

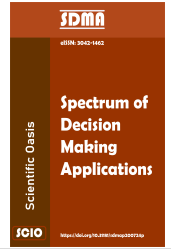


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Multi-Criteria Decision-Making for Smog Mitigation: A Comprehensive Analysis of Health, Economic, and Ecological Impacts

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ABSTRACT

Smog is a significant threat in Pakistan, having become a persistent issue in recent years. Excessive industrialization, increased reliance on fossil fuels, and increased automobile emissions have all led to epidemic levels of air pollution. Smog, or air pollution, can pose significant risks to humans and plants due to its harmful effects. Air pollution contributes to global health issues, including lung, breathing, and skin ailments. Pakistan, an undeveloped nation, is grappling with the detrimental effects of smog on various sectors such as health, ecology, transportation, and education. This study aims to employ multi-criteria decision-making (MCDM) methodologies to examine points of view on smog-related issues in Pakistan. The analysis specifically concentrates on the health, economic, social, and ecological consequences of smog and the solutions employed to mitigate its effects. By employing various approaches, such as the Method based on the Removal Effects of Criteria (MEREC) objective weighting technique to determine the weights of each criterion and select the essential criteria, pair-wise comparisons are performed in the Best-Worst Method (BWM) on the best and worst criteria selected through MEREC. We have created a designated consistency ratio for the BWM to assess the reliability of the comparisons. Entropy is an objective weighting technique used to calculate the weights of the best and worst criteria, and the TOPSIS technique is employed to determine the most suitable alternative from a collection of choices by evaluating their resemblance to an ideal answer.

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1. Introduction

Air pollution is a prominent environmental issue in the current era, with its impacts becoming increasingly apparent over time. Polluted air is the primary factor responsible for infectious diseases and early mortality on a global scale, resulting in probably 9 million in fatalities per year. Sunlight chemically reacts with air contaminants to create a specific type of air pollution known as SMOG, resulting in the appearance of poor ozone. Throughout the last century, people initially employed the term SMOG, which combines the words "smoke" and "fog." Smog is a combination of a variety of chemicals, mostly consisting of particulate matter (PM_{2.5}, PM₁₀), as well as sulfur dioxide (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (VOCs), ozone (O₃), peroxyacetyl nitrates (PAN), and aldehydes. Every constituent poses a significant threat to humans, biodiversity, and the ecological system, especially when present at elevated levels.

Smog is a highly alarming problem for the South Asian region, especially in Pakistan. With a population of 231.4 million, Pakistan is the 5th most populous country globally. In 2022, Pakistan came in with a PM_{2.5} reading of $70.9 \mu\text{g}/\text{m}^3$. The country has been ranked third out of the most polluted countries globally. In 2023, Pakistan came in with a PM_{2.5} reading of $73.7 \mu\text{g}/\text{m}^3$ (more than 14.7 times higher than the WHO PM_{2.5} annual guideline), not only putting it into the 'unhealthy' rating category but also into the second place position out of the most polluted countries in the world [1]. Smog is becoming more prevalent in Punjab, where two-thirds of the country population lives. The problem gets worse in the winter. Lahore, the world's most polluted city in 2022, experienced an average annual PM_{2.5} concentration of $97.4 \mu\text{g}/\text{m}^3$, and in 2023, the PM_{2.5} reading of $99.5 \mu\text{g}/\text{m}^3$, exceeds by over 10 times.

Deforestation, excessive industrialization, brick kilns, and agricultural product burning are the main causes of smog. Pakistan is grappling with air pollution from exhaust from urban vehicles, mostly as a result of gasoline, low-quality lubricating oils, and poorly managed transportation systems. The uncontrolled combustion of waste, encompassing plastics and various materials, releases detrimental pollutants into the atmosphere. The components of smog, such as PM_{2.5}, SO_x, NO_x, CO, VOCs, and O₃, cause serious health problems. Inhalation of VOCs can cause eye, nose, and throat irritation, respiratory issues, nausea, and cancer [2]. O₃ damages tissues and impairs lung function [3], and PM_{2.5} causes cardiovascular and respiratory issues [4]. NO_x irritation can cause coughing, breathlessness, fatigue, and nausea [5].

Smog not only affects the health of individuals but also impacts outdoor activities, social events, ecosystems, tourism, and biodiversity. Smog has a significant negative impact on cultivation and production, making it extremely damaging to agricultural productivity. Smog-induced work productivity declines, local businesses face disruptions, and economic inequalities worsen, especially in vulnerable communities lacking the resources to manage health issues. A comprehensive strategy must mitigate and control smog by considering the various pollutants and sources contributing to its formation. In Figure 1, some mitigation strategies are shown.

Decision-making (DM) is a complicated cognitive process that seeks to ascertain a favorable result by taking into account multiple factors. Multi-criteria decision-making (MCDM) is a strategic technique that involves assessing multiple alternatives to determine the most optimal choice in a DM process [6]. MCDM is a field that integrates various operations research disciplines, encompassing multi-attribute decision-making (MADM) and multi-objective decision-making (MODM). MODM studies continuous decision areas with endless options or continuous problems of DM. The answer is a viable region, with no clear-cut solution. Goals are criteria, and traits are not stated. Limits are clear, and decision-makers

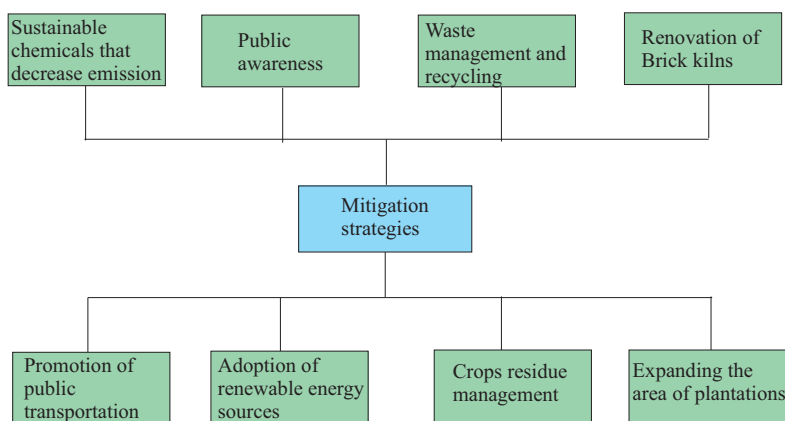


Fig. 1. Mitigation strategies of Smog in Pakistan

(DMs) communicate frequently. MADM, also known as discrete problems, is an evaluation problem with clear goals, attributes, and choices that lacks contact between DMs and has limited limits. MCDM methods provide logical, comprehensible, and viable options in real-life scenarios, identifying options, determining their importance, assessing efficiency, and ranking alternatives based on overall performance [7].

Researchers widely recognize MCDM techniques as the primary approaches for DM that consider multiple factors throughout the process. Simple Additive Weighting (SAW) [8], Grey Relational Analysis/Grey Relational Model (GRA/GRM) [9], ViseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) [10], Analytic Hierarchy Process (AHP) [11], ELimination Et Choix Traduisant la REALité (ELimination Et Choice Translating REALity) (ELECTRE) [12], Data Envelopment Analysis (DEA) [13], Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE) [14] are some common MCDM strategies that academics from various fields of study have used. Several techniques were created to establish criteria weights [15] such as Criterion Impact Loss (CILOS), Integrated Determination of Objective CRiteria Weights (IDOCRIW), Full Consistency Method (FUCOM), Level Based Weight Assessment (LBWA), CRiteria Importance Through Intercriteria Correlation (CRITIC), and Simple Multi-Attribute Rating Technique (SMART). Figure 2 illustrates the classification of weighting methods for the MCDM problem.

Subjective weighting methods, like direct ranking, depend on the preferences of the people making the decisions. As the number of variables increases, these methods become less beneficial. Objective weighting methods, on the other hand, employ particular techniques to compute results. In this paper, we are applying the Method based on the Removal Effects of Criteria (MERECE) objective weighting technique to determine the weights of criteria and select the best and worst. The objective weighting method ENTROPY will be used to calculate the weights of the best and worst criteria, while the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) methodology will be used.

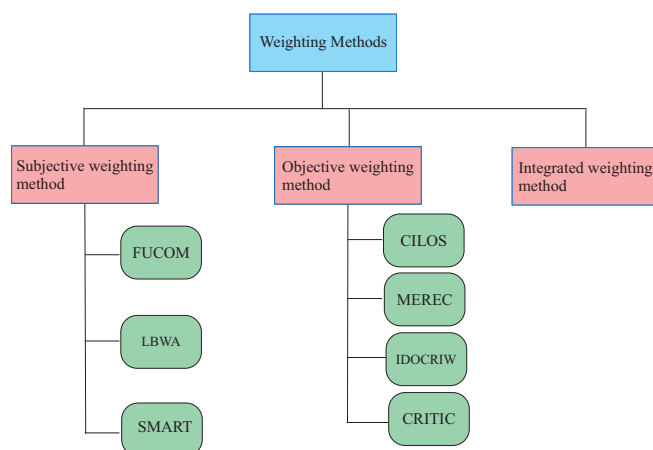


Fig. 2. Classification of weighting method in MCDM

2. Literature Review

Keshavarz-Ghorabae *et al.* [7] developed the MEREC (Minimum Redundancy Criterion) technique, a distinctive MCDM method that provides more precise and reliable results. This approach leverages the impact of removing each requirement on the estimation of alternatives to get the weights of the criteria. The method of evaluating a choice by eliminating the criterion of considering deviations is a novel approach to determining the weights of criteria. A criterion carries significant importance when its elimination results in a greater influence on the overall performance of alternatives. This particular viewpoint establishes the impartial significance of each criterion and facilitates the DM process by enabling DMs to exclude specific criteria. The MEREC method employs an exclusion viewpoint and removal effects to determine objective criteria weights, distinct from other approaches that use an inclusion perspective [16].

The Best Worst Method (BWM) is a multi-criteria decision-making (MCDM) technique developed to evaluate the optimal weights for a given set of criteria based on the decision-maker's preferences. The BWM relies on two assessment vectors: the rest of the criteria compared to the worst and the best criteria compared to the other criteria [17]. Shannon and Weaver [18] developed the entropy weights approach in 1947. The efficiency dispersion in DM is measured using probability theory to determine entropy, which can be interpreted as insufficient data. The entropy methodology calculates the weights of reliable and distinctive criteria by evaluating the importance of each answer attribute, independent of the DM's choice. The entropy weight measurement starts with choosing a goal, then moves on to the decision structure, the criteria and attribute-matched chance, the variance, the criterion, and feature entropy value, and finally the entropy weight. A greater score is thought to be better than a smaller one [19].

TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) is an extensively used MCDM method that helps rank and select a set of alternatives based on their closeness to an ideal solution. The primary idea behind TOPSIS is that the selected alternative should have the shortest distance from the positive-ideal solution (best possible scenario) and the largest distance from the negative-ideal solution (worst possible scenario) [20]. The method includes calculating weights, standardizing data, measuring geometric distances, and identifying optimum choices for each attribute. Normalization is often required in MCDM problems due to incompatibilities in attributes or criteria. The TOPSIS methodology enables compensatory solutions by balancing one attribute's negative im-

pact with another's positive outcome [19].

Pakistan faces significant concerns regarding air pollution and the formation of brown fog [21] recommended water spraying as an effective way to eliminate pollution from waste chemicals and pushed for the use of emerging methods such as DME, gas to liquid, and liquid air to preserve the atmosphere. Mumtaz *et al.* [22] focused on how atmospheric O₃ as well as PM_{2.5} particles affected lung and cardiovascular deaths in Pakistan. It stressed how important it is to improve the condition of the atmosphere. Naveed and Khayyam [23] investigated that children in Lahore had trouble with their brain function because of the polluted air. They do poorly in activities that require mental attention and retention of information.

Khan *et al.* [24] applied MCDM techniques DEMATEL and Fuzzy-TOPSIS to investigate how brick kilns in Pakistan affected the natural world and individual's well-being. Poverty and malnutrition are problems around the globe, and contamination, particularly in Asia, has made them more serious. Using equipment and guns in battle made climate change worse. Combating pollutants requires putting safety first, finding solutions to electricity problems, and working together with other countries [25]. Wang *et al.* [26] illustrated the importance of combining road temperatures and ecological data and working together to improve robustness against weather hazards in the field of transportation.

Due to the effects of the China-Pakistan Economic Corridor (CPEC), smog, and vehicles, global warming has created serious dangers to crops, especially in Pakistan. As such, effective early illness detection and constant surveillance were required. Researchers examined polluted air, health, atmosphere, transportation, and learning in Pakistan using Fuzzy VIKOR. Ali *et al.* [27] suggested preventative measures and ecologically beneficial strategies. Jabeen *et al.* [3] employed a multivariate logistic regression model (MLRM) to investigate the impact of winter contamination on distinct careers in Lahore and its surrounding suburban regions.

The Fuzzy-VIKOR MCDM method evaluated five environmentally friendly transportation alternatives in Pakistan, highlighted cycling as the most economical and environmentally friendly option, and recommended politicians and government involvement [28]. The Pakistani government has implemented environmentally friendly automobiles to address smog pollutants, driven by variables such as awareness of smog, alleged health risks, and an appetite to spend money [29]. Anjum *et al.* [30] evaluated Pakistan's atmosphere, highlighted the physiological and financial impacts of global airborne pollutants, and emphasized the need for improved monitoring methods, regulations, and collaboration between sectors.

Mangotra and Singh [2] examined the harmful effects of VOCs, highlighting their excessive use, lack of biodegradability, and environmental deterioration. It emphasized the importance of environmental organizations safeguarding ecosystems and comprehended their impacts. Wang *et al.* [31] focused on enhanced MCDA utilization in energy-efficient DM and focused on criteria selection, weighting, evaluation, and overall aggregate, with investment expenses and carbon dioxide emissions being crucial. Anwar *et al.* [32] examined pollutants in South Asian countries, focused on India, China, and Pakistan, highlighted socio-economic impacts, health consequences, and legislative deficiencies, and recommended tailored strategies.

In this article, using MEREC, BWM, ENTROPY, and TOPSIS methods a hybrid MCDM technique is proposed. By combining, the first three methods we address the limitations of single weighting methods. Each of these methods captures different aspects of criteria importance—MEREC focuses on

criteria redundancy, Best Worst Method on expert judgment, and Entropy on data-driven analysis. This comprehensive approach provides a more robust and balanced weighting scheme. The integration of TOPSIS for contrasting alternatives against an ideal choice enhances the evaluation process. By establishing a clear structure for comparison, the proposed hybrid method reduces ambiguity in ranking alternatives, leading to more accurate and reliable decision-making. The approach not only provides a clear ranking of alternatives but also ensures that the criteria weighting is reflective of both expert opinions and objective data, addressing gaps in decision-support tools that rely on a single perspective. The flexibility of the proposed method to incorporate different criteria and alternatives makes it applicable to handle complex decision problems involving numerous criteria and alternatives, which might be challenging for traditional MCDM approaches. This complexity handling is crucial for decision-makers facing multifaceted issues in real-world scenarios.

3. Mathematical Model for Decision-making

The multi-criteria decision-making methodology is based on the following steps.

Step 1: The decision matrix, a $n \times m$ matrix with m criteria and n alternatives, is constructed by assigning performance values to each row and column, denoted by x_{ij} .

Step 2: The decision matrix has been standardized. We used the following formula to standardize the decision matrix:

$$z_{ij}^x = \begin{cases} \frac{\min_k x_{kj}}{x_{ij}} & \text{if } j \in M \\ \frac{x_{ij}}{\max_k x_{kj}} & \text{if } j \in D \end{cases} \quad (1)$$

The DM process is influenced by a set of beneficial criteria (M) and non-beneficial criteria (D) refers to the factors that influence the DM process.

Step 3: Evaluate the alternative's overall performance ρ_i .

$$A_i = \ln\left(1 + \left(\frac{1}{m} \sum_j |\ln(z_{ij}^x)|\right)\right) \quad (2)$$

Step 4: The performance of the alternatives is ascertained by removing each criterion $\rho_{ij'}$.

$$\rho_{ij'} = \ln\left(1 + \left(\frac{1}{m} \sum_{k, k \neq j} |\ln(z_{ik}^x)|\right)\right) \quad (3)$$

Step 5: Determine the sum of the absolute deviation (H_j).

$$H_j = \sum_i |\rho_{ij'} - \rho_i| \quad (4)$$

Step 6: You can determine the weights of the criteria using the following formula:

$$W_j = \frac{H_j}{\sum_k H_k} \quad (5)$$

Step 7: To find the best and worst criteria, we used MEREC weights that were calculated in step 6.

Step 8: The pairwise comparison vector compares the best and worst criteria on a scale of 1 to 9.

Step 9: We have used the entropy technique to normalize the best and worst criteria.

$$u_{ij} = \frac{v_{ij}}{\sum_{j=1}^n v_{ij}} \quad (6)$$

Step 10: We compute entropy using the following formula:

$$e_{bw} = -R \sum_{j=1}^n f_{ij} \ln f_{ij} \quad (7)$$

where $-R = \frac{1}{\ln a}$

a indicates the number of alternatives.

Step 11: Determining the best criteria weights.

$$w_b = \frac{1 - e_b}{(1 - e_b) + (1 - e_w)} \quad (8)$$

Step 12: Calculating the weights for the worst criteria.

$$w_w = \frac{1 - e_w}{(1 - e_w) + (1 - e_b)} \quad (9)$$

Step 13: The BWM proposes a consistency ratio to evaluate the validity of the comparisons.

$$CR = \frac{\epsilon}{CI} \quad (10a)$$

$$\epsilon = \left| \frac{w_b - e_b}{e_b} \right| \quad (10b)$$

$$\epsilon = \left| \frac{w_w - e_w}{e_w} \right| \quad (10c)$$

$$CI = a_{bw} \quad (10d)$$

Step 14: We have used the TOPSIS technique to normalize the decision matrix. Out of the 7 alternatives and 5 criteria, we only have to consider the best and worst criteria.

$$\bar{b}_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^n (x_{ij})^2}} \quad (11)$$

Step 15: Equation 12 is used to create weighted normalized decision data by multiplying the columns of \bar{b}_{ij} by the allocated weights.

$$g_{ij} = w_b \times \bar{b}_{ij} \quad (12)$$

$$g_{ij} = w_w \times \bar{b}_{ij}$$

Step 16: The ideal best and worst values for the best and worst criteria should be determined as:

$$C^+ = [g_1^+, g_2^+, \dots, g_j^+, \dots, g_n^+] \quad C^- = [g_1^-, g_2^-, \dots, g_j^-, \dots, g_n^-] \quad (13)$$

g_j^+ and g_j^- are the best and worst values of the j criteria. where $j=1, 2, \dots, n$.

Step 17: Calculate the ideal best K_i^+ and ideal worst K_i^- Euclidean distance.

$$K_{i-} = \sqrt{\sum (g_{ij} - g_{j-})^2} \quad K_{i+} = \sqrt{\sum (g_{ij} - g_{j+})^2} \quad (14)$$

Step 18: Calculate the Multiple Composite Score (MCS) N_i values for each alternative.

$$N_i = \frac{K_{i-}}{K_{i-} + K_{i+}} \quad (15)$$

After ranking the alternatives, we arrange the multiple composite scores obtained in descending order.

4. Application of Decision-Making Methodology on Smog in Pakistan

In this section, we have applied MCDM techniques and utilized data from the questionnaire intended for Exploring Stakeholder Perceptions of Smog Factors in Pakistan: Implications for Health, Economy, and Society. Criteria are given in Table 1.

Table 1
 Criteria for Exploring Stakeholder Perceptions of Smog Factors in Pakistan

Criteria	Indicator	Objective
C_1 : Causes of Smog in Pakistan	Vehicle emissions, agricultural practices, electricity generation, deforestation, brick kilns, incineration of waste	To identify the primary sources of pollutants contributing to smog in Pakistan.
C_2 : Health Impact of Smog in Pakistan	Respiratory issues, cardiovascular health, skin irritation, eye irritations, aggravation of existing conditions, and increased mortality rates	To ensuring a comprehensive assessment of the health risks associated with smog
C_3 : Economic Impact of Smog in Pakistan	Increased health care costs, effect on work efficiency, business disruptions, agricultural losses, increased energy costs, and tourism decline	To identify the multifaceted economic burdens imposed by smog, providing insight into both direct and indirect costs.
C_4 : Social Impact of Smog in Pakistan	Impact on outdoor activities, impact on social events, disruption of daily activities, economic inequality, psychological stress, and education-related problems	To address the less tangible but equally important social consequences, such as psychological stress and disruptions to education
C_5 : Environmental Impact of Smog in Pakistan	Ecosystem damage, deterioration of air quality, climate change, impact on agricultural productivity, depletion of ozone, and formation of acid rain	To capture the long-term environmental damage caused by smog, including both local and global effects
C_6 : Mitigation Strategies for Smog in Pakistan	Promotion of public transportation, adoption of renewable energy sources, agricultural practices and crop residue management, afforestation and ecological areas, renovation of brick kilns, and waste management and recycling	To represent actionable steps that can be taken to reduce smog, targeting the root causes identified in the earlier criteria.

The nine alternatives for the above criteria are:

- A_1 : Agricultural Practice Reforms
- A_2 : Transition to Renewable Energy
- A_3 : Afforestation and Reforestation Programs
- A_4 : Urban Green Space Expansion
- A_5 : Public Transportation Improvement
- A_6 : Industrial Emission Control
- A_7 : Strict Vehicle Emission Regulations
- A_8 : Public Awareness and Education Campaigns
- A_9 : Waste Management and Recycling Initiatives

Step 1: The linguistic terms in the questionnaire responses were assigned numerical values: strongly agree (9), agree (8), somewhat agree (7), slightly agree (6), neutral (5), slightly disagree (4), somewhat disagree (3), disagree (2), strongly disagree (1). The responses are analyzed using the Excel solver algorithm COUNTIF for each criterion. The responses are presented in Table 2. Select $C_1, C_2, C_3, C_4,$

and C_5 as non-beneficial criteria, denoted as $C_i(D)$, and C_6 as beneficial criteria, denoted by $C_i(M)$.

Table 2
 Smog in Pakistan: responses.

Alternatives	$C_1(D)$	$C_2(D)$	$C_3(D)$	$C_4(D)$	$C_5(D)$	$C_6(M)$
A_1	66	64	39	42	72	72
A_2	86	93	95	87	91	86
A_3	24	18	19	28	19	16
A_4	16	19	25	18	16	18
A_5	20	21	32	30	17	26
A_6	6	1	5	7	3	3
A_7	3	9	3	5	1	5
A_8	6	7	13	12	10	7
A_9	7	2	3	5	5	1

Step 2-3: Normalization and overall performance of the alternatives are evaluated by using Equations 1 and 2 and depicted in Table 3.

Table 3
 Overall performance of the alternatives.

Alternatives	C_1	C_2	C_3	C_4	C_5	C_6	ρ_i
A_1	0.767	0.688	0.411	0.483	0.791	0.014	0.755
A_2	1.000	1.000	1.000	1.000	1.000	0.012	0.555
A_3	0.279	0.194	0.200	0.322	0.209	0.063	0.981
A_4	0.186	0.204	0.263	0.207	0.176	0.056	1.030
A_5	0.233	0.226	0.337	0.345	0.187	0.038	0.983
A_6	0.070	0.011	0.053	0.080	0.033	0.333	1.351
A_7	0.035	0.097	0.032	0.057	0.011	0.200	1.391
A_8	0.070	0.075	0.137	0.138	0.110	0.143	1.172
A_9	0.081	0.022	0.032	0.057	0.055	1.000	1.279

Step 4: The performance of alternatives by eliminating each criterion governed by Equation 3 are illustrated in Table 4.

Table 4
 The values of ρ_{ij} .

Alternatives	C_1	C_2	C_3	C_4	C_5	C_6
A_1	0.734	0.725	0.683	0.696	0.737	0.347
A_2	0.555	0.555	0.555	0.555	0.555	0.000
A_3	0.898	0.873	0.875	0.907	0.878	0.791
A_4	0.925	0.931	0.947	0.932	0.921	0.841
A_5	0.888	0.886	0.913	0.914	0.873	0.756
A_6	1.229	1.133	1.215	1.236	1.192	1.303
A_7	1.242	1.290	1.237	1.265	1.184	1.322
A_8	1.024	1.029	1.064	1.064	1.051	1.066
A_9	1.155	1.083	1.104	1.137	1.135	1.279

Step 5-7: The absolute deviation (see Equation 4) and weights (see Equation 5) are calculated for each criterion and presented in Table 5. The weight of criterion C_6 is higher than the others while the weight of criterion C_4 is less than the others. Therefore, C_6 is selected as the best criterion and C_4 as the worst.

Table 5
 Weight calculation using MEREC.

Alternatives	C_1	C_2	C_3	C_4	C_5	C_6
A_1	0.767	0.688	0.411	0.483	0.791	0.014
A_2	1.000	1.000	1.000	1.000	1.000	0.012
A_3	0.279	0.194	0.200	0.322	0.209	0.063
A_4	0.186	0.204	0.263	0.207	0.176	0.056
A_5	0.233	0.226	0.337	0.345	0.187	0.038
A_6	0.070	0.011	0.053	0.080	0.033	0.333
A_7	0.035	0.097	0.032	0.057	0.011	0.200
A_8	0.070	0.075	0.137	0.138	0.110	0.143
A_9	0.081	0.022	0.032	0.057	0.055	1.000
H_j	0.8482	0.9936	0.9048	0.7905	0.9731	1.7927
W_j	0.1346	0.1576	0.1436	0.1254	0.1544	0.2844

Step 8-12: Best to other vector B_V and others to worst vectors W_V , their normalized form, entropy, and weights are computed in Table 6.

Table 6
 Best Worst Method Using Entropy Weights.

Criteria	B_V	W_V	u_i	u_j	e_b	e_w	w_b	w_w
C_1	7	6	0.233	0.207	0.155	0.148		
C_2	4	5	0.133	0.172	0.122	0.138		
C_3	6	7	0.200	0.241	0.146	0.156		
C_4	8	1	0.267	0.034	0.160	0.053		
C_5	4	2	0.133	0.069	0.122	0.084		
C_6	1	8	0.033	0.276	0.052	0.162		
Total	30	29			0.758	0.741	0.483	0.517

Step 13: To calculate consistency, use Equation 10. The consistency ratio of the best and worst criteria is 0.08 and 0.07, respectively, as shown in Table 7.

This suggests a high level of consistency. Next, we employ the TOPSIS technique to determine the ideal alternative from a collection of choices by evaluating their resemblance to an ideal answer.

Table 7
 Consistency Ratio.

	Best	Worst
CI	4.47	4.47
CR	0.08	0.07

Step 14-16: TOPSIS method is used to normalize best and worst criteria. The ideal best and worst values for the best and worst criteria are given in Table 8.

Table 8
 Weighted normalized decision data.

Alternatives	BC C_6	WCC $_4$	BC b_{ij}	WC b_{ij}	w_b *normalized	w_w *normalized
A_1	72	42	0.0052	0.0036	0.0025	0.0019
A_2	86	87	0.0062	0.0075	0.0030	0.0039
A_3	16	28	0.0011	0.0024	0.0006	0.0013
A_4	18	18	0.0013	0.0016	0.0006	0.0008
A_5	26	30	0.0019	0.0026	0.0009	0.0013
A_6	3	7	0.0002	0.0006	0.0001	0.0003
A_7	5	5	0.0004	0.0004	0.0002	0.0002
A_8	7	12	0.0005	0.0010	0.0002	0.0005
A_9	1	5	0.0001	0.0004	0.0000	0.0002
g_j^+					0.0030	0.0002
g_j^-					0.0000	0.0039

Step 17-18: The ideal best and ideal worst Euclidean distance and multiple composite scores (MCS) of alternatives are given in Table 9. Ranks are assigned based on MCS. The alternative A_1 with MCS 0.6487 is ranked 1.

Table 9
 Multiple composite scores.

Alternatives	K_i^-	K_i^+	$K_i^- + K_i^+$	N_i	Rank
A_1	0.0032	0.0017	0.0049	0.6487	1
A_2	0.0030	0.0037	0.0066	0.4462	9
A_3	0.0027	0.0026	0.0053	0.5045	8
A_4	0.0031	0.0024	0.0056	0.5635	3
A_5	0.0027	0.0024	0.0051	0.5323	7
A_6	0.0036	0.0029	0.0065	0.5535	5
A_7	0.0037	0.0028	0.0065	0.5659	2
A_8	0.0034	0.0028	0.0061	0.5487	6
A_9	0.0037	0.0030	0.0066	0.5538	4

5. Conclusion

Pakistan faces a persistent threat from smog due to industrialization, fossil fuel reliance, and automobile emissions. This issue poses risks to humans and plants contributing to global health issues and negatively impacting sectors like health, ecology, transportation, and education. This research uses MCDM techniques and data from a questionnaire to explore stakeholder perceptions of smog factors in Pakistan. The analysis is based on six criteria including causes of smog, health impact, economic impact, social impact, environmental impact, and mitigation strategies. The linguistic terms in the responses were assigned numerical values. The results were analyzed using the Excel solver algorithm COUNTIF for each of the six criteria. The objective weighting technique MEREC was used to select the best and worst criteria. The current study conducted a comprehensive multi-criteria decision-making (MCDM) analysis to address the pressing issue of smog in Pakistan. Among the six criteria evaluated, Mitigation Strategies for Smog in Pakistan (C_6) emerged as the most critical, reflecting the urgent need for effective interventions to combat smog. Conversely, the Social Impact of Smog in Pakistan (C_4) was ranked as the least critical criterion, suggesting that social impacts, while significant, may be perceived

as less immediately actionable compared to other factors.

The study employed the entropy method for normalization, enabling an objective calculation of entropy and the determination of criterion weights. The analysis discovered a weight of 0.483 for the best criterion (C_6), showing its substantial importance in the overall evaluation framework. In contrast, the worst criterion (C_4) was assigned a weight of 0.517. The consistency ratios of 0.08 and 0.07 for the best and worst criteria, respectively, confirm the robustness and reliability of the weighting process. To further improve the decision-making process, the study employed the TOPSIS technique, a widely recognized method for ranking alternatives based on their proximity to an ideal solution. By calculating Euclidean distances, the study determined the ideal best and worst values for each alternative. These values were then used to rank the alternatives according to their multiple composite scores (MCS), providing a clear and quantifiable basis for decision-making. The alternative Agricultural Practice Reforms (A_1) was ranked first, with an MCS of 0.6487, underscoring its potential as the most effective strategy for mitigating smog in Pakistan. This finding highlights the critical role that changes in agricultural practices can play in reducing smog, given the significant contribution of agricultural activities to air pollution. The study's findings offer valuable insights for policymakers, supporting them in prioritizing strategies that not only address the environmental and health impacts of smog but also consider the economic and social dimensions of this complex issue.

The proposed approach is more effective than the previously defined MCDM methods. But it also has certain limitations, for instance, the proposed method might be less effective in cases where criteria and alternatives are subject to frequent changes. The combination of techniques may not be easily adaptable to rapidly evolving scenarios, requiring recalculations and adjustments that could be time-consuming. However, developing software tools or decision-support systems that automate the complex processes involved in the proposed hybrid MCDM method could make it more accessible to a wider range of users. Future work could discover methods to adaptively update criteria weights in real time as new information becomes accessible. This would make the approach more flexible and responsive to changing environments, enhancing its applicability in dynamic decision-making scenarios. Integrating machine learning techniques to optimize the selection and weighting of criteria could further improve the accuracy and efficiency of the decision-making process. For example, machine learning models could be trained to predict the best and worst criteria based on historical data, reducing reliance on expert judgment.

Conflicts of Interest

The authors declare no conflicts of interest.

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