 2024; Pathak et al., 2024; Agarwal et al., 2024; Dashore & Sohani, 2013; Zhu et al., 2012; Singh et al., 2012; Balasubramanian, 2012
8	Higher cost of environment friendly goods & packaging (B8)	Rane et al., 2025; Gagandeep et al., 2024; Menon & Ravi, 2022; Xu et al., 2013
9	Uneconomic reusing & recycling (B9)	Prastyantoro et al., 2024; Rahman et al., 2020; Govindan & Hasanagic, 2018;
10	Too complex to implement(B10)	Panigrahi et al., 2025; Dashore & Sohani, 2013; Balasubramanian, 2012
11	Increased cost of environmental programs (B11)	Gagandeep et al., 2024; Min & Galle, 2001; Sarkis, 2004; Jorgensen & Wilcoxen, 1990
12	Lack of company-wide environmental standards or auditing programs(B12)	Hebaz & Oulfarsi, 2021; Dhull & Narwal, 2016; Choudhary & Seth, 2011
13	Lack of awareness in the society(B13)	Agarwal et al., 2024; Parmar & Shah, 2016, Min & Galle, 2001
14	Strain due to cut price issue with competitors(B14)	Panigrahi et al., 2025; Dhull & Narwal 2016; Orsato, 2006
15	Not willing to exchange trade information(B15)	Kumar & Joji, 2023; Kaur et al., 2018; Govindan et al., 2014; Dashore & Sohani, 2013; Balasubramanian, 2012
16	Lack of adaptation of advancement in technology(B16)	Chen at al., 2025; Panigrahi et al., 2025; Khan et al., 2023; Agarwal et al., 2024; Rahman et al., 2020; Srivastav & Gaur, 2015
17	Drop in cost at the value of environment(B17)	Ghaderi et al., 2024; Chotia et al., 2023; Marimuthu et al., 2021; Kaur et al., 2018
18	Shortage of understanding to incorporate green buying(B18)	Mankar et al., 2025; Zaman et al., 2024; Khan et al., 2023; Kaur et al., 2018
19	Shortage of righteous standards and corporate social responsibility(B19)	Kharat et al., 2025; Mughal et al., 2023; Panigrahi et al., 2025; Dhull & Narwal, 2016
20	No/ low return from investment(B20)	Do et al., 2024; Chotia et al., 2023; Menon & Ravi, 2022; Govindan et al., 2014

de Oliveira et al., 2018 a comprehensive literature review revealed a notable absence of studies that integrate all four perspectives within the analysis of Green Supply Chain Management (GSCM) barriers. This significant research gap provides the primary motivation for investigating GSCM barriers within Indian industries. To address the multi-criteria decision-making (MCDM) challenges inherent in this prioritization, the current study adopts the fuzzy-TOPSIS methodology. The subsequent section will elaborate on fuzzy-set theory, relevant terminology, and the foundational TOPSIS method.

4 Fuzzy-TOPSIS Methodology

The TOPSIS methodology is a prominent multi-criteria decision-making (MCDM) technique and frequently employed to prioritize the real world problems. One of the major limitations of TOPSIS is that it can't work efficiently in ambiguous and sceptical conditions (Yu, 2002). Integration with fuzzy systems can be used to effectively manage TOPSIS's ambiguous and sceptical conditions. Researchers and industrial experts can utilize the vague and scepticism-filled data provided by decision makers in their decision-making process instead of relying on precise and accurate values (Kumar et al., 2024; Lee, 2005). In real-world decision-making problems quantifying inherently qualitative data poses significant challenges. This problem in addressed by (Bellman & Zadeh, 1970) and introduced the fuzzy TOPSIS methodology as a novel approach to handle such imprecise information. According to (Gumus, 2009), this approach is an extremely effective strategy when compared to the conventional TOPSIS methodology.

Bellman & Zadeh, 1970 introduced the fuzzy sets technique for prioritization of real industrial problems. The combination of MCDM and fuzzy set theory has steered towards the decision-making theory. This decision-making theory can work very efficiently in incomplete knowledge and uncertain environments. The most positive thing about this technique is that when we want to evaluate, review, and take decisions, we frequently practice a natural language in which the words do not have a perfect or definite meaning. This is a key feature of fuzzy set theory: it uses fuzzy numbers in an uncertain and vague decision-making environment. It uses the subjective judgment of the decision-makers in an uncertain environment. The fuzzy numbers help the decision-makers to give their judgment in comparative terms rather than in numeric terms. This methodology can precisely and professionally tackle the uncertainty and vagueness in real-world problems.

Hwang & Yoon, 1981 primarily presented the theory of the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), which demonstrates the relationship between the criteria and the alternative. The present research considers four criteria and twenty alternatives. The TOPSIS approach uses the concepts of positive ideal solution (PIS) and negative ideal solution (NIS). The TOPSIS approach applies the theory that the selected alternative should have the smallest geometric distance from the PIS for profit criteria and the longest geometric distance from the NIS for cost criteria. A fuzzy environment further supports the TOPSIS methodology by measuring and evaluating the criteria and alternatives in linguistic terms. The present work implements the fuzzy-TOPSIS procedure to solve the MCDM problem of barrier ranking. This section below describes the steps used for ranking GSCM's barriers.

According to the fuzzy methodology, we can demarcate a triangular fuzzy number using the fuzzy set (triplet) (a1, a2, a3) shown in Figure 1. Table 2 employs a conversion scale to mutate the linguistic terms into fuzzy numbers. The membership function $\mu_{\tilde{a}}(x)$ can be written as.

$$\mu(x) = \begin{cases} \frac{x-a_1}{a_2-a_1}, & a_1 \leq x \leq a_2 \\ \frac{a_3-x}{a_3-a_2}, & a_2 \leq x \leq a_3 \\ 0 & \text{Otherwise} \end{cases} \quad \text{(i)}$$

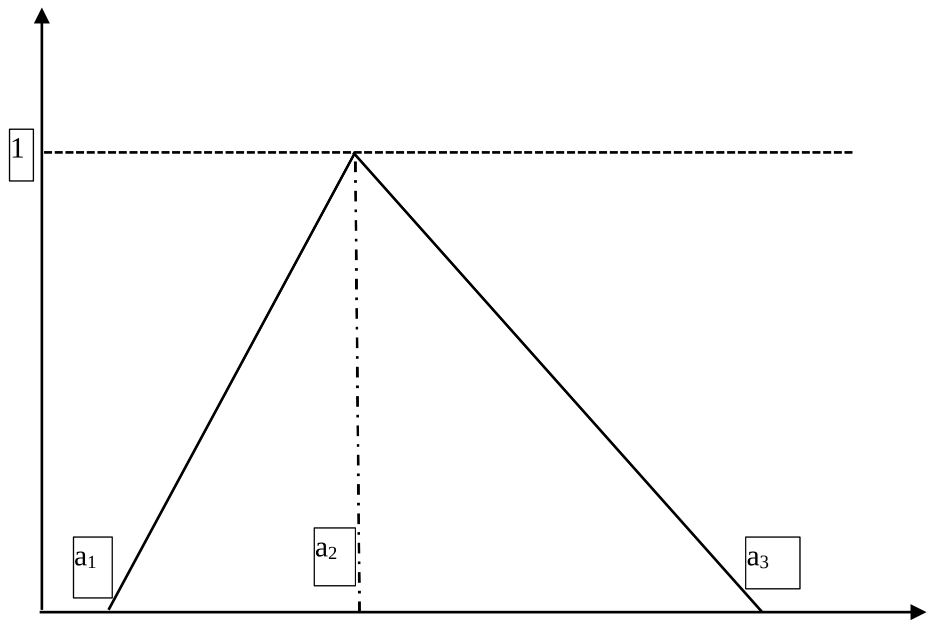

Figure 1: Fuzzy Number ã (Triangular)

Table 2: A Fuzzy Linguistic Frameworks For Prioritizing Alternatives And Evaluating Criteria (In Linguistic Terms)

Criteria Weight	[VL] Very Low	[L] Low	[M] Medium	[H] High	[VH] Very High
Membership Function	[1, 1, 3]	[1, 3, 5]	[3, 5, 7]	[5, 7, 9]	[7, 9, 9]
Alternative Weight	[NI]Not Important	[LI]Less Important	[FI]Fairly Important	[I]Important	[VI]Very Important
Membership Function	[1, 1, 3]	[1, 3, 5]	[3, 5, 7]	[5, 7, 9]	[7, 9, 9]

The following steps are used for ranking the barriers of GSCM.

Step I: Decision Maker's Rating on Criteria and Alternative:

The decision-makers gave their rating on government, industry, environment, and the public perspectives. Three experts from each perspective specify the criteria and alternative ratings for the twenty barriers listed in Tables 3 and 4. We select the decision-makers based on their designation in their respective domain and their tenure in the decision-making position, which typically requires over 10 years of experience. Experts with director level or above designations provide the government perspective. The general manager and experts ranked above provide the industry viewpoint.

Table 3: Fuzzy assessments of criteria (linguistic terms given by D.M.)

D. M.	**Criteria**			
	Government [C-1]	**Industry [C-2]**	**Environment [C-3]**	**Public [C-4]**
1.	VH	M	H	L
2.	VH	H	H	M
3.	H	H	H	M
4.	H	H	VH	L
5.	H	M	H	L
6.	VH	H	VH	M
7.	H	M	VH	M
8.	H	M	H	M
9.	H	H	H	M
10.	H	H	VH	L
11.	VH	M	H	M
12.	H	H	H	M

Experts in the pollution control department, including executive engineers and above, provide their perspective on the environment. Decision-makers in the environment field, such as non-government organizations, provide the public judgment.

Table 4: Fuzzy Rating of Alternatives (Barriers) in Linguistic Terms

Barriers	Perspectives											
	Government [C-1]			**Industry [C-2]**			**Environment [C-3]**			**Public [C-4]**		
	Decision Makers (D.M.)											
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Lack of knowledge, necessary tools & management skills. (B1)	I	VI	I	I	I	VI	VI	I	I	I	I	I
Shortage of management(B2)	I	I	VI	I	VI	I	I	I	I	FI	I	VI
Slack government legislation(B3)	FI	I	FI	I	I	VI	I	FI	I	VI	I	I
Lack of awareness in companies(B4)	I	VI	I	I	VI	I	VI	I	I	I	FI	VI
Insufficient coordination between different departments (B5)	LI	LI	FI	FI	LI	LI	LI	FI	LI	FI	FI	LI
Inability to adopt adequate environmental treatment measures (B6)	VI	VI	I	VI	VI	VI	VI	VI	I	I	VI	VI
Lack of government support(B7)	VI	VI	VI	I	VI	VI	I	VI	VI	VI	I	VI
Higher cost of environment friendly goods & packaging (B8)	I	VI	I	VI	I	VI	I	VI	I	FI	I	VI
Uneconomic reusing & recycling (B9)	FI	FI	FI	VI	VI	I	FI	I	FI	FI	I	FI
Too complex to implement(B10)	I	FI	FI	FI	I	VI	I	I	FI	FI	FI	I
Increased cost of environmental programs (B11)	I	I	FI	VI	I	I	I	FI	FI	I	FI	I
Lack of company-wide environmental standards or auditing programs(B12)	VI	VI	VI	I	VI	I	VI	I	VI	I	FI	I
Lack of awareness in the society(B13)	VI	I	I	I	FI	I	VI	I	VI	VI	I	FI
Strain due to cut price issue with competitors(B14)	I	I	FI	I	VI	I	FI	I	I	I	FI	I
Not willing to exchange trade information(B15)	LI	FI	LI	FI	I	I	LI	FI	FI	FI	LI	FI
Lack of adaptation of advancement in technology(B16)	VI	VI	VI	I	VI	VI	I	VI	VI	I	VI	I
Drop in cost at the value of environment(B17)	I	FI	FI	FI	LI	I	LI	FI	FI	FI	FI	LI
Shortage of understanding to incorporate green buying(B18)	FI	FI	FI	I	FI	FI	FI	LI	FI	FI	FI	FI
Shortage of righteous standards and corporate social responsibility(B19)	FI	I	FI	FI	FI	FI	I	FI	FI	FI	VI	FI
No/ low return from investment(B20)	VI	VI	VI	VI	VI	VI	VI	I	VI	VI	FI	VI

Step II: Calculation of Aggregate Fuzzy Weight:

Table 2 is used to convert rating specified by experts in linguistic terms for each criterion. The aggregation of the linguistic terms yields a composite fuzzy score, which is derived using the formulas specified in the subsequent section.

Suppose the fuzzy weight of m D.M. may be written in a triangular fuzzy number $\tilde{S}_m = (a_m, b_m, c_m)$, Where $m = 1, 2, 3 \ldots m$.

Table 5 shows the aggregate fuzzy weight for criteria.

$$\text{Where} \quad a = \min_m\{a_m\}, \quad b = \frac{1}{M}\sum_{m=1}^{M} b_m, \quad \& \quad c = \max_m\{c_m\} \tag{ii}$$

$$\text{The fuzzy criteria weight } (\widetilde{W_j}) = (\widetilde{w}_1, \widetilde{w}_2, \ldots\ldots\ldots\ldots\ldots \widetilde{w}_n) \tag{iii}$$

Table 5: Aggregate fuzzy weights (Barriers)

Criteria's	Government [C-1]	Industry [C-2]	Environment [C-3]	Public [C-4]
D.M.-1	(7,9,9)	(3,5,7)	(5,7,9)	(1,3,5)
D.M.-2	(7,9,9)	(5,7,9)	(5,7,9)	(3,5,7)
D.M.-3	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)
D.M.-4	(5,7,9)	(5,7,9)	(7,9,9)	(1,3,5)
D.M.-5	(5,7,9)	(3,5,7)	(5,7,9)	(1,3,5)
D.M.-6	(7,9,9)	(5,7,9)	(7,9,9)	(3,5,7)
D.M.-7	(5,7,9)	(3,5,7)	(7,9,9)	(3,5,7)
D.M.-8	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)
D.M.-9	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)
D.M.-10	(5,7,9)	(5,7,9)	(7,9,9)	(1,3,5)
D.M.-11	(7,9,9)	(3,5,7)	(5,7,9)	(3,5,7)
D.M.-12	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)
Aggregated Fuzzy Weight	(5, 7.67, 9)	(3, 6.17,9)	(5, 7.67, 9)	(1, 4.33, 7)

Step III: Fuzzy Resultant Matrix: Methodology and Calculation

To construct the Fuzzy Resultant Matrix (Table 6), the linguistic weights provided by individual decision makers are first converted into corresponding fuzzy ratings.

This matrix was subsequently utilized to generate the fuzzy decision matrix for alternatives ($\tilde{A}$)

$$\tilde{A} = \begin{array}{c} \\ A_1 \\ A_2 \\ \cdots \\ A_m \end{array} \begin{array}{c} \begin{array}{ccccc} c_1 & c_2 & c_3 & \cdots & c_n \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \tilde{x}_{13} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \tilde{x}_{23} & \cdots & \tilde{x}_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \tilde{x}_{m3} & \cdots & \tilde{x}_{mn} \end{bmatrix} \end{array} \tag{iv}$$

Table 6: Fuzzy weight of alternatives (Barriers)

Barriers	Perspectives											
	Government [C-1]			**Industry [C-2]**			**Environment [C-3]**			**Public [C-4]**		
1.	(5,7,9)	(7,9,9)	(5,7,9)	(5,7,9)	(5,7,9)	(7,9,9)	(7,9,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)
2.	(5,7,9)	(5,7,9)	(7,9,9)	(5,7,9)	(7,9,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,9)
3.	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(7,9,9)	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,9)	(5,7,9)	(5,7,9)
4.	(5,7,9)	(7,9,9)	(5,7,9)	(5,7,9)	(7,9,9)	(5,7,9)	(7,9,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(7,9,9)
5.	(1,3,5)	(1,3,5)	(3,5,7)	(3,5,7)	(1,3,5)	(1,3,5)	(1,3,5)	(3,5,7)	(1,3,5)	(3,5,7)	(3,5,7)	(1,3,5)
6.	(7,9,9)	(7,9,9)	(5,7,9)	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)	(5,7,9)	(5,7,9)	(7,9,9)	(7,9,9)
7.	(7,9,9)	(7,9,9)	(7,9,9)	(5,7,9)	(7,9,9)	(7,9,9)	(5,7,9)	(7,9,9)	(7,9,9)	(7,9,9)	(5,7,9)	(7,9,9)
8.	(5,7,9)	(7,9,9)	(5,7,9)	(7,9,9)	(5,7,9)	(7,9,9)	(5,7,9)	(7,9,9)	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,9)
9.	(3,5,7)	(3,5,7)	(3,5,7)	(7,9,9)	(7,9,9)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)

10.	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(7,9,9)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)
11.	(5,7,9)	(5,7,9)	(3,5,7)	(7,9,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)
12.	(7,9,9)	(7,9,9)	(7,9,9)	(5,7,9)	(7,9,9)	(5,7,9)	(7,9,9)	(5,7,9)	(7,9,9)	(5,7,9)	(3,5,7)	(5,7,9)
13.	(7,9,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,9)	(5,7,9)	(7,9,9)	(7,9,9)	(5,7,9)	(3,5,7)
14.	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,9)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)
15.	(1,3,5)	(3,5,7)	(1,3,5)	(3,5,7)	(5,7,9)	(5,7,9)	(1,3,5)	(3,5,7)	(3,5,7)	(3,5,7)	(1,3,5)	(3,5,7)
16.	(7,9,9)	(7,9,9)	(7,9,9)	(5,7,9)	(7,9,9)	(7,9,9)	(5,7,9)	(7,9,9)	(7,9,9)	(5,7,9)	(7,9,9)	(5,7,9)
17.	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(1,3,5)	(5,7,9)	(1,3,5)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(1,3,5)
18.	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(1,3,5)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)
19.	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(7,9,9)	(3,5,7)
20.	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)	(5,7,9)	(7,9,9)	(7,9,9)	(3,5,7)	(7,9,9)

Step IV: Consolidating fuzzy expert judgments for alternatives (aggregate)

The fuzzy weights and evaluations for each alternative, as provided by the m[th] decision maker, are represented by the triangular fuzzy number $\tilde{x}_{ijm} = (a_{ijm}, b_{ijm}, c_{ijm})$. Table 7 then displays the resulting fuzzy decision matrix, comprising the fuzzy ratings $(\tilde{x}_{ij})$ for each alternative across all criteria.

$$\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}) \quad \text{(v)}$$

Where $a_{ij} = \min_m\{a_m\}, \; b_{ij} = \frac{1}{M}\sum_{m=1}^{M} b_m, \quad and c_{ij} = \max_m\{c_m\}$ (vi)

Table 7: Aggregate fuzzy ratings (Barriers)

S. No.	Name of Barriers	Perspective			
		Government [C-1]	Industry [C-2]	Environment [C-3]	Public [C-4]
1.	Lack of knowledge, necessary tools & management skills. (B1)	(5,7.67,9)	(5,7.67,9)	(5,7.67,9)	(5,7,9)
2.	Shortage of management(B2)	(5,7.67,9)	(5,7.67,9)	(5,7,9)	(3,7,9)
3.	Slack government legislation(B3)	(3, 5.67,9)	(5,7.67,9)	(3,6.33,9)	(5,7.67,9)
4.	Lack of awareness in companies(B4)	(5,7.67,9)	(5,7,9)	(3,6.33,9)	(3,6.33,9)
5.	Insufficient coordination between different departments (B5)	(1,3.67,7)	(1,3.67,7)	(1,3.67,7)	(1,4.33,7)
6.	Inability to adopt adequate environmental treatment measures (B6)	(5,8.33,9)	(7,9,9)	(5,8.33,9)	(5,8.33,9)
7.	Lack of government support(B7)	(7,9,9)	(5,8.33,9)	(5,8.33,9)	(5,8.33,9)
8.	Higher cost of environment friendly goods & packaging (B8)	(5,7.67,9)	(5,8.33,9)	(5,7.67,9)	(3,7,9)
9.	Uneconomic reusing & recycling (B9)	(3,5,7)	(5,8.33,9)	(3,5.67,9)	(3,5.67,9)
10.	Too complex to implement(B10)	(1,4.33,7)	(3,6.33,9)	(1.4.33,7)	(1.4.33,7)
11.	Increased cost of environmental programs (B11)	(3,6.33,9)	(5,7.67,9)	(3,5.67,9)	(3,6.33,9)
12.	Lack of company-wide environmental standards or auditing programs(B12)	(7,9,9)	(5,7.67,9)	(5,8.33,9)	(3,6.33,9)
13.	Lack of awareness in the society(B13)	(5,7,9)	(3,7,9)	(5,8.33,9)	(3,6.33,9)
14.	Strain due to cut price issue with competitors(B14)	(5,7.67,9)	(5,7.67,9)	(3,6.33,9)	(5,7.67,9)
15.	Not willing to exchange trade information(B15)	(1,3.67,7)	(1,5,9)	(1.4.33,7)	(1.4.33,7)
16.	Lack of adaptation of advancement in technology(B16)	(7,9,9)	(5,8.33,9)	(5,8.33,9)	(5,7.67,9)
17.	Drop in cost at the value of environment(B17)	(3, 5.67,9)	(3,6.33,9)	(3,6.33,9)	(3,5.67,9)
18.	Shortage of understanding to incorporate green buying(B18)	(3,5,7)	(3,5.67,9)	(1.4.33,7)	(3,5,7)
19.	Shortage of righteous standards and corporate social responsibility(B19)	(3, 5.67,9)	(3,5,7)	(3,5.67,9)	(3,6.33,9)
20.	No/ low return from investment(B20)	(7,9,9)	(7,9,9)	(5,8.33,9)	(5,7.67,9)

Step V: Normalization Techniques for Fuzzy Decision Matrices

Table 7 and Table 8 shows the aggregate fuzzy weights and normalized fuzzy weights respectively. To ensure comparability across criteria and alternatives, the aggregated fuzzy weights are normalized by scaling them to a common range using a linear transformation. The standardize decision matrix can be given as:

$$\tilde{S}_k = [\tilde{s}_{ij}]_{x\times y}\text{, where, } i = 1,2,3 \ldots\ldots\ldots, x;\ and j = 1,2,3,\ldots\ldots\ldots, y. \quad \text{(vii)}$$

$$\text{Where} \quad \tilde{s}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \text{ and } c_j^* = \max_i\{c_{ij}\} \ldots \text{(benefit or important criteria)} \quad \text{(viii)}$$

Table 8: Barrier's normalized fuzzy weights

S. No.	Name of Barriers ($\overset{*}{C}$j)		Perspectives		
		Government [C-1]	Industry [C-2]	Environment [C-3]	Public [C-4]
		9	9	9	9
1.	Lack of knowledge, necessary tools & management skills. (B1)	(0.56,0.85,1)	(0.56,0.85,1)	(0.56,0.85,1)	(0.56,0.78,1)
2.	Shortage of management(B2)	(0.56,0.85,1)	(0.56,0.85,1)	(0.56,0.78,1)	(0.33,0.78,1)
3.	Slack government legislation(B3)	(0.33,0.63,1)	(0.56,0.85,1)	(0.33,0.70,1)	(0.56,0.85,1)
4.	Lack of awareness in companies(B4)	(0.56,0.85,1)	(0.56,0.78,1)	(0.33,0.70,1)	(0.33,0.70,1)
5.	Insufficient coordination between different departments (B5)	(0.11,0.41,0.78)	(0.11,0.41,0.78)	(0.11,0.41,0.78)	(0.11,0.48,0.78)
6.	Inability to adopt adequate environmental treatment measures (B6)	(0.56,0.93,1)	(0.78,1,1)	(0.56,0.93,1)	(0.56,0.93,1)
7.	Lack of government support(B7)	(0.78,1,1)	(0.56,0.93,1)	(0.56,0.93,1)	(0.56,0.93,1)
8.	Higher cost of environment friendly goods & packaging (B8)	(0.56,0.85,1)	(0.56,0.93,1)	(0.56,0.85,1)	(0.33,0.78,1)
9.	Uneconomic reusing & recycling (B9)	(0.33,0.56,0.78)	(0.56,0.93,1)	(0.33,0.63,1)	(0.33,0.63,1)
10.	Too complex to implement(B10)	(0.11,0.48,0.78)	(0.33,0.70,1)	(0.11,0.48,0.78)	(0.11,0.48,0.78)
11.	Increased cost of environmental programs (B11)	(0.33,0.70,1)	(0.56,0.85,1)	(0.33,0.63,1)	(0.33,0.70,1)
12.	Lack of company-wide environmental standards or auditing programs(B12)	(0.78,1,1)	(0.56,0.85,1)	(0.56,0.93,1)	(0.33,0.70,1)
13.	Lack of awareness in the society(B13)	(0.56,0.78,1)	(0.33,0.78,1)	(0.56,0.93,1)	(0.33,0.70,1)
14.	Strain due to cut price issue with competitors(B14)	(0.56,0.85,1)	(0.56,0.85,1)	(0.33,0.70,1)	(0.56,0.85,1)
15.	Not willing to exchange trade information(B15)	(0.11,0.41,0.78)	(0.11,0.56,0.78)	(0.11,0.48,0.78)	(0.11,0.48,0.78)
16.	Lack of adaptation of advancement in technology(B16)	(0.78,1,1)	(0.56,0.93,1)	(0.56,0.93,1)	(0.56,0.85,1)
17.	Drop in cost at the value of environment(B17)	(0.33,0.63,1)	(0.33,0.70,1)	(0.33,0.70,1)	(0.33,0.63,1)
18.	Shortage of understanding to incorporate green buying(B18)	(0.33,0.56,0.78)	(0.33,0.63,1)	(0.11,0.48,0.78)	(0.33,0.56,0.78)
19.	Shortage of righteous standards and corporate social responsibility(B19)	(0.33,0.63,1)	(0.33,0.56,0.78)	(0.33,0.63,1)	(0.33,0.70,1)
20.	No/ low return from investment(B20)	(0.78,1,1)	(0.78,1,1)	(0.56,0.93,1)	(0.33,0.85,1)

Step VI: Normalized Weight Matrix Calculation

The Table 9 illustrate the $\widetilde{V}$ (weighted normalized matrix) for criteria are multiplied by $(\tilde{s}_{ij})$ with $(\widetilde{w}_j)$. The weighted normalized matrix ($\widetilde{V}$) is given below.

$$\widetilde{V} = [\breve{v}_{ij}]_{x\times y}, i = 1,\ 2\ ,3\ \ldots.\ x;\ j = 1,\ 2,\ 3, \ldots\ldots., y \quad \text{(ix)}$$

$$\tilde{v}_{ij} = \tilde{s}_{ij}(.)\widetilde{w}_j \quad \text{(x)}$$

Table 9: Weighted normalized matrix (Barriers)

S. No.	Barriers		Perspectives		
		Government [C-1]	**Industry [C-2]**	**Environment [C-3]**	**Public [C-4]**
1.	Lack of knowledge, necessary tools & management skills. (B1)	(2.78,6.53,9)	(1.67,5.25,9)	(2.78,6.53,9)	(0.56,3.37,7)
2.	Shortage of management(B2)	(2.78,6.53,9)	(1.67,5.25,9)	(2.78,5.96,9)	(0.33,3.37,7)
3.	Slack government legislation(B3)	(1.67,4.83,9)	(1.67,5.25,9)	(1.67,5.40,9)	(0.56,3.69,7)
4.	Lack of awareness in companies(B4)	(2.78,6.53,9)	(1.67,4.80,9)	(1.67,5.40,9)	(0.33,3.05,7)
5.	Insufficient coordination between different departments (B5)	(0.56,3.12,7)	(0.33,2.51,7)	(0.56,3.12, 7)	(0.11,2.09,5.44)
6.	Inability to adopt adequate environmental treatment measures (B6)	(2.78,7.10,9)	(2.33,6.17,9)	(2.78,7.10,9)	(0.56,4.01,7)
7.	Lack of government support(B7)	(3.89,7.67,9)	(1.67,5.71,9)	(2.78,7.10,9)	(0.56,4.01,7)
8.	Higher cost of environment friendly goods & packaging (B8)	(2.78,6.53,9)	(1.67,5.71,9)	(2.78,6.53,9)	(0.33,3.37,7)
9.	Uneconomic reusing & recycling (B9)	(1.67,5.40,9)	(1.67,5.71,9)	(1.67,4.83,9)	(0.33,2.73,7)
10.	Too complex to implement(B10)	(0.56,3.69,7)	(1,4.34,9)	(0.56,3.69,7)	(0.11,2.09,5.44)
11.	Increased cost of environmental programs (B11)	(1.67,5.40,9)	(1.67,5.25,9)	(1.67,4.83,9)	(0.33,3.05,7)
12.	Lack of company-wide environmental standards or auditing programs(B12)	(3.89,7.67,9)	(1.67,5.25,9)	(2.78,7.10,9)	(0.33,3.05,7)
13.	Lack of awareness in the society(B13)	(2.78,5.96,9)	(1,4.80,9)	(2.78,7.10,9)	(0.33,3.05,7)
14.	Strain due to cut price issue with competitors(B14)	(2.78,6.53,9)	(1.67,5.25,9)	(1.67,5.40,9)	(0.56,3.69,7)
15.	Not willing to exchange trade information(B15)	(0.56,3.12,7)	(0.33,3.43,9)	(0.56,3.69,7)	(0.11,2.09,5.44)
16.	Lack of adaptation of advancement in technology(B16)	(3.89,7.67,9)	(1.67,5.71,9)	(2.78,7.10,9)	(0.56,3.69,7)
17.	Drop in cost at the value of environment(B17)	(1.67,4.83,9)	(1,4.34,9)	(1.67,5.40,9)	(0.33,2.73,5.44)
18.	Shortage of understanding to incorporate green buying(B18)	(1.67,4.26,7)	(1,3.88,9)	(0.56,3.69,7)	(0.33,2.41,7)
19.	Shortage of righteous standards and corporate social responsibility(B19)	(1.67,4.83,9)	(1,3.43,7)	(1.67,4.83,9)	(0.33,3.05,7)
20.	No/ low return from investment(B20)	(3.89,7.67,9)	(2.33,6.17,9)	(2.78,7.10,9)	(0.33,3.69,7)
FPIS (B+)		(9,9,9)	(6.17,6.17,6.17)	(7.10,7.10,7.10)	(9,9,9)
FNIS (B-)		(0.56, 0.56, 0.56)	(0.33, 0.33, 0.33)	(0.56, 0.56, 0.56)	(0.11,0.11,0.11)

Step VII: Calculation of FPIS and FNIS

The TOPSIS approach aims to calculate the alternative with the shortest geometric distance (GD) from the FPIS and highest geometric distance from the FNIS for cost criteria. This involves minimizing the distance from FPIS for benefit criteria and maximizing the distance from the FNIS for cost criteria. The computed FPIS and FNIS are shown in Table 10.

$$F^* = (\tilde{v}_1^*, \tilde{v}_2^*, \tilde{v}_3^*, \dots, \tilde{v}_n^*),$$

$$F^- = (\tilde{v}_1^-, \tilde{v}_2^-, \tilde{v}_3^-, \dots, \tilde{v}_n^-) \tag{xi}$$

Where

$$\tilde{v}_j^* = max_i\{v_{ij3}\},$$

$$\tilde{v}_j^- = min_i\{v_{ij3}\},$$

$$i = 1, 2, 3, \dots\dots, x;$$

$$j = 1,2,3, \dots\dots, y; \tag{xii}$$

Step VIII: Distance of Alternatives from FPIS and FNIS

The distances (d_i^*, d_i^-) of individual weighted alternative i = 1, 2, 3… x from the FPIS to FNIS are determined. Table 11 shows distances of alternatives from FIPS & FNIS. Vertex technique is adopted to get the geometric distance from FPIS and FNIS, the procedure is given below

$$d(\tilde{a}, \tilde{b}) = \sqrt{\frac{1}{3}\left[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2\right]} \tag{xiii}$$

$$d_i^* = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, \tilde{v}_{ij}^*) \text{ where } i = 1, 2, 3, \dots, x \tag{xiv}$$

$$d_i^- = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, \tilde{v}_{ij}^-) \text{ where } i = 1, 2, 3, \dots, x \tag{xv}$$

Table 10: Distances of alternatives from FIPS and FNIS

S. No.	Barriers	Distance from FPIS				Distance from FNIS			
	$\check{C}$j	C_1^+	C_2^+	C_3^+	C_4^+	C_1^-	C_2^-	C_3^-	C_4^-
1.	d(B1, B+)	3.86	4.75	3.86	4.27	6.11	5.80	6.11	4.41
2.	d(B2, B+)	3.86	4.75	4.00	4.38	6.11	5.80	5.93	4.40
3.	d(B3, B+)	4.87	4.75	4.72	4.18	5.50	5.80	5.66	4.49
4.	d(B4, B+)	3.86	4.88	4.72	4.47	6.11	5.68	5.66	4.33
5.	d(B5, B+)	6.05	6.36	6.05	4.97	4.01	4.05	4.01	3.28
6.	d(B6, B+)	3.76	4.18	3.76	4.10	6.30	6.14	6.30	4.58
7.	d(B7, B+)	3.05	4.64	3.76	4.10	6.66	5.94	6.30	4.58
8.	d(B8, B+)	3.86	4.64	3.86	4.38	6.11	5.94	6.11	4.40
9.	d(B9, B+)	5.17	4.64	4.87	4.57	4.34	5.94	5.50	4.26
10.	d(B10, B+)	5.87	5.35	5.87	4.97	4.14	5.53	4.14	3.28
11.	d(B11, B+)	4.72	4.75	4.87	4.47	5.66	5.80	5.50	4.33
12.	d(B12, B+)	3.05	4.75	3.76	4.47	6.66	5.80	6.30	4.33
13.	d(B13, B+)	4.00	5.22	3.76	4.47	5.93	5.64	6.30	4.33
14.	d(B14, B+)	3.86	4.75	4.72	4.18	6.11	5.80	5.66	4.49
15.	d(B15, B+)	6.05	5.95	5.87	4.97	4.01	5.31	4.14	3.28
16.	d(B16, B+)	3.05	4.64	3.76	4.18	6.66	5.94	6.30	4.49
17.	d(B17, B+)	4.87	5.35	4.72	4.57	5.50	5.53	5.66	4.26
18.	d(B18, B+)	5.17	5.48	5.87	4.76	4.34	5.42	4.14	3.35
19.	d(B19, B+)	4.87	5.75	4.87	4.47	5.50	4.26	5.50	4.33
20.	d(B20, B+)	3.05	4.18	3.76	4.30	6.66	6.14	6.30	4.48

Step IX: Evaluate the CCi Values for Alternatives

Ranking of the barrier is on the basis of CCi values. The individual alternatives are arranged in descending order. The CCi represent the proximity of an alternative to the ideal solutions. Specifically, it considers both the geometric distance be minimum from the Fuzzy Positive Ideal Solution (FPIS) denoted as d^*, for benefit criteria and the geometric distance from the Fuzzy Negative Ideal Solution (FNIS) denoted as d^- for cost criteria. The CCi signifies the geometric distance of alternative from FPIS d^* (benefit) and for FNIS d^-(for cost). Cumulative CCi values and the individual perspective CCi values for individual barrier are shown in Table 12. (Figure 2)

The CCi is computed by the formula given below. The CCi values for individual alternative are given in Table 11:

$$CC_i = \frac{d_i^-}{(d_i^- + \quad d_i^*)} \qquad \text{(xvi)}$$

$$where \ \ i = 1, 2, 3, \qquad \dots, x$$

Table 11: Values of CCi (barriers)

S. No.	Barriers	d_i^*	d_i^-	CC_i
1.	Lack of knowledge, necessary tools & management skills.(B1)	16.75	22.43	0.572
2.	Shortage of management(B2)	17.00	22.25	0.567
3.	Slack government legislation(B3)	18.53	21.45	0.537
4.	Lack of awareness in companies(B4)	17.94	21.77	0.548
5.	Insufficient coordination between different departments (B5)	23.43	15.34	0.396
6.	Inability to adopt adequate environmental treatment measures (B6)	15.80	23.32	0.596
7.	Lack of government support(B7)	15.55	23.47	0.602
8.	Higher cost of environment friendly goods & packaging (B8)	16.75	22.56	0.574
9.	Uneconomic reusing & recycling (B9)	19.26	20.04	0.510
10.	Too complex to implement(B10)	22.06	17.09	0.436
11.	Increased cost of environmental programs (B11)	18.82	21.29	0.531
12.	Lack of company-wide environmental standards or auditing programs(B12)	16.03	23.09	0.590
13.	Lack of awareness in the society(B13)	17.45	22.20	0.560
14.	Strain due to cut price issue with competitors(B14)	17.52	22.06	0.557
15.	Not willing to exchange trade information(B15)	22.84	16.74	0.423
16.	Lack of adaptation of advancement in technology(B16)	15.63	23.39	0.599
17.	Drop in cost at the value of environment(B17)	19.51	20.94	0.518
18.	Shortage of understanding to incorporate green buying(B18)	21.29	17.25	0.448
19.	Shortage of righteous standards and corporate social responsibility(B19)	19.96	19.59	0.495
20.	No/ low return from investment(B20)	15.29	23.58	0.607

Table 12: Individual perspective closeness coefficient for alternatives

Barriers			Perspectives		
		CC_i (Govt.)	CC_i (Industry)	CC_i (Envir.)	CC_i (Public)
1.	Lack of knowledge, necessary tools & management skills. (B1)	0.612	0.550	0.612	0.508
2.	Shortage of management(B2)	0.612	0.550	0.597	0.501
3.	Slack government legislation(B3)	0.530	0.550	0.545	0.518
4.	Lack of awareness in companies(B4)	0.612	0.538	0.545	0.492
5.	Insufficient coordination between different departments (B5)	0.398	0.389	0.398	0.398
6.	Inability to adopt adequate environmental treatment measures (B6)	0.626	0.595	0.626	0.527
7.	Lack of government support(B7)	0.686	0.561	0.626	0.527
8.	Higher cost of environment friendly goods & packaging (B8)	0.612	0.561	0.612	0.501

9.	Uneconomic reusing & recycling (B9)	0.456	0.561	0.530	0.482
10.	Too complex to implement(B10)	0.413	0.508	0.413	0.398
11.	Increased cost of environmental programs (B11)	0.545	0.550	0.530	0.492
12.	Lack of company-wide environmental standards or auditing programs(B12)	0.686	0.550	0.626	0.492
13.	Lack of awareness in the society(B13)	0.597	0.520	0.626	0.492
14.	Strain due to cut price issue with competitors(B14)	0.612	0.550	0.545	0.518
15.	Not willing to exchange trade information(B15)	0.398	0.472	0.413	0.398
16.	Lack of adaptation of advancement in technology(B16)	0.686	0.561	0.626	0.518
17.	Drop in cost at the value of environment(B17)	0.530	0.508	0.545	0.482
18.	Shortage of understanding to incorporate green buying(B18)	0.456	0.497	0.413	0.413
19.	Shortage of righteous standards and corporate social responsibility(B19)	0.530	0.426	0.530	0.492
20.	No/ low return from investment(B20)	0.686	0.595	0.626	0.511

Step X: Ranking of the Alternatives/ Barriers

The ranking of barriers is established by their respective CCi values, such that a higher CCi corresponds to a higher position in the table. The underlying principle for the top-ranked alternative is its closest geometric proximity to the FPIS and greatest geometric separation from the FNIS. Table 13 illustrates this final ranking of barriers.

Table 13: Closeness coefficient index (aggregated) for barriers

Barriers	Name of the barriers	CCi	Rank
20	No/ low return from investment	0.607	1
7	Lack of government support	0.602	2
16	Lack of adaptation of advancement in technology	0.599	3
6	Inability to adopt adequate environmental treatment measures	0.596	4
12	Lack of company-wide environmental standards or auditing programs	0.59	5
8	Higher cost of environment friendly goods & packaging	0.574	6
1	Lack of knowledge, necessary tools & management skills.	0.572	7
2	Lack of management commitment	0.567	8
13	Lack of awareness in the society	0.56	9
14	Pressure for lower price with competitors	0.557	10
4	Lack of awareness in companies	0.548	11
3	Slack government legislation	0.537	12
11	Increased cost of environmental programs	0.531	13
17	Cost reduction at the cost of environment	0.518	14
9	Uneconomic reusing & recycling	0.51	15
19	Lack of ethical standards and corporate social responsibility	0.495	16
18	Lack of understanding to incorporate green buying	0.448	17
10	Too complex to implement	0.436	18
15	Not willing to exchange trade information	0.423	19
5	Insufficient coordination between different departments	0.396	20

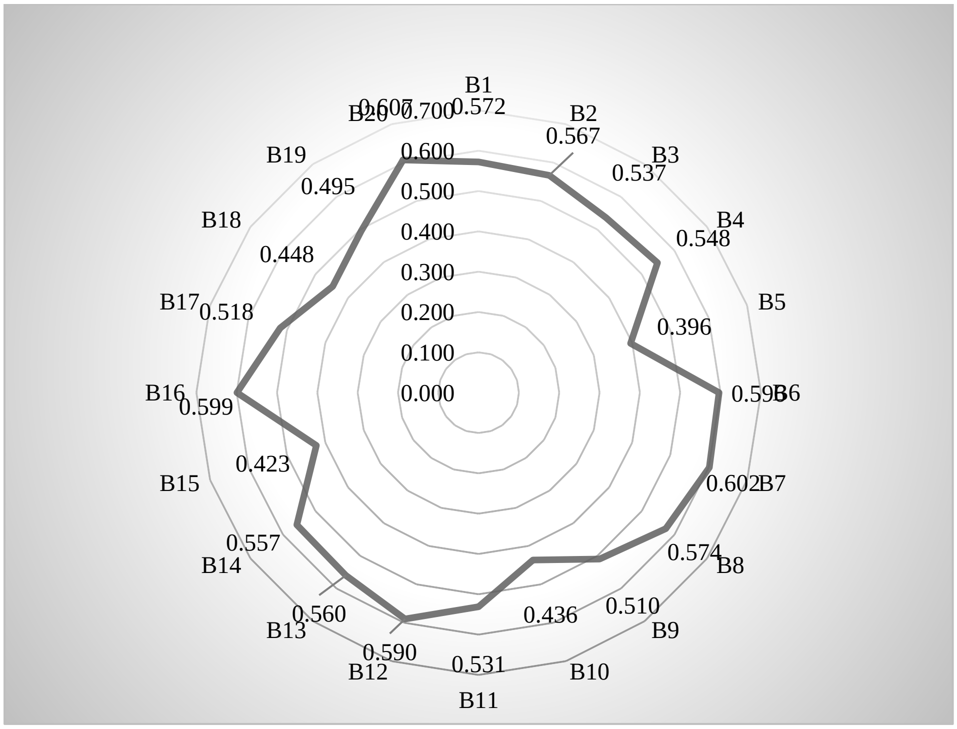

Figure 2: Closeness coefficient (CCi) of alternatives/barriers

5 Sensitivity Analysis

We conducted a sensitivity study to scrutinize the DM's decision regarding the ranking of barriers. (Awasthi et al., 2011). The weight of criteria that affect GSCM's ranking varies from very low to very high, as shown in Table 2.

Table 14: Sensitivity study (Criteria)

Exp. No	Description	Barriers
1.	$C_{w1}, C_{w2}, C_{w3}, C_{w4}$, (1,1,3)	$B_{20} > B_6 > B_7 > B_{16} > B_{12} > B_1 > B_8 > B_{14} > B_2 > B_{13} > B_3 > B_4 > B_{11} > B_{17} > B_9 > B_{19} > B_{18} > B_{10} > B_{15} > B_5$
2.	$C_{w1}, C_{w2}, C_{w3}, C_{w4}$, (1,3,5)	$B_{20} > B_6 > B_7 > B_{16} > B_{12} > B_1 > B_8 > B_{14} > B_2 > B_{13} > B_3 > B_4 > B_{11} > B_{17} > B_9 > B_{19} > B_{18} > B_{10} > B_{15} > B_5$
3.	$C_{w1}, C_{w2}, C_{w3}, C_{w4}$, (3,5,7)	$B_{20} > B_6 > B_7 > B_{16} > B_{12} > B_1 > B_8 > B_{14} > B_2 > B_{13} > B_3 > B_4 > B_{11} > B_{17} > B_9 > B_{19} > B_{18} > B_{10} > B_{15} > B_5$
4.	$C_{w1}, C_{w2}, C_{w3}, C_{w4}$, (5,7,9)	$B_{20} > B_6 > B_7 > B_{16} > B_{12} > B_1 > B_8 > B_{14} > B_2 > B_{13} > B_3 > B_4 > B_{11} > B_{17} > B_9 > B_{19} > B_{18} > B_{10} > B_{15} > B_5$
5.	$C_{w1}, C_{w2}, C_{w3}, C_{w4}$, (7,9,9)	$B_{20} > B_6 > B_7 > B_{16} > B_{12} > B_1 > B_8 > B_2 > B_{14} > B_{13} > B_4 > B_3 > B_{11} > B_9 > B_{17} > B_{19} > B_{18} > B_{10} > B_{15} > B_5$
6.	C_{w1}= (7,9,9), C_{w2}, C_{w3}, C_{w4}= (1,1,3)	$B_{20} > B_7 > B_{16} > B_{12} > B_6 > B_1 > B_8 > B_{14} > B_2 > B_4 > B_{13} > B_{11} > B_3 > B_{17} > B_{19} > B_9 > B_{18} > B_{10} > B_{15} > B_5$
7.	C_{w2} =(7,9,9), C_{w1}, C_{w3}, C_{w4}= (1,1,3)	$B_{20} > B_6 > B_7 > B_{16} > B_8 > B_{12} > B_1 > B_{14} > B_2 > B_3 > B_{11} > B_4 > B_9 > B_{13} > B_{17} > B_{10} > B_{19} > B_{18} > B_{15} > B_5$
8.	C_{w3} =(7,9,9), C_{w1}, C_{w2}, C_{w4}= (1,1,3)	$B_{20} > B_6 > B_7 > B_{16} > B_8 > B_{12} > B_1 > B_{14} > B_2 > B_3 > B_{11} > B_4 > B_9 > B_{13} > B_{17} > B_{10} > B_{19} > B_{18} > B_{15} > B_5$
9.	C_{w4} = (7,9,9), C_{w1}, C_{w2}, C_{w3}= (1,1,3)	$B_6 > B_7 > B_{16} > B_{14} > B_1 > B_3 > B_{20} > B_8 > B_2 > B_{12} > B_{13} > B_4 > B_{11} > B_{17} > B_{19} > B_9 > B_{18} > B_{10} > B_{15} > B_5$

Table 14 outlines the nine experiments carried out in the present investigation. Initially, we assign criteria weights (1,1,3), (1,3,5), (3,5,7), (5,7,9), and (7,9,9) to five experiments. We fix one criteria weight to the highest value in experiments 6 to 9, and set the other criteria weights to the lowest values. The ranking of GSCM barriers did not significantly differ in the first five experiments. In experiment number five, B2 and B14 interchanged their positions at 9th and 10th positions, respectively. Similarly, B4 and B3 interchanged their positions. B9 and B17 correspondingly exchanged their positions. This shows that there is a very insignificant change in the ranking. There is only one significant ranking change, which occurs in experiment number 9. In this experiment, we assign the maximum weight to the criteria, leading to the replacement of barrier number B6 (inability to adopt adequate environmental treatment measures) with the first-ranked barrier B12 (no/low return from investment). Table 14 shows the results obtained from the sensitivity analysis.

6 Results and Discussions

The barriers and their ranking are completed based on four major perspectives. This study provides very encouraging and productive outcomes. We accomplish the ranking by using the fuzzy-TOPSIS methodology. The values of CCi for individual alternatives establish the ranking. The barrier with the utmost value of CCi is measured the most optimum barrier, whereas barriers with the smallest value of CCi are considered the least essential barriers.

The results indicate that "no/low return from investment" is the top-ranked barrier, with a CCi value of 0.607. The second most effective barrier limiting GSCM practices is “lack of government support,” with a CCi value of 0.602. The third most effective barrier is “lack of adaptation to advancements in technology." The fourth position ranks "inability to adopt adequate environmental treatment measures", while the fifth position ranks "lack of company-wide environmental standards or auditing programs".

The main aim of the industries is to earn profit, and if they do not see return from investment is negligible and people are not willing to pay, moreover people in India are not ready to give extra money for environmentally sustainable products. So, these industries are reluctant to invest on sustainability, and secondly, industries do not provide/allocate funds for implementing green practices. Moreover, these industries do not receive financial assistance from the government. The government's lack of support for these industries prevents them from adopting developing countries' technology, which in turn creates obstacles to reducing environmental hazards.

Sixth place goes to the "higher cost of environmentally friendly goods and packaging." This is also an important factor in Indian manufacturing industries, as the cost of the environmentally friendly goods and packaging is higher than the normally used materials. This increases the overall cost of the product, which customers are not willing to pay. The seventh position belongs to "lack of knowledge, necessary tools, and management skills." India's manufacturing industries lag behind in terms of tools, techniques, and professional approaches to mitigate the environmental impact of their supply chains. The eighth rank goes to "lack of management commitment." Industries are not committed to reducing environmental hazards. These industries aim to earn more and more money. They rarely consider the impact of their supply chain on the environment. "Society's lack of awareness" ranks ninth. Indian citizens lack awareness about environmental issues and their impact on humanity. At the tenth rank, we experience "pressure for lower prices from competitors." The manufacturers are always under pressure to reduce their costs in comparison to their core competitors. Thus, the manufacturing industries focus on cost reduction rather than environment.

"Insufficient coordination between different departments" ranks as the least important barrier at the bottom of the table. The Indian industries do not consider this barrier to be a very important one that can significantly restrict the implementation of GSCM, followed by "not willing to exchange trade information." The 18th position is occupied by the phrase "too complex to implement." The industries do not think it is difficult to implement, but they require technical and financial support to implement GSCM practices.

The barriers of "no or very low return from the investment" and "lack of government support" significantly hinder the adoption of GSCM practices. Industries find it challenging to implement GSCM practices due to the significant financial investment required, particularly if there is no or very low return from the investment. Therefore, “no or very low return from the investment” is considered the most important barrier for Indian manufacturing industries. It is also evident that government policies do not support the implementation of GSCM practices in India. Furthermore, the government does not provide any financial support or aid to encourage and support industries to implement GSCM practices. The Indian manufacturing industries' failure to adapt to technological advancements is primarily due to financial constraints, which can be attributed to either a lack of monetary funding from the government or a lack of knowledge about technological advancements. We should provide adequate support and training to achieve improved outcomes. Manufacturing industries in India do not have their own environmental standards, nor do they have any auditing programs to check their pollution level. Furthermore, we observe that the majority of these industries do not prioritize self-environmental auditing or the supplier's environmental quotient.

Manufacturing industries in India should use efficient tools and techniques, as well as a professional approach, to set their own environmental standards that can moderate the environmental impact of their supply chain. This will assist Indian manufacturing industries in mitigating environmental hazards and promoting sustainable development within the country, thereby addressing a critical environmental issue of the twenty-first century.

7 Conclusion

GSCM is a relatively new technique for the manufacturing industries in India. The Indian government and manufacturing industries are now recognizing the significance and benefits of GSCM practices. The various government agencies have already begun to force the Indian manufacturing industries to moderate ecological hazards. This is the reason many industries in India have started to demonstrate their obligation to be acquainted with GSCM principles (Jabbour et al., 2013). The current work extends the classical TOPSIS technique, known as the fuzzy TOPSIS method, to address real-world MCDM problems related to GSCM barrier ranking in linguistic environments. The ranking of the barriers will assist managers and industrial experts in resolving issues related to GSCM barriers by ranking their importance.

References

[1] Abosuliman, S. S., Abdullah, S., & Ali, N. (2025). Barriers and enhance strategies for green supply chain management using continuous linear diophantine neural networks. *Complex & Intelligent Systems*, *11*(2), 163.

[2] Agarwal, S., Saxena, K. K., Agrawal, V., Dixit, J. K., Prakash, C., Buddhi, D., & Mohammed, K. A. (2024). Prioritizing the barriers of green smart manufacturing using AHP in implementing Industry 4.0: a case from Indian automotive industry. *The TQM Journal*, *36*(1), 71-89. https://doi.org/10.1108/TQM-07-2022-0229

[3] Ahluwalia, S., Vaishya, R. O., Tyagi, M., & Walia, R. S. (2024). Drivers and barriers for implementation of green supply chain management: a review. *Challenges and Opportunities in Industrial and Mechanical Engineering: A Progressive Research Outlook*, 621-633.

[4] Awasthi, A., Chauhan, S. S., Omrani, H., & Panahi, A. (2011). A hybrid approach based on SERVQUAL and fuzzy TOPSIS for evaluating transportation service quality. *Computers & Industrial Engineering*, *61*(3), 637-646. https://doi.org/10.1016/j.cie.2011.04.019

[5] Balon, V., Sharma, A. K., & Barua, M. K. (2016). Assessment of barriers in green supply chain management using ISM: A case study of the automobile industry in India. *Global Business Review*, *17*(1), 116-135. https://doi.org/10.1177/0972150915610701

[6] Bellman, R. E., & Zadeh, L. A. (1970). Decision-making in a fuzzy environment. *Management science*, *17*(4), B-141. https://doi.org/10.1287/mnsc.17.4.B141

[7] Bhatia, M. S., & Srivastava, R. K. (2018). Analysis of external barriers to remanufacturing using grey-DEMATEL approach: An Indian perspective. *Resources, Conservation and Recycling*, *136*, 79-87. https://doi.org/10.1016/j.resconrec.2018.03.021

[8] Chen, T., Ab Jamil, N., Liang, W., Bao, Y., & Ma, H. (2025). Mapping and prioritizing barriers to sustainable green supply chain management: An integrated fuzzy MADM approach in manufacturing enterprises. *Journal of Applied Research on Industrial Engineering*, *12*(3), 388-413. https://doi.org/10.22105/jarie.2025.530831.1834

[9] Chotia, V., Soni, S., Jain, G., & Papa, A. (2023). Barriers for adoption of green supply chain management in cement industry: an interpretive structural modelling (ISM) approach. *Annals of Operations Research*, 1-34.

[10] de Oliveira, U. R., Espindola, L. S., da Silva, I. R., da Silva, I. N., & Rocha, H. M. (2018). A systematic literature review on green supply chain management: Research implications and future perspectives. *Journal of cleaner production*, *187*, 537-561. https://doi.org/10.1016/j.jclepro.2018.03.083

[11] Dhull, S., & Narwal, M. (2016). Drivers and barriers in green supply chain management adaptation: A state-of-art review. *Uncertain Supply Chain Management*, *4*(1), 61-76.

[12] Dhull, S., & Narwal, M. S. (2018). Prioritizing the drivers of green supply chain management in Indian manufacturing industries using fuzzy TOPSIS method: government, industry, environment, and public perspectives. *Process Integration and Optimization for Sustainability*, *2*(1), 47-60.

[13] Do, M. H., Huang, Y. F., & Phan, V. D. V. (2024). Analyzing the barriers to green supply chain management implementation: a case study of the Vietnamese agriculture sector. *Journal of Enterprise Information Management*, *37*(1), 125-147. https://doi.org/10.1108/JEIM-10-2021-0459

[14] Ghaderi, Z., Shakori, H., Bagheri, F., Hall, C. M., Rather, R. A., & Moaven, Z. (2024). Green supply chain management, environmental costs and supply chain performance in the hotel industry: the mediating role of supply chain agility and resilience. *Current Issues in Tourism*, *27*(13), 2101-2117. https://doi.org/10.1080/13683500.2023.2223911

[15] Govindan, K., & Hasanagic, M. (2018). A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective. *International journal of production research*, *56*(1-2), 278-311. https://doi.org/10.1080/00207543.2017.1402141

[16] Govindan, K., Kaliyan, M., Kannan, D., & Haq, A. N. (2014). Barriers analysis for green supply chain management implementation in Indian industries using analytic hierarchy process. *International journal of production economics*, *147*, 555-568. https://doi.org/10.1016/j.ijpe.2013.08.018

[17] Gumus, A. T. (2009). Evaluation of hazardous waste transportation firms by using a two step fuzzy-AHP and TOPSIS methodology. *Expert systems with applications*, *36*(2), 4067-4074. https://doi.org/10.1016/j.eswa.2008.03.013

[18] Hebaz, A., & Oulfarsi, S. (2021). The drivers and barriers of green supply chain management implementation: a review. *Acta logistica*, *8*(2), 123-132. https://doi.org/10.22306/al.v8i2.211

[19] Hwang, C. L., & Yoon, K. (1981). Methods for multiple attribute decision making. In *Multiple attribute decision making: methods and applications a state-of-the-art survey* (pp. 58-191). Berlin, Heidelberg: Springer Berlin Heidelberg.

[20] Jalali, M., Feng, B., & Feng, J. (2022). An analysis of barriers to sustainable supply chain management implementation: the fuzzy DEMATEL approach. *Sustainability*, *14*(20), 13622. https://doi.org/10.3390/su142013622

[21] Kareem, S., Fehrer, J. A., Shalpegin, T., & Stringer, C. (2025). Navigating tensions of sustainable supply chains in times of multiple crises: A systematic literature review. *Business Strategy and the Environment*, *34*(1), 316-337. https://doi.org/10.1002/bse.3990

[22] Kaur, J., Sidhu, R., Awasthi, A., Chauhan, S., & Goyal, S. (2018). A DEMATEL based approach for investigating barriers in green supply chain management in Canadian manufacturing firms. *International journal of production research*, *56*(1-2), 312-332. https://doi.org/10.1080/00207543.2017.1395522

[23] Khan, S., Zaman, S. I., & Mubarik, S. (2023). Obstacles in disruption and adoption of green supply chain management (GSCM) practices by manufacturing industries. In *Advanced Technologies and the Management of Disruptive Supply Chains: The Post-COVID Era* (pp. 153-179). Cham: Springer Nature Switzerland.

[24] Kharat, M. G., Kapoor, S., Parhi, S., Kharat, M. G., & Pandey, S. (2025). Operationalizing sustainability in pharmaceuticals: Green supply chain metrics for circular economy. *Sustainable Futures*, *9*, 100413. https://doi.org/10.1016/j.sftr.2024.100413

[25] Kumar, M., & Joji, R. T. (2023). Study of the interplay among internal and external barriers to GSCM in the Indian leather industry using the total ISM and MICMAC methodology. *Cogent Business & Management*, *10*(2), 2234697. https://doi.org/10.1080/23311975.2023.2234697

[26] Kumar, P., Dhull, S., Gandhi, A., & Mehla, S. (2024). Prioritizing the Barriers of EVs adaptation in India using Fuzzy TOPSIS Methodology. In *Computational Intelligence and Mathematical Applications* (pp. 270-275). CRC Press.

[27] Lee, K. H. (2005). *First course on fuzzy theory and applications*. Berlin, Heidelberg: Springer Berlin Heidelberg.

[28] Luthra, S., Garg, D., & Haleem, A. (2014). Empirical analysis of green supply chain management practices in Indian automobile industry. *Journal of The Institution of Engineers (India): Series C*, *95*(2), 119-126.

[29] Mankar, V. A., Katare, V., Lodhi, L., & Kaushik, T. K. (2025). A Study of Drivers and Barriers of Green Supply Chain Management Practices in the Context of Developing Framework for SMEs. In *Leveraging AI for Innovative Sustainable Energy: Solar, Wind and Green Hydrogen* (pp. 1-14). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3373-0045-0.ch001

[30] Massoud, M. A., Fayad, R., Kamleh, R., & El-Fadel, M. (2010). Environmental management system (ISO 14001) certification in developing countries: challenges and implementation strategies. https://doi.org/10.1021/es902714u

[31] Mathiyazhagan, K., Haq, A. N., Mohapatra, A., & Srinivasan, P. (2017). Application of structural equation modelling to evaluate the barrier relationship for green supply chain management implementation. *International Journal of Business Performance and Supply Chain Modelling*, *9*(2), 87-116. https://doi.org/10.1504/IJBPSCM.2017.085487

[32] Menon, R. R., & Ravi, V. (2022). An analysis of barriers affecting implementation of sustainable supply chain management in electronics industry: a Grey-DEMATEL approach. *Journal of Modelling in Management*, *17*(4), 1319-1350. https://doi.org/10.1108/JM2-02-2021-0042

[33] Mughal, Y. H., Nair, K. S., Arif, M., Albejaidi, F., Thurasamy, R., Chuadhry, M. A., & Malik, S. Y. (2023). Employees' perceptions of green supply-chain management, corporate social responsibility, and sustainability in organizations: Mediating effect of reflective moral attentiveness. *Sustainability*, *15*(13), 10528. https://doi.org/10.3390/su151310528

[34] Panigrahi, S. S., Mishra, S., & Sahu, B. (2025). What hinders the green supply chain management adoption in the Indian aluminium sector?. *Environment, Development & Sustainability*, *27*(6).

[35] Pathak, D. K., Verma, A., & Kumar, V. (2024). GSCM barriers to sustainable development in Indian manufacturing organisations: a mixed-method approach. *International Journal of Logistics Systems and Management*, *47*(3), 388-410. https://doi.org/10.1504/IJLSM.2024.136858

[36] Rahman, T., Ali, S. M., Moktadir, M. A., & Kusi-Sarpong, S. (2020). Evaluating barriers to implementing green supply chain management: An example from an emerging economy. *Production Planning & Control*, *31*(8), 673-698. https://doi.org/10.1080/09537287.2019.1674939

[37] Rane, S. B., Abhyankar, G. J., & Kirkire, M. S. (2025). Barriers to adoption of reusable packaging from supply chain perspective: multi criteria decision making analysis and industry 4.0 strategies. *OPSEARCH*, 1-52.

[38] Schöggl, J. P., Baumgartner, R. J., O'Reilly, C. J., Bouchouireb, H., & Göransson, P. (2024). Barriers to sustainable and circular product design–A theoretical and empirical prioritisation in the European automotive industry. *Journal of Cleaner Production*, *434*, 140250. https://doi.org/10.1016/j.jclepro.2023.140250

[39] Soda, S., Sachdeva, A., & Garg, R. K. (2017). Barriers analysis for green supply chain management implementation in power industry using ISM. *International Journal of Logistics Systems and Management*, *27*(2), 225-259. https://doi.org/10.1504/IJLSM.2017.083820

[40] Yang, F., & Zhang, X. (2017). Analysis of the barriers in implementing environmental management system by interpretive structural modeling approach. *Management research review*, *40*(12), 1316-1335. https://doi.org/10.1108/MRR-08-2016-0196

[41] Yu, C. S. (2002). A GP-AHP method for solving group decision-making fuzzy AHP problems. *Computers & Operations Research*, *29*(14), 1969-2001. https://doi.org/10.1016/S0305-0548(01)00068-5

[42] Zaman, S. I., Ali, M. R., & Khan, S. A. (2024). Exploring interrelationships among barriers and enablers of green procurement for a sustainable supply chain. *International Journal of Procurement Management*, *19*(2), 226-252. https://doi.org/10.1504/IJPM.2024.136051

Authors Biography

Dr. Sunil Dhull is an Associate Professor in the Department of Mechanical Engineering at Panipat Institute of Engineering and Technology, Panipat, Haryana, India. With a strong academic foundation, he holds a B.Tech, M.Tech, and Ph.D. in Mechanical Engineering. Dr. Dhull brings a unique perspective to his work with over 20 years of combined industrial and academic experience. His research interests span both traditional and emerging areas of mechanical engineering, including Green Supply Chain Management, Industrial and Production Engineering, 3-D printing, and Laser Cutting. He is particularly focused on integrating advanced computational technologies such as Artificial Intelligence, Machine Learning, and Data Science into these domains to develop innovative solutions. A prolific researcher, Dr. Dhull has authored numerous papers published in reputed national and international journals. His contributions to academia extend beyond publications; he has actively organized knowledge-sharing initiatives by convening several technical events, including Faculty Development Programs (FDPs), workshops, and training programmes. His excellence in research and innovation has been recognized through various awards and grants, most notably for his instrumental role in establishing an AICTE Idea Lab.

Dr. Anju Bhandari Gandhi is a distinguished academic and research leader with 19 years of extensive experience in Computer Science and Engineering. She is currently serving as the Professor Incharge of Research & Development at the Panipat Institute of Engineering and Technology, Panipat, where she provides strategic direction for the institution's research endeavours. Holding a B.Tech, M.Tech, and Ph.D. in CSE, Dr. Gandhi has a formidable publication record, with 65 research papers in reputed, Scopus-indexed international journals. Her research expertise is centered on cutting-edge domains including Artificial Intelligence, Machine Learning, and Data Science. A dynamic organizer, she has convened numerous high-profile technical events, including international conferences, seminars, Faculty Development Programs (FDPs), workshops, and training sessions. Her contributions to research and innovation have been recognized through multiple awards and grants, most notably her pivotal role in securing and establishing an AICTE Idea Lab.

Dr. Stuti Mehla is an Associate Professor in the Computer Science and Engineering department at PIET. With a robust academic foundation, she earned her B.Tech. and M.Tech. from Kurukshetra University and her Ph.D. in CSE from Maharishi Markandeshwar University, Mullana in 2022. She also enhanced her qualifications by qualifying the prestigious GATE examination in 2011. Boasting over a decade of experience, Dr. Mehla has established a strong research profile, having published more than 20 articles in esteemed international journals and presented her work at numerous conferences. Her research expertise lies in the cutting-edge domains of Artificial Intelligence, Machine Learning, Data Science, and Recommendation Systems. She is an active contributor to the global professional community, holding memberships in both the IEEE and the ACM.

Dr. Upasana Lakhina is an Assistant Professor and a distinguished academic with a strong research focus on sustainable energy solutions. She holds a B.Tech. from Kurukshetra University, followed by M.Tech in optimization in cloud Computing (Gold medallist). She also enhanced her qualifications by qualifying the prestigious GATE examination in 2014. Dr. Lakhina earned her Ph.D. in 2023, conducting pioneering research on the "Optimization of Renewable Energy Systems using Artificial and computational Intelligence." Her work has been widely disseminated through numerous publications in high-impact international journals and presentations at both national and international conferences. An active member of the IEEE since 2018, Dr. Lakhina is a dedicated contributor to the advancement of her field.

Jaya Rani is an Assistant Professor in the Department of Computer Science and Engineering at the Panipat Institute of Engineering and Technology (PIET), India. She earned her B.Tech in Computer Science and Engineering from Kurukshetra University and her M.Tech from Deenbandhu Chhotu Ram University of Science and Technology (DCRUST). She is currently pursuing her Ph.D. in Computer Science and Engineering at Maharishi Markandeshwar University, Mullana. With over 6.5 years of teaching experience, her academic work is complemented by a strong research focus on cutting-edge computational technologies. Her primary research interests lie in the fields of Artificial Intelligence, Machine Learning, and Deep Learning.

Geeta Rani is an Assistant Professor in the Department of Computer Science and Engineering at the Panipat Institute of Engineering and Technology (PIET), India. She received her B.Tech. and M.Tech. degrees in Computer Science and Engineering from Bhagat Phool Singh Women University. With nearly two years of teaching experience, her academic focus is complemented by a strong research orientation. Her research interests primarily lie in securing cloud infrastructure and leveraging advanced computational intelligence. Specifically, she focuses on Network Security in Cloud Computing, Generative AI, and the broader domains of Artificial Intelligence, Machine Learning, and Deep Learning.