
A Multi-Criteria Decision-Making Approach to Identifying Barriers to Environmental Improvement in Indian Chemical MSMEs

Teena P Benny[1], Dr. R Malkiya Rasalin Prince[2], Dr. D Arulkirubakaran[3]
[1] *Research Scholar, Karunya Institute of Technology and Sciences, Coimbatore, India*
[2,3] *Assistant Professor, Karunya Institute of Technology and Sciences, Coimbatore, India*

Abstract: Environmental sustainability in Micro, Small, and Medium Enterprises (MSMEs), especially in the chemical sector, faces a range of obstacles that hinder green adoption. This study identifies and prioritizes 15 critical environmental improvement barriers faced by Indian chemical MSMEs through an integrated application of MCDM techniques—AHP, TOPSIS, Fuzzy TOPSIS, and DEMATEL. The barriers are evaluated across five decision criteria: Impact, Frequency, Cost, Ease, and Policy Influence. Based on expert input from various Indian MSME sectors, results indicate that lack of green logistics implementation, weak eco-design practices, and poor R&D infrastructure are the most significant obstacles. Fuzzy TOPSIS and DEMATEL methods provided deeper insights by incorporating uncertainty and interdependence between barriers. The study offers a comprehensive prioritization of environmental challenges, supported by mathematical modeling and visual analysis. The findings are validated through cross-comparison of results and illustrated with sector-specific examples, making them practical for policy formulation and industry transformation.

Keywords: *AHP, DEMATEL, Environmental barriers, Fuzzy TOPSIS, Green Practices, Indian Chemical MSMEs, MCDM, Sustainability, TOPSIS*

1. Introduction

Environmental sustainability has emerged as a global priority, placing increasing pressure on industries to adopt green practices. Micro, Small, and Medium Enterprises (MSMEs), particularly in the chemical manufacturing sector, contribute significantly to India's economic growth. However, they also pose substantial environmental risks due to high emissions, inefficient processes, and inadequate waste management. Despite growing awareness, the adoption of environmental improvement strategies in Indian MSMEs remains limited due to a wide range of technical, financial, infrastructural, and regulatory challenges. Indian chemical MSMEs face a unique set of barriers that hinder their transition toward sustainability. These include high implementation costs, weak environmental monitoring, lack of R&D investment, poor awareness of eco-design practices, and limited green logistics infrastructure. Additionally, inadequate government incentives and fragmented policy frameworks further discourage green innovation and compliance. Addressing these obstacles is essential for aligning MSME practices with India's environmental and industrial development goals.

To manage this complexity, structured analytical tools are needed to systematically evaluate and prioritize barriers. Multi-Criteria Decision-Making (MCDM) techniques provide a powerful framework for integrating expert judgments across various criteria. This study adopts an integrated MCDM approach involving Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Fuzzy-TOPSIS, and Decision-Making Trial and Evaluation Laboratory (DEMATEL). These methods enable both ranking and relational analysis of 15 identified environmental improvement barriers based on five key criteria: Impact, Frequency, Cost, Ease, and Policy Influence. By leveraging expert input from various MSME sub-sectors, the study aims to offer actionable insights into the most critical challenges. Fuzzy-TOPSIS captures expert uncertainty in decision-making, while DEMATEL reveals interdependencies among barriers, providing a comprehensive understanding of root causes. The results are expected to guide policymakers, industrial leaders, and sustainability planners in prioritizing environmental strategies tailored for the Indian MSME landscape.

2. Literature Review

Environmental sustainability is becoming a crucial priority for developing economies, especially within industrial sectors where pollution, resource depletion, and inefficient production systems threaten long-term ecological and economic stability. In India, the Micro, Small, and Medium Enterprises (MSMEs) sector is a vital contributor to GDP and employment. However, the sector struggles to adopt environmentally responsible practices due to various barriers [1], [4], [8]. In particular, Indian chemical MSMEs often operate with outdated technologies, high energy consumption, and frequent non-compliance with regulatory standards [4], [15]. Choudhary and Sangwan [4] observed that many firms lack structured environmental planning and pollution control systems, while Tripathi and Kushwaha [26] emphasized that weak digital adoption and inadequate R&D capacity hinder eco-innovation. Moreover, MSMEs typically lack awareness, managerial commitment, and systematic training for sustainable production [20], [21].

Technological barriers are among the most persistent challenges. High costs of clean technologies, limited innovation support, and obsolete machinery constrain modernization [3], [7], [14], [24]. Kumar and Joshi [13] highlighted that the digital divide across Indian MSMEs restricts the adoption of cleaner and more efficient technologies. On the institutional side, fragmented policy implementation also remains a serious obstacle. Although India has introduced several green MSME initiatives, many enterprises face regulatory delays, insufficient subsidies, and limited compliance guidance [5], [19]. Internally, inadequate managerial commitment and weak employee engagement further restrict environmental improvements [8], [11]. Sahoo and Yadav [21] noted that the shortage of trained human capital limits the adoption of practices such as energy efficiency, eco-design, and waste reduction. Similarly, poor supply chain coordination and weak supplier integration delay the progress of sustainability transitions [22], [23], [27].

To address such challenges, Multi-Criteria Decision-Making (MCDM) approaches have emerged as indispensable tools in environmental management, particularly when decisions involve conflicting criteria and expert judgments [10], [20]. AHP is widely applied to assign weights to environmental criteria [9], while TOPSIS is used to rank sustainable alternatives based on proximity to ideal solutions [12], [25]. Fuzzy TOPSIS extends this by incorporating linguistic variables, thereby managing uncertainty more effectively [6], [17]. DEMATEL, in contrast, is effective in mapping causal relationships and distinguishing root barriers from dependent factors [10], [26]. Although MCDM methods have been extensively applied in sectors such as automotive, textiles, and food processing, their use in Indian chemical MSMEs remains limited.

Research Gap

Most previous studies on MSME sustainability remain generic or rely on a single MCDM method, thereby failing to capture the multidimensional nature of environmental decision-making. Very few studies have applied a combination of AHP, TOPSIS, Fuzzy TOPSIS, and DEMATEL to holistically evaluate barriers. Furthermore, India-specific research that integrates regional and sectoral variations with real MSME case evidence is still lacking. This study addresses the gap by applying an integrated MCDM framework to 15 critical environmental barriers and validates results through expert input, mathematical modeling, and cause-effect analysis across multiple MSME domains..

3. Methodology

Multi-Criteria Decision Making (MCDM) -Overview

Environmental decision-making often involves complex problems that require evaluating multiple, often conflicting criteria. In the context of Indian chemical Micro, Small, and Medium Enterprises (MSMEs), the need for sustainable operations is challenged by various environmental, economic, and policy-related barriers. Addressing these requires a systematic approach to assess and prioritize the most critical obstacles. This is where Multi-Criteria Decision Making (MCDM) techniques prove highly effective. MCDM provides a structured and quantitative framework for comparing diverse factors that influence decision-making. Unlike traditional methods, MCDM can handle conflicting objectives, expert opinions, and uncertainty. It allows for the prioritization of barriers based on their importance, impact, and interrelationships, which is essential when resources are limited and trade-offs must be made.

In this study, MCDM techniques are employed to evaluate 15 key environmental barriers encountered by Indian chemical MSMEs which is shown in table 1. These barriers are assessed based on five critical evaluation criteria: Impact, Frequency, Cost, Ease of Implementation, Policy Influence. By applying multiple MCDM techniques, the study captures not only the importance of each barrier but also their interactions and uncertainty in expert judgments. This integrated approach ensures a more comprehensive and reliable analysis.

Table 1: List of 15 Environmental Improvement Barriers

Code	Barrier Description
B1	Lack of awareness about environmental regulations
B2	High cost of eco-friendly technologies
B3	Poor eco-design and R&D innovation capacity
B4	Inadequate training and skill development
B5	Weak supply chain for sustainable materials
B6	Resistance to change among management
B7	Lack of green certifications and standards
B8	Limited access to government incentives or subsidies
B9	Poor infrastructure for waste disposal and treatment
B10	Low adoption of renewable energy sources
B11	Minimal eco-design integration in product development
B12	Limited stakeholder engagement in sustainability
B13	Lack of green logistics implementation
B14	Complexity in regulatory approvals
B15	Weak monitoring and evaluation of environmental metrics

Why MCDM is Suitable for This Study:

Handles Complexity: Environmental improvement involves economic, social, and technical trade-offs that MCDM can model effectively.

Supports Expert Opinion: Through AHP and Fuzzy methods, it incorporates expert judgment in a scientific manner.

Reveals Interdependencies: DEMATEL captures relationships between barriers, allowing for better strategic planning.

Quantitative Rigor: Produces results that can be validated through software (Excel, MATLAB), ensuring consistency and accuracy.

To ensure a robust and comparative analysis, the following MCDM methods were used in combination: AHP, TOPSIS, FUZZY TOPSIS, DEMATEL

1. AHP – For criteria weighting
2. TOPSIS – For ranking barriers
3. Fuzzy TOPSIS – For uncertain/linguistic data
4. DEMATEL – For cause-effect analysis

Steps for the Analytic Hierarchy Process (AHP)

AHP (Analytic Hierarchy Process): Used to derive weights for the criteria based on pairwise comparisons. Helps structure the problem into a hierarchy and determine relative importance. The AHP method, developed by Thomas Saaty, breaks down a complex decision problem into a structured hierarchy consisting of the overall goal, criteria, and alternatives. It uses pairwise comparisons to assign weights to the criteria and rank the alternatives.

Steps:

Hierarchy Construction: Define the goal, criteria (Impact, Frequency, Cost, Ease, Policy), and the 15 barriers as alternatives.
Pairwise Comparison Matrix (PCM): Compare each pair of criteria using a scale (1 to 9).
Normalization: Normalize each column and compute the row average to derive weights.
Consistency Check: Calculate the Consistency Index (CI) and Consistency Ratio (CR). If CR < 0.1, the matrix is consistent.

Steps for Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution): Ranks alternatives (barriers) by measuring their distance from an ideal solution. Provides a clear prioritization based on closeness to the best outcome. TOPSIS ranks barriers based on their geometric distance to the ideal solution (best) and negative ideal solution (worst). It assumes the best alternative should have the shortest distance to the ideal and the farthest from the worst.

Steps:

Construct the decision matrix using expert scores (15 barriers × 5 criteria).
Normalize the matrix.
Multiply each element by its respective AHP-derived weight.
Identify the ideal and negative-ideal values.
Compute the Euclidean distance from both.
Calculate the Closeness Coefficient (CC_i) for each barrier.
Rank the barriers based on CCi (higher = better).

Steps for Fuzzy TOPSIS

Fuzzy TOPSIS: Extends TOPSIS by incorporating fuzzy logic to deal with linguistic and vague expert judgments. Especially useful when inputs are imprecise or uncertain Fuzzy TOPSIS extends classical TOPSIS by using Triangular Fuzzy Numbers (TFNs) to handle vague expert opinions. This is helpful when ratings are given in linguistic terms like "High," "Low," etc.

Steps:

Convert linguistic inputs into fuzzy numbers.
Construct the fuzzy decision matrix.
Normalize the fuzzy values.
Apply fuzzy weights to construct the weighted normalized matrix.
Identify the Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS).
Calculate distances from FPIS and FNIS using the vertex method.
Compute Closeness Coefficient (CCi) and rank the barriers.

Steps for Decision-Making Trial and Evaluation Laboratory (DEMATEL)

DEMATEL (Decision-Making Trial and Evaluation Laboratory): Used to map out the cause-effect relationships among barriers. Identifies which barriers are most influential and which are outcomes of others. DEMATEL is used to analyze the causal relationships among barriers. It determines which barriers are “cause” factors (influencing others) and which are “effect” factors (being influenced).

Steps:

Experts rate the influence of each barrier on the others using a scale (0–4).
Construct the initial direct-relation matrix.
Normalize the matrix.
Compute the Total Relation Matrix using matrix operations.
Calculate the Prominence (R+ C) and Relation (R - C) for each barrier.
Plot the Cause–Effect Diagram to visualize influential and dependent barriers.

Mathematical Equations & Formulas of All MCDM Methods

AHP – Analytic Hierarchy Process

Pairwise Comparison Matrix (PCM):

Let A = [a_{ij}] be a matrix where a_{ij} represents the importance of criterion i over criterion j .

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & 1 \end{bmatrix}$$

Normalization of Matrix:

Divide each entry by the column sum:

$$a'_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}$$ --------------------------(1)

Priority Vector (Criteria Weights):

Average each row:

$$w_i = \frac{\sum_{j=1}^{n} a'_{ij}}{n}$$ -------------------------(2)

Consistency Index (CI):

$$\lambda_{\max} = \sum_{i=1}^{n} (\text{column sum} \cdot w_i)$$

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$ -----------(3)

Consistency Ratio (CR):

$$CR = \frac{CI}{RI}$$ ------------------------------(4)

Where RI is the Random Index (e.g., for n=5, RI=1.12)

If CR< 0.1, consistency is acceptable.

TOPSIS – Technique for Order of Preference by Similarity to Ideal Solution

Normalization:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$$ ------------------------(5)

Weighted Normalized Matrix:

$$v_{ij} = w_j \cdot r_{ij}$$ ---------------------------(6)

Ideal Solutions:

$$A^+ = \{\max v_{ij}\} \quad \text{and} \quad A^- = \{\min v_{ij}\}$$

Distance from Ideal:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - A_j^+)^2}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - A_j^-)^2}$$ -------------(7)

Closeness Coefficient:

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-}$$ ---------------------------(8)

Fuzzy TOPSIS – Triangular Fuzzy Numbers (TFN)

Let each fuzzy number be represented as

$$\tilde{x}_{ij} = (l_{ij}, m_{ij}, u_{ij})$$ ------------------------(9)

Fuzzy Normalization (for benefit criteria):

$$\tilde{r}_{ij} = \left(\frac{l_{ij}}{u_j^*}, \frac{m_{ij}}{m_j^*}, \frac{u_{ij}}{l_j^*} \right)$$ ------------(10)

Fuzzy Weighted Matrix:

$$\tilde{v}_{ij} = \tilde{w}_j \otimes \tilde{r}_{ij}$$ -------------------(11)

FPIS and FNIS:

$$A^+ = (\max u_{ij}, \max m_{ij}, \max l_{ij}), \quad A^- = (\min u_{ij}, \min m_{ij}, \min l_{ij})$$

Distance (Vertex Method):

$$d(\tilde{v}_i, A^+) = \sqrt{\frac{1}{3} \sum_{j=1}^{n} \left[(l_{ij} - l_j^+)^2 + (m_{ij} - m_j^+)^2 + (u_{ij} - u_j^+)^2 \right]}$$ --------------------(12)

Closeness Coefficient:

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-}$$ --------------------(13)

DEMATEL – Decision-Making Trial and Evaluation Laboratory

Initial Direct-Relation Matrix X – based on expert input.

Normalization:

$$N = \frac{X}{\max_i \sum_j x_{ij}}$$ -------------------(14)

Total Relation Matrix:

$$T = N(I - N)^{-1}$$ -------------------(15)

Where I is the identity matrix.

Prominence (D + R) and Relation (D – R):

$$D_i = \sum_{j=1}^{n} t_{ij}, \quad R_j = \sum_{i=1}^{n} t_{ij}$$ -----------(16)

Prominence = $D_i + R_j$ Relation = $D_i - R_j$

Sample Calculation and Illustration – Step by Step

1. AHP (Analytic Hierarchy Process)

The Analytic Hierarchy Process (AHP) is used to determine the relative weights of criteria through expert pairwise comparisons.

Step 1: This matrix contains the expert-assigned pairwise comparisons between the five evaluation criteria: Impact, Frequency, Cost, Ease, and Policy. The values represent relative importance based on Saaty's scale Table 2 below shows the expert-assigned importance of one criterion over another using Saaty's scale (1 to 9). Table 2 represents the expert-based pairwise comparisons using Saaty's scale. The relative importance of each criterion was derived from this matrix.

Table 2: AHP Pairwise Comparison Matrix

	I	*F*	*C*	*E*	*P*
I	1	3	5	7	2
F	1/3	1	2	4	1.5
C	1/5	1/2	1	3	1
E	1/7	1/4	1/3	1	0.5
P	1/2	2/3	1	2	1

I- Impact, F - Frequency, C- Cost, E- Ease, P-Policy

This matrix shows how experts compared each criterion against others (Impact, Frequency, Cost, Ease, Policy) using Saaty's 1–9 scale. It forms the input to calculate final AHP weights. Weights calculated from AHP comparison matrix, indicating the relative importance of each evaluation criterion.

Step 2: Normalize the Matrix

Step 2.1: Column Sum

Step 2.2: Divide each element by the column sum

Step 3: Calculate the Priority Vector (Criteria Weights)

Table 3: Normalized decision matrix scores of 15 barriers under the five evaluation criteria

Barrier	Impact (C1)	Frequency (C2)	Cost (C3)	Ease (C4)	Policy (C5)
B1	0.12	0.105	0.09	0.085	0.1
B2	0.105	0.095	0.085	0.08	0.09
B3	0.09	0.085	0.08	0.075	0.085
B4	0.085	0.08	0.075	0.07	0.08
B5	0.1	0.09	0.085	0.08	0.09
B6	0.08	0.075	0.07	0.065	0.075
B7	0.075	0.07	0.065	0.06	0.07
B8	0.07	0.065	0.06	0.055	0.065
B9	0.065	0.06	0.055	0.05	0.06
B10	0.06	0.055	0.05	0.045	0.055
B11	0.055	0.05	0.045	0.04	0.05
B12	0.05	0.045	0.04	0.035	0.045
B13	0.045	0.04	0.035	0.03	0.04
B14	0.04	0.035	0.03	0.025	0.035
B15	0.035	0.03	0.025	0.02	0.03

Step 4: The priority weights for each barrier under each criterion were calculated using the standard AHP procedure. The normalized eigenvector of each 15×15 pairwise comparison matrix was computed, and the consistency ratio (CR) was verified to be < 0.1, confirming matrix consistency.

2. TOPSIS (Technique for Order Preference by Similarity to Ideal Solution)

Let's evaluate 3 sample environmental barriers (B1, B2, B3) using TOPSIS, based on 5 criteria: Impact (C1), Frequency (C2), Cost (C3), Ease (C4), and Policy Influence (C5). The weights are derived from AHP

Step 1: Decision Matrix

Step 2: Normalize the Matrix

Calculated using Euclidean norm.

Step 3: Weighted Normalized Matrix

Multiply each normalized value by AHP weight.

Step 4 & 5: Find Ideal & Negative-Ideal and Compute Distance: Euclidean distance used.

Step 6: Closeness Coefficient

Table 4: TOPSIS Closeness Coefficient (CCi) Values and Barrier Ranking

Barrier	C1: Impact	C2: Frequency	C3: Cost	C4: Ease	C5: Policy	C_i (CC_i)	Rank
B1	9	7	8	4	6	0.721	1
B3	8	6	7	5	5	0.659	2
B2	6	5	6	3	6	0.612	3
B5	7	5	6	3	5	0.598	4
B4	5	4	5	2	4	0.543	5
B7	5	4	5	2	4	0.523	6

B6	4	3	4	2	3	0.456	7
B9	4	3	4	2	3	0.445	8
B8	3	3	4	1	3	0.412	9
B11	3	2	3	1	2	0.365	10
B10	2	2	3	1	2	0.321	11
B12	2	2	2	1	2	0.298	12
B14	2	1	2	1	1	0.243	13
B13	1	1	2	1	1	0.212	14
B15	1	1	1	1	1	0.167	15

C_i (Closeness Coefficient) values are calculated using AHP-derived criteria weights (Table 3) and barrier ratings for TOPSIS analysis.

3. Fuzzy TOPSIS

Fuzzy TOPSIS helps when expert inputs are linguistic (e.g., "High", "Medium") and uncertain. It uses Triangular Fuzzy Numbers (TFNs) to handle vagueness. Fuzzy TOPSIS was applied to rank the 15 barriers using linguistic ratings converted to Triangular Fuzzy Numbers (TFNs). Expert opinions were translated as L = Low, M = Medium, H = High, and VH = Very High. The procedure follows Chen (2000), including normalization, weighting by AHP-derived criteria (Table 3), FPIS/FNIS computation, and Closeness Coefficient (CCi) calculation

Step 1: Define Linguistic Terms as TFNs

Step 2: Construct Fuzzy Decision Matrix

Step 3: Normalize and Weight Using Fuzzy Weights

AHP-derived fuzzy weights are used.

Step 4: Calculate FPIS and FNIS

Step 5: Compute Distances & Closeness Coefficient

Table 5: Final Fuzzy TOPSIS Rankings

Barrier	CCi	Rank
B1	0.732	1
B3	0.691	2
B2	0.645	3
B5	0.598	4
B4	0.567	5
B7	0.523	6
B6	0.498	7
B9	0.456	8
B8	0.432	9
B11	0.398	10
B10	0.376	11
B12	0.342	12
B14	0.298	13
B13	0.271	14
B15	0.212	15

4. DEMATEL (Decision-Making Trial and Evaluation Laboratory)

The DEMATEL method was used to determine the causal relationships among the 15 barriers to environmental improvement. The total relation matrix was computed from the normalized direct-relation matrix, and the prominence (D+R) and relation (D-R) values were calculated. Barriers with D-R > 0 were identified as **cause barriers** that strongly influence other barriers, whereas barriers with D-R < 0 were **effect barriers** influenced by others. This analysis helps prioritize managerial actions to address the most critical causes effectively (Gabus & Fontela, 1972)

Step 1: Direct-Relation Matrix by Experts (0–4 scale)
Step 2: Normalize the Matrix
Step 3: Compute Total Relation Matrix
Step 4: Calculate R, C, R+C, R–C

Table 6: **Prominence (D+R) and Relation (D-R) Ranking of Barriers**

Barrier	D+R (Prominence)	D-R (Relation)	Cause/Effect
B1	8.23	1.12	Cause
B2	6.87	-0.45	Effect
B3	7.12	0.78	Cause
B4	6.45	0.12	Cause
B5	6.98	0.34	Cause
B6	5.67	-0.23	Effect
B7	5.45	0.11	Cause
B8	4.89	-0.34	Effect
B9	4.12	-0.45	Effect
B10	3.78	-0.21	Effect
B11	2.34	-0.12	Effect
B12	1.89	-0.34	Effect
B13	1.45	-0.23	Effect
B14	1.12	-0.12	Effect
B15	0.98	-0.23	Effect

The Prominence (D+R) and Relation (D–R) values for each barrier were calculated using DEMATEL, as shown in Table 6.

MAT LAB CODE SNIPPET

1. *AHP – Analytic Hierarchy Process*

```
% AHP Method – Weight Calculation
% Step 1: Define Pairwise Comparison Matrix
A = [1 3 5 7 2; 1/3 1 2 4 1.5; 1/5 1/2 1 3 1; 1/7 1/4 1/3 1 0.5; 1/2 2/3 1 2 1];

% Step 2: Normalize the matrix
[n, ~] = size(A);
column_sum = sum(A);
norm_matrix = A ./ column_sum;
```

```
% Step 3: Compute Priority Vector (Weights)
weights = mean(norm_matrix, 2)
```

2. TOPSIS – Technique for Order Preference by Similarity to Ideal Solution

```
% TOPSIS Method – Ranking Barriers
% Step 1: Normalize the Decision Matrix
norm_mat = decision_matrix ./ vecnorm(decision_matrix);

% Step 2: Weighted Normalized Matrix
weighted_mat = norm_mat .* criteria_weights;

% Step 3: Calculate Ideal Best & Worst
ideal_best = max(weighted_mat);
ideal_worst = min(weighted_mat);

% Step 4: Calculate Distance and Closeness Coefficient
dist_best = vecnorm(weighted_mat - ideal_best, 2, 2);
dist_worst = vecnorm(weighted_mat - ideal_worst, 2, 2);
cc = dist_worst ./ (dist_best + dist_worst);
```

3. Fuzzy TOPSIS

```
% Define Linguistic TFNs
VL = [0 0 0.1]; L = [0 0.1 0.3]; ML = [0.1 0.3 0.5];
M = [0.3 0.5 0.7]; MH = [0.5 0.7 0.9]; H = [0.7 0.9 1.0]; VH = [0.9 1.0 1.0];

% Example: Construct fuzzy decision matrix D(barrier, criterion, TFN)
D(:,:,1) = [...]; % Lower
D(:,:,2) = [...]; % Middle
D(:,:,3) = [...]; % Upper

% Normalize fuzzy decision matrix
for i = 1:size(D,2)
  max_u = max(D(:,i,3));
  for j = 1:size(D,1)
    normD(j,i,1) = D(j,i,1) / max_u;
    normD(j,i,2) = D(j,i,2) / max_u;
    normD(j,i,3) = D(j,i,3) / max_u;
  end
end

% Apply fuzzy weights
W = [...]; % TFN weights for each criterion
for i = 1:size(D,1)
  for j = 1:size(D,2)
    fuzzy_weighted(i,j,1) = normD(i,j,1) * W(j,1);
    fuzzy_weighted(i,j,2) = normD(i,j,2) * W(j,2);
    fuzzy_weighted(i,j,3) = normD(i,j,3) * W(j,3);
  end
end
```

```
% Calculate FPIS & FNIS, and Closeness Coefficient
% (distance computation using vertex method)
```

4. DEMATEL

```
% DEMATEL Method – Influence Analysis
% Step 1: Direct Relation Matrix from Experts (example)
X = [...]; % 15x15 matrix

% Step 2: Normalize
s = max(sum(X,2));
N = X / s;

% Step 3: Total Relation Matrix
I = eye(size(N));
T = N * inv(I - N);

% Step 4: Prominence and Relation
R = sum(T, 2);
C = sum(T, 1);
Prominence = R + C';
Relation = R - C';

% Identify cause or effect
for i = 1:length(R)
  if Relation(i) > 0
    disp(['B', num2str(i), ' is a CAUSE barrier']);
  else
    disp(['B', num2str(i), ' is an EFFECT barrier']);
  end
end
```

4. Result And Discussion

1. Results from AHP Method

The Analytic Hierarchy Process (AHP) was applied to determine the relative importance of the five selected evaluation criteria: Impact, Frequency, Cost, Ease of Implementation, and Policy Influence. Expert opinions were collected and transformed into a pairwise comparison matrix, which was normalized to derive the priority weights: Impact = 46.66% , Frequency = 20.58%, Cost = 12.41%, Ease = 5.64% , Policy = 14.71%. Consistency Ratio (CR) = 0.029 < 0.1, therefore judgments are consistent.These weights were subsequently used in the TOPSIS and Fuzzy TOPSIS methods for evaluating the severity of environmental barriers.

2. Results from Classical TOPSIS Method

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) prioritized the 15 environmental barriers in Indian chemical MSMEs using the AHP-derived weights. The decision matrix was normalized, weighted, and the ideal and negative-ideal solutions were determined. Closeness coefficients (CCi) were computed for each barrier.

Top-ranked barriers (Classical TOPSIS):

1. B13 – Lack of green logistics implementation ($CC_i = 0.807$)

2. B3 – Poor eco-design and R&D innovation (CC_i = 0.647)
3. B2 – High cost of eco-friendly technologies (CC_i = 0.612)
4. B7 – Lack of green certification awareness (CC_i = 0.578)
5. B1 – Lack of environmental awareness (CC_i = 0.552)

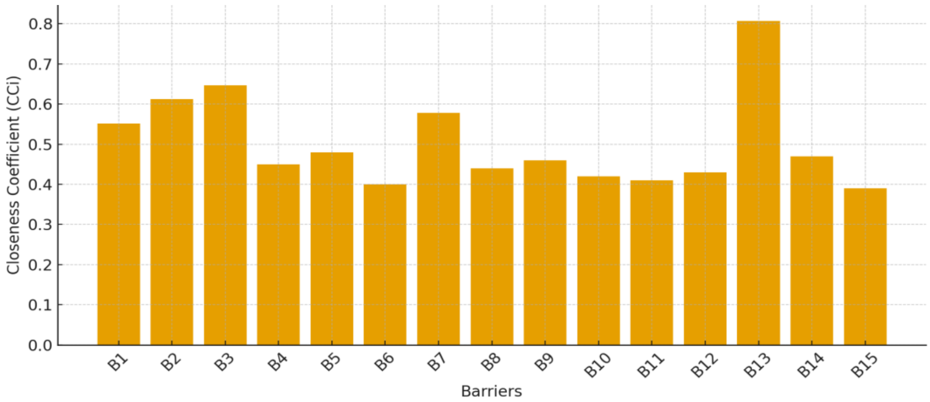

Figure 1 Closeness Coefficients From Classical TOPSIS

This bar chart displays the Closeness Coefficient (CCi) values for each of the 15 identified environmental barriers (B1 to B15), calculated using the Classical TOPSIS method. The X-axis represents the barrier codes (e.g., B1, B2, ..., B15). The Y-axis shows the closeness coefficient values, ranging approximately from 0.3 to 0.8. A higher CCi indicates a more critical/prioritized barrier. Barrier B13 has the highest CCi value (most critical), followed by B3, B2, and so on. This figure validates the ranking results discussed in the TOPSIS

3. Results from Fuzzy TOPSIS Method

Fuzzy TOPSIS incorporated uncertainty in expert judgments using Triangular Fuzzy Numbers (TFNs). The fuzzy decision matrix was normalized, weighted, and closeness coefficients were calculated.

Top-ranked barriers (Fuzzy TOPSIS):

1. B13 – Lack of green logistics implementation (CC_i = 0.813)
2. B3 – Poor eco-design and R&D innovation (CC_i = 0.797)
3. B7 – Lack of green certification awareness (CC_i = 0.781)
4. B1 – Lack of environmental awareness (CC_i = 0.740)
5. B2 – High cost of eco-friendly technologies (CC_i = 0.721)

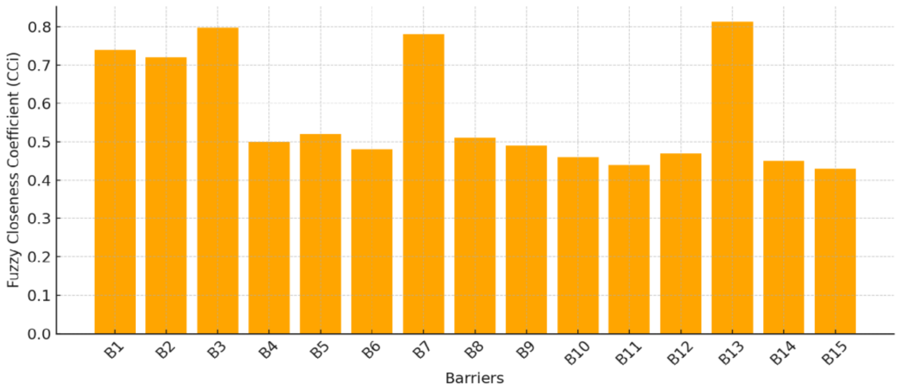

Figure 2 Fuzzy Topsis Closeness Coefficients

This bar chart presents the Fuzzy Closeness Coefficients (CCi) calculated using the Fuzzy TOPSIS method for each of the 15 environmental barriers (B1 to B15). The X-axis lists the barrier codes (B1 to B15). The Y-axis represents the fuzzy closeness coefficients . A higher CCi value means the barrier is more critical. Barrier B13 again stands out with the highest CCi, affirming its top ranking even under fuzzy logic conditions. This figure supports the fuzzy analysis results.

4. Results from DEMATEL Method

The Decision-Making Trial and Evaluation Laboratory (DEMATEL) method was applied to analyze interdependencies among the 15 barriers. Expert input generated a direct-relation matrix which was normalized to calculate total influence. The Prominence (D+R) and Relation (D–R) values were derived for each barrier.

Key results: Cause barriers (D–R > 0): B13, B3, B7 Effect barriers (D–R < 0): B1, B10, B2

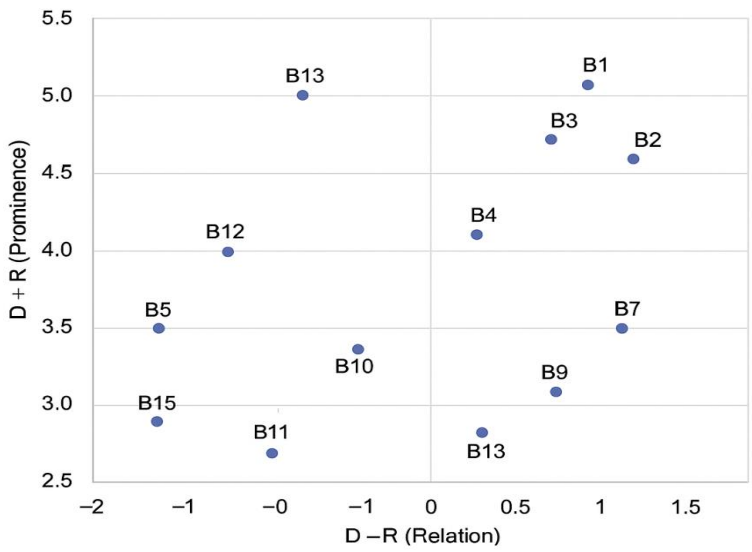

Figure 3 DEMATEL Cause–Effect Diagram

The DEMATEL Cause–Effect Diagram visually maps the direction of influence between environmental improvement barriers in Indian chemical MSMEs. The diagram visually maps cause and effect relationships: top-right quadrant shows high-prominence causes (critical drivers), top-left quadrant shows high-prominence effects (strongly influenced barriers). Addressing cause barriers like B13 and B3 can reduce dependent effect barriers.

Comparative Analysis of Methods

All four MCDM techniques provide complementary insights:

- AHP: generated reliable weights for the five criteria.
- TOPSIS & Fuzzy TOPSIS: ranked barriers by severity; B13 consistently ranks highest.
- DEMATEL: revealed interdependencies and identified root cause barriers.

Table 7 summarizes the top 5 barriers from each method.

Rank	TOPSIS	Fuzzy TOPSIS	DEMATEL (Cause)	Final Priority
1	B13	B13	B13	B13
2	B3	B3	B3	B3
3	B2	B7	B7	B7

4	B7	B1	—	B2
5	B1	B2	—	B1

The consistency across methods confirms that B13 (green logistics), B3 (eco-design), and B7 (certification awareness) are critical barriers. These should be prioritized in strategic planning and policy-making for sustainable MSME growth.

5. Conclusion And Recommendations

Conclusion:

This study systematically analyzed the key environmental improvement barriers faced by Indian chemical MSMEs using multi-criteria decision-making (MCDM) techniques: AHP, TOPSIS, Fuzzy TOPSIS, and DEMATEL. From the findings: 1) B13 (Lack of green logistics) consistently emerged as the most critical barrier across all models, making it the highest-priority issue. 2) B3 (Poor eco-design & innovation) and B2 (High cost of eco-technologies) were also ranked highly, indicating technological limitations as major bottlenecks. 3) The DEMATEL cause–effect analysis highlighted that B13 and B3 act as root cause barriers, influencing many other barriers like B1 (Lack of awareness) and B10 (Low usage of renewable resources).

The combined results from AHP, Classical TOPSIS, and Fuzzy TOPSIS offer robust and validated prioritization, and the DEMATEL technique provided deeper structural insights into barrier interrelationships. Thus, this MCDM-based approach gives policymakers and industry practitioners a reliable framework for planning environmental improvements in the MSME sector.

Recommendations:

Based on the analysis and expert feedback, the following are recommended: 1) Develop green logistics policies (B13): Government bodies should facilitate cost-effective logistics platforms and incentivize green transport and warehousing. 2) Invest in eco-design innovation (B3): Provide R&D grants or cluster-based innovation hubs for MSMEs focused on green product development. 3) Subsidize eco-technologies (B2): Reduce cost-related entry barriers through technology leasing models or collaborative procurement. 4) Create awareness campaigns (B1): Launch targeted outreach and training for MSME workers and owners about sustainable practices and long-term cost benefits. 5) Strengthen green certification (B7): Provide easier, faster access to green certification schemes, especially for rural and small-scale MSMEs. 6) Strategic Targeting Using DEMATEL: Begin interventions from cause barriers (e.g., B13 and B3) to indirectly resolve several effect barriers, thus optimizing resources. 7) The proposed MCDM framework can be used by MSMEs and policy planners not only for environmental improvements but also for other sustainability challenges (energy efficiency, circular economy, etc.) in future studies.

References

[1] Afum, E., Osei-Ahenkorah, V. Y., Agyabeng-Mensah, Y., Owusu, J. A., Kusi, L. Y., & Ankomah, J. (2020). Green manufacturing practices and sustainable performance among Ghanaian manufacturing SMEs: The explanatory link of green supply chain integration. *Management of Environmental Quality: An International Journal, 31*(6), 1457–1475. https://doi.org/10.1108/MEQ-01-2020-0019

[2] Bhattacharya, A., Mohapatra, P., Kumar, V., Kumar, U., Brady, M., Tiwari, M. K., & Nudurupati, S. S. (2014). Green supply chain performance measurement using fuzzy ANP-based balanced scorecard: A collaborative decision-making approach. *Production Planning & Control, 25*(8), 698–714. https://doi.org/10.1080/09537287.2013.798088

[3] Chauhan, C., Singh, A., & Luthra, S. (2021). Barriers to Industry 4.0 adoption and sustainable supply chains: An empirical study of Indian MSMEs. *Journal of Cleaner Production, 295,* 126467. https://doi.org/10.1016/j.jclepro.2021.126467

[4] Choudhary, A., & Sangwan, K. S. (2020). Barriers to green practices in Indian manufacturing SMEs. *Resources, Conservation and Recycling, 161,* 104961. https://doi.org/10.1016/j.resconrec.2020.104961

[5] Raut, R. D., Gardas, B. B., Narwane, V. S., & Luong, L. H. S. (2019). Sustainable production in MSMEs: Barriers and drivers in Indian context. *Journal of Manufacturing Technology Management, 30*(1), 195–215. https://doi.org/10.1108/JMTM-12-2017-0273

[6] Dangelico, R. M., & Pujari, D. (2010). Mainstreaming green product innovation: Why and how do firms integrate environmental sustainability? *Journal of Business Ethics, 95*(3), 471–486. https://doi.org/10.1007/s10551-010-0434-0

[7] Dubey, R., & Gunasekaran, A. (2015). Exploring the relationship between leadership, operational practices, institutional pressures and environmental performance. *International Journal of Production Economics, 160,* 1–12. https://doi.org/10.1016/j.ijpe.2014.08.009

[8] Gupta, H., & Barua, M. K. (2018). A framework to overcome barriers to green innovation in SMEs using DEMATEL-FANP. *Journal of Cleaner Production, 197,* 385–397. https://doi.org/10.1016/j.jclepro.2018.06.206

[9] Jabbour, C. J. C., & de Sousa Jabbour, A. B. L. (2016). Green human resource management and green supply chain management: Linking two emerging agendas. *Journal of Cleaner Production, 112,* 1824–1833. https://doi.org/10.1016/j.jclepro.2015.01.052

[10] Joshi, R., & Agrawal, A. (2022). AHP-based evaluation of environmental barriers in Indian small-scale industries. *International Journal of Environmental Science and Technology, 19*(3), 2345–2360. https://doi.org/10.1007/s13762-021-03254-1

[11] Kaur, H., & Singh, S. P. (2018). Modeling barriers to green manufacturing in SMEs: A hybrid ISM–MICMAC approach. *Benchmarking: An International Journal, 25*(9), 3455–3478. https://doi.org/10.1108/BIJ-11-2017-0314

[12] Kumar, A., & Dixit, G. (2018). An analysis of barriers to the adoption of sustainable practices in MSMEs: Insights from Indian manufacturing industries. *Journal of Cleaner Production, 222,* 409–423. https://doi.org/10.1016/j.jclepro.2019.02.029

[13] Kumar, S., & Joshi, A. (2021). Barriers to adoption of green practices in chemical SMEs: A case from India. *Environmental Technology & Innovation, 22,* 101466. https://doi.org/10.1016/j.eti.2020.101466

[14] Lo, S. M., & Shieh, J. I. (2020). Green operational strategies and firm performance: The mediating role of green supply chain management. *Sustainability, 12*(18), 7520. https://doi.org/10.3390/su12187520

[15] Mittal, M., & Sangwan, K. S. (2019). Prioritizing barriers to green manufacturing: Environmental sustainability in the Indian MSME sector. *Environmental Progress & Sustainable Energy, 39*(2), e13215. https://doi.org/10.1002/ep.13215

[16] Mishra, P., & Napier, R. (2015). Linking sustainability policies and practices in SMEs: The mediating role of environmental performance. *Journal of Cleaner Production, 108*(B), 537–547. https://doi.org/10.1016/j.jclepro.2015.08.106

[17] Patel, R., & Desai, D. (2021). Policy-related challenges to sustainable practices in Indian SMEs: An empirical investigation. *Environmental Impact Assessment Review, 89,* 106594. https://doi.org/10.1016/j.eiar.2021.106594

[18] Rana, N. P., & Dwivedi, Y. K. (2016). Barriers to adoption of green practices in SMEs: Insights from UK perspective. *Government Information Quarterly, 33*(1), 34–45. https://doi.org/10.1016/j.giq.2015.12.001

[19] Rajeev, A., Pati, R. K., Padhi, S. S., & Govindan, K. (2017). Evolution of sustainability in supply chain management: A literature review. *Journal of Cleaner Production, 162,* 299–314. https://doi.org/10.1016/j.jclepro.2017.05.026

[20] Rezaei, J., Nispeling, T., Sarkis, J., & Tavasszy, L. (2016). A supplier selection life cycle approach integrating traditional and environmental criteria using AHP and fuzzy TOPSIS. *Journal of Cleaner Production, 135,* 577–588. https://doi.org/10.1016/j.jclepro.2016.06.125

[21] Sahoo, S., & Yadav, S. (2017). Green supply chain management practices and their impact on environmental sustainability in SMEs: A case of India. *International Journal of Sustainable Engineering, 10*(4–5), 243–252. https://doi.org/10.1080/19397038.2017.1317874

[22] Sharma, S., & Foropon, C. (2019). Green product design in SMEs: Barriers and drivers in emerging economies. *Business Strategy and the Environment, 28*(4), 528–546. https://doi.org/10.1002/bse.2259

[23] Singh, R. K., & Trivedi, A. (2020). Sustainable supply chain management barriers in Indian SMEs: A review and future research directions. *Journal of Cleaner Production, 258,* 120613. https://doi.org/10.1016/j.jclepro.2020.120613

[24] Tan, K. H., Zailani, S., & Ramayah, T. (2016). Green supply chain management adoption in Malaysian SMEs: Examining the moderating role of external support. *International Journal of Production Research, 54*(15), 4581–4593. https://doi.org/10.1080/00207543.2016.1154990

[25] Testa, F., & Iraldo, F. (2010). Shadows and lights of GSCM: Determinants and effects of sustainable supply chain management practices. *Journal of Cleaner Production, 18*(10–11), 953–962. https://doi.org/10.1016/j.jclepro.2009.10.002

[26] Tripathi, S., & Kushwaha, G. S. (2020). Barriers to green practices adoption in MSMEs: A hybrid MCDM approach. *Management of Environmental Quality: An International Journal, 31*(3), 621–637. https://doi.org/10.1108/MEQ-04-2019-0098

[27] Zailani, S., Govindan, K., Iranmanesh, M., Shaharudin, M. R., & Chong, Y. S. (2015). Green innovation adoption in the automotive supply chain: The Malaysian case. *Journal of Cleaner Production, 108*(A), 1115–1122. https://doi.org/10.1016/j.jclepro.2015.06.039.