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Application of AHP-TOPSIS for determining priority solutions in provincial air quality management: A case study of Vinh Phuc province, Vietnam

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Abstract: *Vinh Phuc Province is experiencing increased air pollution due to rapid urbanization and industrialization, with industrial activities and traffic being the primary contributors. To achieve sustainable economic growth, it is essential to propose effective air pollution control strategies that align with the province's socioeconomic development status and budget. These methods should also be prioritized to enable authorities in Vinh Phuc to make urgent decisions while formulating a long-term strategy for effective air quality management (AQM). This study aims to develop a method for determining priority solutions for AQM in Vinh Phuc Province, Vietnam, by applying the AHP-TOPSIS multi-criteria analysis method (Analytic Hierarchy Process - Technique for Order of Preference by Similarity to Ideal Solution). The AHP method is utilized for pairwise comparison to establish a criteria set for evaluating priority solutions. TOPSIS is then applied to rank AQM solutions based on their proximity to ideal positive and negative alternatives using closeness coefficients. The proposed solutions, classified into four groups - management, technical, economic, and communication - are based on emission sources. The primary criteria for Vinh Phuc Province include community health (weight 0.20), emission and greenhouse gas reduction potential (0.15), and investment cost (0.13). Results indicate that management and technical solutions are the priority AQM methods, as they offer high feasibility and address the province's urgent needs. These findings align with the current status of AQM and the socio-economic development goals of Vinh Phuc Province.*
Keywords: *Priority solution; Air quality management; AHP-TOPSIS; Multi-criteria analysis method; Vinh Phuc Province*

1. Introduction

Air quality is becoming a primary concern in many major cities worldwide, including Vietnam. Air pollution not only impacts public health but also hinders sustainable economic development. To effectively manage air quality, it is crucial not only to identify the causes of air pollution and propose mitigation solutions, but also to recommend and prioritize management solutions for air quality that align with (i) the socio-economic development context, (ii) investment attraction policies, (iii) the budget of each locality, and (iv) sustainable development goals.

To determine priority solutions in AQM, MCDM (Multi-Criteria Decision-Making) methods are widely utilized in many countries worldwide. Techniques such as ELECTRE (ELimination Et Choix Traduisant la REalite), SAW (Simple Additive Weighting), VIKOR (Vise Kriterijumska Optimizacija I Kompromisno Resenje), AHP, and TOPSIS are frequently applied in research. Specifically, the TOPSIS method was employed to assess urban air quality [4], and the fuzzy AHP-TOPSIS method was applied to control noise pollution at the Abadan refinery in Iran [13]. In Vietnam, MCDM methods have also been widely applied across various environmental fields, such as water management, biodiversity conservation, and climate change. For instance, the research employed AHP-VIKOR to evaluate the ecotourism potential in Dak Lak Province [2]. Similarly, another research utilized AHP-TOPSIS to develop an integrated multi-criteria decision-making model for classifying green suppliers [1] and the AHP-TOPSIS was applied to prioritize and identify restoration measures for wetland ecosystems in the Dong Thap Muoi region [12]. In the field of AQM, several studies have incorporated MCDM methods. For example, the AHP was used to propose climate change adaptation solutions for agriculture in Ho Chi Minh City [5]. Meanwhile, AHP-SAW was employed to establish indicators and indices for evaluating carbon emissions in the Trang Bang industrial park in Tay Ninh [11]. These examples highlight that there are currently very few studies applying

MCDM methods specifically in AQM in Vietnam, and no research has yet focused on identifying priority AQM solutions domestically. Policy-makers often prioritize AQM solutions based solely on cost-benefit analyses, overlooking other critical factors. As a result, implemented solutions typically fulfill economic criteria, particularly financial considerations, without adequately addressing the interrelationship between economic, environmental, and social criteria.

In this paper, aiming to identify priority solutions for air quality management, the study applies a combined AHP-TOPSIS approach to develop criteria and recommend priority solutions in air quality management. This approach ensures a balance among local economic, social, and environmental factors, aligning with sustainable development goals.

According to Nguyen Viet Vu and colleagues [6], air quality in Vinh Phuc Province is heavily polluted due to industrialization and urbanization. Studies indicate that Vinh Phuc is affected by pollution from industrial production, transportation, residential activities, and the burning of straw. Specifically, the primary pollution source is road traffic, with emissions predominantly from vehicles such as motorcycles, cars, buses, and heavy trucks - especially motorcycles, which contribute 90% of total emissions. Next are point sources, notably from the province's key industries, such as iron and steel manufacturing, automobile and motorcycle production, and building materials manufacturing. Finally, area sources include household activities like fuel burning for cooking, waste burning, and straw burning. The area with the highest pollution risk is Vinh Yen City, where industrial zones and urban areas are densely concentrated, leading to high traffic volumes from transport vehicles.

Based on the causes of air pollution identified by Nguyen Viet Vu and colleagues [6], this study proposes solution groups to effectively control air quality in Vinh Phuc. These solutions are categorized into four main groups: management, technical, economic, and communication solutions. Additionally, study the combined usage of the AHP-TOPSIS method to identify priority solutions for air quality control in Vinh Phuc.

2. Method

This study was conducted using the following methods: (i) The AHP method to determine the weight of evaluation criteria; (ii) The TOPSIS method to rank priority solutions for air pollution control; (iii) expert elicitation to compare the importance levels of the criteria and solutions; and (iv) data collection, statistical methods, etc., to propose air quality management solutions, calculate criterion weights, and rank air pollution control solutions.

The AHP-TOPSIS based process to determine priority solutions for air quality management in Vinh Phuc Province (Fig. ***1***) consists of three main stages: (i) Data collection and analysis; (ii) Determination of criterion weights using AHP; (iii) Ranking and identifying priority solutions for air quality management using TOPSIS. In the first stage, data to be collected and analyzed include the number of solutions and expert consultation survey responses. The consultation form consists of two parts: (i) Determining criterion weights by pairwise comparison of main and sub-criteria using the Saaty scale, and (ii) Rating the priority of solutions based on criteria using a Likert scale from 1 to 5. The study surveyed the opinions of 55 experts based on four criteria: (1) Expertise: Experts were required to possess extensive knowledge and practical experience in the environmental field, be employed at government agencies, or be engaged in teaching or research at universities, with a minimum educational qualification of a Master's degree. (2) Diversity of Perspectives: The study ensured the participation of experts from various fields to comprehensively reflect economic, social, and environmental factors. (3) Representativeness: The number of experts (ranging from 30 to 50) was deemed sufficient to ensure reliability and comprehensiveness, as supported by the studies of Xu & Yang (2001) [9] and Sekizaki et al. (2019) [8]. (4) Objectivity: Experts' evaluations were required to remain unbiased, free from the influence of personal or group interests, to avoid distorting the results. However, this method has certain limitations, such as its dependence on the perspectives and expertise of individual experts, which can lead to bias if the selection is inappropriate or fails to ensure representativeness in the survey sample. The findings of expert consultations were examined, collated, and utilized to create computation matrices that determined criterion weights and ranked priority air pollution mitigation strategies.

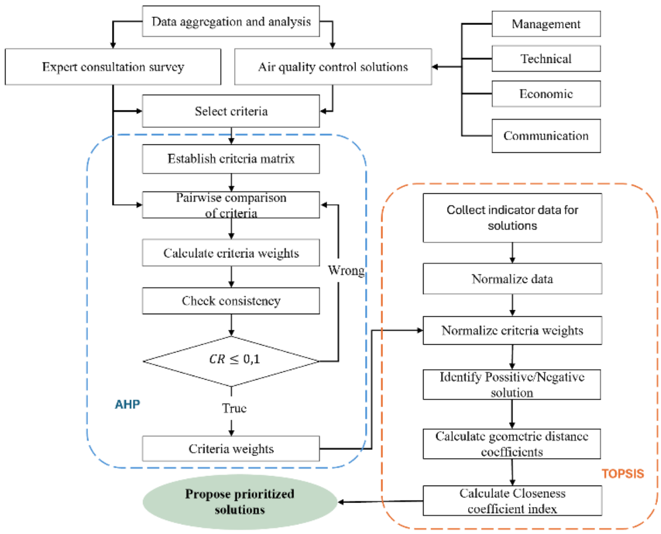

Fig. 1. The process of evaluating and determining priority solutions for AQM in Vinh Phuc province using the combined AHP-TOPSIS method

2.1. AHP method

The study employs the AHP method developed by Thomas L. Saaty [6] to determine the weights of criteria. These criteria are constructed based on two fundamental factors: the principle of criteria development and the structural framework. Specifically, the study adopts the sustainable development indicator principles of (1) the United Nations, aligned with the national sustainable development orientation under Decision No. 985a/QĐ-TTg by the Prime Minister, which approves the National Action Plan on Air Quality Management up to 2020 with a vision toward 2025, and (2) a thematic framework for criteria construction. Accordingly, the criteria are organized into two levels: main criteria and sub-criteria. The main criteria include economic, environmental, and social factors, while sub-criteria are derived from these main categories, as detailed in Tab. ***1***.

Tab. 1. Criteria for evaluating priority solutions in air quality control management based on thematic framework

Main criteria	Sub-criteria	Symbol	Definition
Environmental	Emission and greenhouse gas reduction potential	MC1	Evaluate the solution's capacity for reducing air pollution to ensure pollutant levels meet QCVN 05:2023/BTNMT standards.
	Energy and fuel consumption savings	MC2	Assess the energy and fuel consumption savings achievable through the solution
	Alignment with air quality management objectives	MC3	The proposed solution must meet the air quality management objectives of the area/province.
Economic	Investment cost	KC1	Evaluate whether the investment cost of the solution is reasonable and aligns with the local budget.
	Growth rate (GDP)	KC2	Assess the solution's contribution to the local economic growth rate; the implementation should promote or sustain the region's economic development.
	Attraction of foreign direct investment (FDI)	KC3	Evaluate the solution's potential to attract foreign direct investment (FDI), contributing to the region's economic growth.

Main criteria	Sub-criteria	Symbol	Definition
	Growth in the clean energy market	KC4	Assess the potential for economic growth in the clean energy market, in alignment with the region's green economic development goals.
Social	Community health	XC1	Evaluate the solution's impact on public health, particularly its effectiveness in reducing respiratory diseases.
	Employment opportunities	XC2	Assess the potential for job creation when implementing the solution, including maintaining or increasing income levels for local residents.
	Public consensus	XC3	Measure the level of public support and willingness to participate in the solution's implementation.

Figure 2 shows a hierarchical system of criteria and solutions for air quality control, with the primary objective being air quality management in the study area. At level 1, the main criteria include Environment, Economy, and Society. Level 2 consists of sub-criteria that further break down each primary criterion, while level 3 includes four solution groups: management, technical, economic, and communication solutions. The AHP method is applied to pairwise comparisons among criteria at Levels 1 and 2.

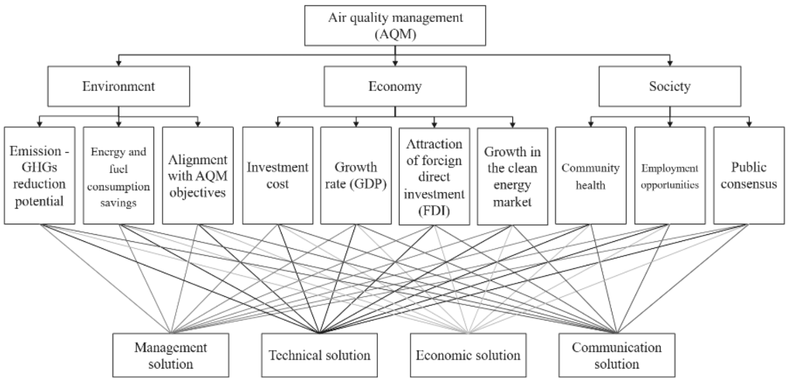

Fig. 2. The hierarchical diagram of criteria and proposed solutions.

The AHP method is applied to determine criterion weights by conducting pairwise comparisons and assessing the consistency of evaluations regarding the importance of each criterion relative to the desired objective. The comparisons are conducted in pairs and aggregated into a matrix as shown in formula (1), with n columns and n rows (n: the number of criteria), where a_{ij} represents the importance of criterion i relative to criterion j. When comparing the inverse pair, criterion j with criterion i, the relationship is defined by aij = 1/aji. The importance of each criterion pair is determined using Saaty's rating scale from 1 to 9 [7]. After the expert evaluations, weights were calculated by normalizing the geometric mean of the scores using the Geometric Mean Method, as shown in Equation (2) [10]. Here, X_i (where i = 1,2, …) represents the weight of each criterion; a_{ij}: the pairwise comparison value of each criterion by row; n: the total number of evaluation criteria. Then, determine the weight W by normalizing the mean product using formula (3).

$$A = (a_{ij})_{nxn} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} \quad (1)$$

$$X_i = \sqrt[n]{\prod_{j-1}^{n} a_{ij}} \quad (2) \qquad W = \left(\frac{X_1}{\sum X} + \frac{X_2}{\sum X} + \cdots + \frac{X_n}{\sum X}\right) \quad (3)$$

AHP assesses the consistency of pairwise comparisons made by experts through the consistency ratio (CR), calculated using formulas (4) and (5) [7], where CI is the consistency index, and RI is the random index, with reference values provided in Tab. **2**. Here, n represents the number of criteria in matrix A. If CR<0.1, the pairwise comparison matrix is considered consistent, and the criterion weights are accepted to proceed to the next calculation step.

$$CR = \frac{CI}{RI} \quad (4) \qquad CI = \frac{\lambda_{max} - n}{n - 1} \quad (5)$$

***Tab. 2.** Random index values (RI)*

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45

TOPSIS method

The TOPSIS method is a multi-criteria decision-making approach introduced by Hwang and Yoon (1981) [3]. The method is applied to rank solutions by evaluating each solution's proximity to the positive ideal solution and the negative ideal solution. The calculation data include criterion weights and expert consultation results on prioritizing solutions based on a Likert scale evaluation of the criteria. The specific solutions, presented in Tab. **3**, are proposed based on the causes of air pollution in Vinh Phuc Province [6]. The data are aggregated and normalized into a matrix. Subsequently, the geometric distance coefficients between each solution and both the positive and negative ideal solutions are calculated according to formulas (6) and (7), where d^+ represents the distance from the solution to the positive ideal solution, d^- is the distance to the negative ideal solution, r represents benefit and cost attributes, and W: criterion weights. Finally, the Closeness Coefficient Index (CI) for each solution is computed using formula (8) to measure proximity to the ideal solutions. Solutions are then ranked in descending order based on their CI values; the higher the CI value of a solution, the closer it is to the positive ideal solution and thus is identified as the priority solution.

$$d^+ = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_{ij}^+\right) = \sqrt{\sum_{j=1}^{n} \left((r \times W)_{ij} - (r \times W)_j^+\right)^2} \quad (6)$$

$$d^- = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_{ij}^-\right) = \sqrt{\sum_{j=1}^{n} \left((r \times W)_{ij} - (r \times W)_j^-\right)^2} \quad (7)$$

$$CI_i = \frac{d^-}{d^- + d^+} ;\ 0 \le \mathrm{CI} \le 1 \quad (8)$$

***Tab. 3.** Proposed AQM solutions for Vinh Phuc province*

No.	**Group of solutions**	**Specific solutions**	**Symbol**
1	Management	**Planning integrated infrastructure and transportation** (industrial zones, craft villages, construction, transportation, etc.), relocating polluting facilities away from residential areas.	Q1
2		**Clearly assigning environmental protection responsibilities** to management agencies. Strengthening environmental inspections and monitoring, controlling air pollution from transportation, industry, and area sources (e.g., prohibiting parking, banning expired vehicles, reducing factory emissions, straw burning, etc.).	Q2

No.	Group of solutions	Specific solutions	Symbol
3		**Establishing policy mechanisms** that encourage the use of clean fuels. Developing public transportation and green transportation options (metro, clean buses, electric vehicles, bicycles, etc.).	Q3
4		**Modernizing the air quality monitoring system** and establishing a data transmission system for air quality monitoring.	Q4
5	Technical	**Transitioning to clean fuel usage** and implementing new environmentally friendly production technologies in transportation, industry, and residential activities.	Y1
6		**Treating emissions to meet standards** and installing continuous automatic monitoring systems, while promoting the reuse of straw for biochar production or mushroom cultivation.	Y2
7		**Controlling dust emissions** during material transportation and construction activities.	Y3
8	Economic	**Implementing parking fees and congestion charges** and providing subsidies for public transportation services.	K1
9		**Prioritizing the development of green and clean industries** through investment attraction initiatives.	K2
10		**Developing afforestation projects** and promoting carbon credit trading.	K3
11	Communication	**Training and enhancing knowledge and skills** for personnel involved in air quality management. Strengthening cooperation and experience sharing in air quality management with international organizations.	T1
12		**Increasing the dissemination and sharing of air quality monitoring data** with the community.	T2
13		**Developing a communication strategy** to raise public awareness about the impacts of air pollution and the environment.	T3

3. Results and discussion

3.1. Results of Determining Criterion Weights

The study identified the weights of criteria in urban environmental quality management in Vinh Phuc Province. The results are shown in Table 4.

Tab. 4. Weight of criteria for evaluating priority solutions for air quality management of Vinh Phuc province

Sub- criteria	Criteria weight
Community health	0.20
Emission and greenhouse gas reduction potential	0.15
Investment cost	0.13

Sub- criteria	Criteria weight
Alignment with air quality management objectives	0.12
Public consensus	0.08
Growth rate (GDP)	0.08
Attraction of foreign direct investment (FDI)	0.07
Energy and fuel consumption savings	0.06
Growth in the clean energy market	0.06
Employment opportunities	0.05

The criterion with the highest weight is *Community Health*, followed by *Emission and greenhouse gas reduction potential*. The criterion *Investment Cost* ranks third, while *Alignment with Air Quality Management Objectives* is fourth. The ranking results of criterion weights highlight that community health is the top priority among the criteria, reflecting the importance of protecting public health and minimizing diseases caused by air pollution as a key objective in air quality management. In addition, the potential to reduce emissions, improve environmental quality, and decrease greenhouse gas emissions to mitigate the long-term impacts of climate change is also a very important criterion in air quality management. The results also indicate that, for effective air quality management, it is essential to consider the cost of implementing air pollution mitigation measures that align with the local air quality management goals and are suitable for the local budget allocated for environmental protection in general and air quality management specifically.

The mid-level criteria groups include: (1) *public consensus*, which reflects the level of public interest and agreement with air pollution mitigation solutions when implemented by government levels; (2) *growth rate (GDP)*, which shows the impact of air pollution mitigation solutions on the GDP growth rate of Vinh Phuc Province, with these solutions potentially acting as either a driver or inhibitor of sustainable local economic development; and (3) *Attraction of foreign direct investment (FDI)*, which reflects the ability to attract foreign investment capital when implementing air pollution mitigation solutions in Vinh Phuc.

The criteria with the lowest weights include: (1) *Energy and fuel consumption savings*, which evaluates the level of energy and fuel savings achieved when implementing air pollution mitigation solutions in Vinh Phuc; (2) the *Growth in the clean energy market* criterion, which assesses the potential for developing clean and renewable energy (such as carbon credit trading) when applying air pollution mitigation measures; and (3) the *Employment opportunities* criterion, aimed at evaluating the potential for job creation or income increase for residents through the implementation of air pollution mitigation solutions in Vinh Phuc.

The criteria *Energy and fuel consumption savings* and *Growth in the clean energy market* have low weights, reflecting the fact that the potential for consumption and fuel savings, as well as the development of the renewable energy market, are not highly valued in the current context of Vinh Phuc province. However, although not a top priority, the development of a clean energy market remains an important long-term goal within the air quality management strategy, contributing to emissions reduction and promoting sustainable economic growth. Similarly, the low weight of the *Employment opportunities* criterion indicates that this is not a primary determining factor when selecting priority solutions. This may be because air pollution control solutions tend to be more technical and managerial rather than immediately generating large numbers of jobs.

Additionally, when evaluating individual sub-criteria within each main criteria group, the Investment cost criterion has the highest weight in the economic group; similarly, the Emission and greenhouse gas reduction potential criterion has the highest weight in the environmental group, and in the social group, the *Community Health* criterion holds the highest weight.

3.2. Results of ranking priority solutions implemented in Vinh Phuc

Tab. **5** presents the ranking results of management solutions based on the TOPSIS method, with d^+ and d^- values indicating the distance of each solution from the positive and negative ideal solutions. The Closeness Coefficient Index (CI) reflects the prioritization level, with higher CI values indicating higher priority.

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Tab. 5. *Priority ranking and closeness coefficient index (CI) of solutions for Vinh Phuc province*

Alternatives	di+	di-	CI	Rank
Q1	0.17	0.07	0.72	1
Q2	0.16	0.06	0.71	2
Q3	0.10	0.09	0.55	8
Q4	0.12	0.07	0.62	6
Y1	0.13	0.07	0.66	5
Y2	0.14	0.06	0.69	4
Y3	0.15	0.06	0.70	3
K1	0.08	0.11	0.42	10
K2	0.12	0.07	0.62	6
K3	0.07	0.17	0.28	13
T1	0.06	0.15	0.30	12
T2	0.10	0.09	0.53	9
T3	0.06	0.14	0.31	11

Tab. ***6*** provides the names of specific priority solutions according to the ranking. Based on the TOPSIS method, the ranking of air quality management solutions in Vinh Phuc Province clearly shows the effectiveness and priority of each solution according to the CI.

Tab. 6. Priority solutions for Air Quality Management in Vinh Phuc Province

Priority solutions	Symbol	Rank
Planning integrated infrastructure and transportation (industrial zones, craft villages, construction, transportation, etc.), relocating polluting facilities away from residential areas.	Q1	1
Clearly assigning environmental protection responsibilities to management agencies. Strengthening environmental inspections and monitoring, controlling air pollution from transportation, industry, and area sources (e.g., prohibiting parking, banning expired vehicles, reducing factory emissions, straw burning, etc.)	Q2	2
Controlling dust emissions during material transportation and construction activities.	Y3	3
Treating emissions to meet standards and installing continuous automatic monitoring systems, while promoting the reuse of straw for biochar production or mushroom cultivation.	Y2	4
Transitioning to clean fuel usage and implementing new environmentally friendly production technologies in transportation, industry, and residential activities.	Y1	5
Modernizing the air quality monitoring system and establishing a data transmission system for air quality monitoring.	Q4	6
Prioritizing the development of green and clean industries through investment attraction initiatives.	K2	6
Establishing policy mechanisms that encourage the use of clean fuels. Developing public transportation and green transportation options (metro, clean buses, electric vehicles, bicycles, etc.).	Q3	8
Increasing the dissemination and sharing of air quality monitoring data with the community.	T2	9

Priority solutions	Symbol	Rank
Implementing parking fees and congestion charges and providing subsidies for public transportation services.	K1	10
Developing a communication strategy to raise public awareness about the impacts of air pollution and the environment.	T3	11
Training and enhancing knowledge and skills for personnel involved in air quality management. Strengthening cooperation and experience sharing in air quality management with international organizations.	T1	12
Developing afforestation projects and promoting carbon credit trading.	K3	13

First ranked is solution Q1, with a CI of 0.72, which ranks highest, highlighting the importance of "Planning infrastructure and relocating polluting facilities away from residential areas." This approach effectively and rapidly reduces emissions from industrial facilities near residential zones, improving air quality and promoting sustainable urban development. Second ranked is solution Q2 (CI = 0.71), focused on "Assigning responsibilities and strengthening environmental inspections," emphasizing the necessity of closely monitoring and controlling pollution sources from traffic and industry to meet urgent compliance needs. The third place is solution Y3, with a CI of 0.70, prioritizes "Controlling dust during material transport and construction," aiming to reduce fine particulate matter ($PM_{2.5}$), a significant factor affecting respiratory health. Fourth place is solution Y2 (CI = 0.69), underscoring the importance of "Ensuring emissions meet standards and installing continuous automated monitoring systems." This measure guarantees that air quality indicators are monitored and managed in real-time, particularly critical in high-emission industrial areas like Vinh Phuc.

In fifth place, solution Y1 (CI = 0.66) encourages "Switching to clean fuel and adopting environmentally friendly technology," which reduces emissions from industrial and traffic sources, despite potential initial cost challenges. Tied for sixth place are solutions Q4 and K2 (CI = 0.62), which focus on "Modernizing the air monitoring system" and "Developing green industries," aligning with long-term sustainability goals and reducing emissions from industrial sources. Solutions with lower CI values, such as T1, T3, and K3, represent indirect or long-term measures, including afforestation and awareness campaigns. Although these solutions lack the immediate impact of direct management solutions, they play an important role in sustainable development strategies, particularly by raising public awareness and establishing a long-term foundation for air quality improvements.

The overall results indicate that immediate solutions with direct impacts on emission sources are prioritized highest, followed by long-term solutions. This finding aligns with the current state of air pollution and the socio-economic development orientation of Vinh Phuc Province. The results from the TOPSIS method ensure that the selected solutions are not only feasible but also effectively address the urgent needs of the locality, while also providing a foundation for long-term solutions aimed at sustaining air quality.

4. Conclusions

The study has identified priority solutions for air quality management in Vinh Phuc Province by applying the combined AHP-TOPSIS method. The criteria deemed most significant by experts for prioritizing solutions include public health, the potential for reducing emissions and greenhouse gases, and ensuring that the investment costs are compatible with the local budget. The proposed priority solutions are primarily management and technical solutions, which are highly feasible and meet the urgent needs of the province. The research findings align with the status of air quality management and the socio-economic development orientation of Vinh Phuc Province.

The AHP-TOPSIS method used in this study shows high potential for application in other regions to identify priority solutions for air quality management. This method is particularly beneficial in areas facing complex pollution issues, where an objective and comprehensive assessment system is required to select optimal solutions based on multidimensional criteria (environmental, economic, and social). AHP allows for flexible adjustment of criteria to fit the local context, while TOPSIS enables the ranking of solutions based on their proximity to an ideal solution, ensuring that the chosen solutions effectively address the specific needs of the region.

However, this method also has some limitations, such as reliance on the subjective evaluations of experts, necessitating the involvement of knowledgeable specialists about the area, which may be lacking in some localities. Additionally, the data collection and processing process can be complex, especially in resource-limited regions. Updating criteria over time is also essential to ensure that the prioritized solutions remain relevant to changes in environmental and socio-economic conditions.

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