

An evaluation of sustainable development levels in cities using multi-criteria decision-making methods: a case study of three major Vietnamese cities

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Received: 5 November 2025 / Accepted: 7 January 2026

Abstract. Evaluating and ranking the sustainability levels of cities is a complex decision-making task that plays a crucial role in supporting urban management. This study investigates the application and comparison of Multi-Criteria Decision-Making (MCDM) methods in the assessment of urban sustainability. Based on a comprehensive review of existing studies in the field of sustainable development, the research identifies prevailing trends in the use of MCDM approaches and reveals that their application in specific national contexts — particularly in Vietnam — remains limited. To address this gap, multiple MCDM techniques are applied to evaluate and compare the sustainability levels of three major Vietnamese cities — Hanoi, Can Tho, and Ho Chi Minh City — using a framework based on 17 United Nations Sustainable Development Goals (SDGs). The results are further examined through sensitivity analysis to identify key criteria influencing the evaluation outcomes and the robustness of results. The findings demonstrate that different MCDM approaches vary results due to their data-processing mechanisms and decision logic, highlighting the importance of a multi-method approach. Overall, the study provides a robust decision-support framework that can assist urban planners in promoting sustainable urban development in Vietnam and other similar contexts.

Keywords: multi-criteria decision-making (MCDM) / sustainable urban development / AHP / TOPSIS / PROMETHEE / ELECTRE

1 Introduction

Sustainable development is considered as the process of meeting present needs without compromising the ability of future generations to meet their own, requiring a balance between economic growth, social progress, and environmental protection [1]. This makes the decision-making process in sustainable projects inherently complex. To address this complexity, various multi-criteria decision-making (MCDM) methods have been applied to support sustainable development planning. The MCDM system encompasses a wide range of methods that can be broadly categorized into three groups [2]. The first group includes basic methods, which are simple in design, easy to implement, and apply linear weighting schemes (e.g., WSM, WPM); second, composite indicator-based methods rely on aggregated indicators for more systematic and transparent decision-making. The third is a group of ranking-based methods, which prioritize alternatives based

on multiple criteria. Many studies have utilized various MCDM approaches to support decision-making and evaluate sustainable development-related issues [3, 4].

On September 25, 2015, the 2030 Agenda for Sustainable Development was unanimously adopted by the United Nations. This agenda includes 17 sustainable development goals (SDGs) and 169 specific targets. It calls for global cooperation to address shared challenges, aiming for a just, prosperous, and sustainable world where no one is left behind. Vietnam has made notable progress in implementing the 2030 Agenda for Sustainable Development. According to statistics, Vietnam currently ranks 54th out of 166 countries in terms of sustainable development, a rise of 34 positions since 2016. Despite these advances, Vietnam still faces challenges such as development disparities, rapid urbanization, and environmental pressures. Therefore, evaluating and ranking the level of sustainable development of cities has become essential.

First, this study conducts a literature review of the past 10 yr to identify trends in the application of MCDM methods in sustainable development. From an initial pool of 239 relevant articles, we carefully reviewed the abstracts

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to select 92 studies focusing on the application of one of the MCDM methods relating to sustainable development projects. Based on these studies, it is evident that the application of MCDM in case studies remains relatively limited, particularly within Asian contexts (specifically with no documentation in Vietnam). Moreover, most of these studies tend to apply individual MCDM methods in isolation, without comparing or cross-validating the results across different methods. This can reduce the accuracy and objectivity of the findings and limit the persuasiveness of the conclusions.

In the second section, this study aims to address the problem of evaluating and ranking the level of sustainable development among three Vietnamese cities — Hanoi, Can Tho, and Ho Chi Minh City — by integrating two groups of MCDM methods: composite indicator-based methods and ranking-based methods. Four of the most widely used techniques are employed: AHP, TOPSIS, ELECTRE, and PROMETHEE. The study adopts 28 evaluation criteria derived from 14 SDGs and uses a scientifically validated set of weights from the study by Londoño-Pineda et al. (2021) [5]. These weights reflect the relative importance of economic, social, and environmental criteria, thereby ensuring a comprehensive and objective assessment. An empirical study was conducted to collect data from three representative cities in Vietnam. The data collection process involved synthesizing official statistical reports and local development documentation and analyzing key indicators of the selected cities. Additionally, a sensitivity analysis was conducted to verify the reliability of the results. It also served as an important tool to compare the differences in evaluation outcomes among various MCDM methods and to examine the differing impacts of each criterion on the final results. The results of this study not only reflect the current state of sustainable development but also provide strategic directions to enhance urban management effectiveness in the future.

2 Material and methods

2.1 Methodology of literature review

The search string TITLE-ABS-KEY (“multi-criteria decision-making” OR “mcdm” AND “sustain*” AND “cit*” AND “AHP” OR “TOPSIS” OR “ELECTRE” OR “PROMETHEE”) was used to find journals and conference papers in English through Beluga – UGA’s online library. Initially, 239 publications were identified, but after considering only review articles published since 2015, the number was reduced to 224. The next step involved scanning abstracts and removing duplicates to further refine the results. After the initial screening process, a total of 224 articles were included in the analysis. Of these, there are 132 review articles focusing on systematizing knowledge and 92 applied studies that implemented MCDM methods. The summary table of the reviewed articles is provided in Appendix (Tab. A1).

In terms of research levels, studies can be categorized into four distinct stages: concept, model, experiment, and evaluation [6]. At the concept stage, research papers only

present theoretical frameworks and outline general research directions based on a literature review. At the model stage, not only is the theory discussed, but the importance of evaluation criteria for the issue is also considered. In the experiment stage, alternative approaches are examined using hypothetical or real datasets to generate ranking results and select the most suitable option. Finally, at the evaluation stage, it is essential to assess the model’s results using supporting tools to verify the reliability of the dataset and enhance the scientific rigor of the study.

2.2 Multi-criteria sustainability assessment and sensitivity analysis

The following MCDM methods support the decision-making process in complex situations where multiple criteria must be considered simultaneously. In this study, we apply these four methods – AHP, TOPSIS, ELECTRE, and PROMETHEE – to evaluate and rank the sustainability levels of Vietnamese cities based on 28 criteria, using a set of weights inherited from a previous study. The detailed steps are presented as follows:

Step 1: Determine the criteria set [5] and alternatives.

Among the 17 SDGs set by the United Nations under the 2030 Agenda to promote global economic, social, and environmental development, we selected 14 goals relevant to the three cities under study and identified 28 corresponding evaluation criteria. These 28 criteria and their associated weights were adopted from a previous study, as referenced in Section I. The Table 1 below presents the selected goals and their corresponding criteria:

This research chooses 3 alternatives (Vietnamese cities), which are Hanoi (A_1), Ho Chi Minh City (A_2) and Can Tho (A_3) to evaluate and rank their sustainability levels based on the aforementioned criteria set.

The selection of these three cities is not only based on their prominent socio-economic roles but also aimed at ensuring representativeness and analytical value. First, the cities were chosen to capture regional diversity, encompassing the three major geographic areas of Vietnam: the North, the South, and the Mekong Delta. Second, they exhibit distinct socio-economic characteristics: Hanoi serves as the national political and administrative center, Ho Chi Minh City is the country’s largest economic hub, and Can Tho is the central urban area of the Mekong Delta — a region that is heavily affected by climate change and faces urgent demands for sustainable development. Third, all three cities offer a high degree of data availability, ensuring consistency and reliability in evaluating sustainability indicators. Finally, these cities are actively implementing sustainable development policies, making them suitable case studies for reflecting a more comprehensive picture of urban sustainability at the national level while enhancing the generalizability, comparability, and practical applicability of the research findings.

Step 2: Apply the weights of the criteria.

The study uses a scientifically validated set of weights from the study by Londoño-Pineda et al. (2021) [5] to ensure objectivity and methodological rigor in the evaluation process. This weighting scheme was developed through a comprehensive analytical framework that

Table 1. Indicators for assessing sustainable development.

Sustainable development goals	Goal code	Indicator	Indicator code
No poverty	SDG_1	Near-poverty rate	x_1
		Poverty rate	x_2
Zero hunger	SDG_2	Rate of malnutrition in children under 5 yr old	x_3
Good health and well-being	SDG_3	Immunization coverage among children under one year of age	x_4
		Under-five mortality rate/1.000	x_5
		MortalityrateforHIV–AIDS/100.000 persons	x_6
		School attendance rate in primaryschool (5–11 yr old)	x_7
		Secondary school attendance rate (12–17 yr old)	x_8
		Schooling rate in higher education (>18 yr old)	x_9
Quality education	SDG_4	Secondary school attendance rate/ 1 teacher	x_{10}
		Illiteracy rate in people older than 15 yr	x_{11}
Gender equality	SDG_5	Percentage of women in municipal councils	x_{12}
Clean water and sanitation	SDG_6	Proportion of households with access to clean water	x_{13}
		Percentage of households with toilet facilities	x_{14}
		Electricity access rate	x_{15}
Affordable and clean energy	SDG_7	Per capita energy consumption	x_{16}
Decent work and economic growth	SDG_8	Unemployment trate	x_{17}
		Underemployment rate	x_{18}
		Dependency ratio	x_{19}
Reduce dinequalities	SDG_{10}	Income inequality index (GINI)	x_{20}
		Internet coverage	x_{21}
Sustainable cities and communities	SDG_{11}	Proportion of agricultural land	x_{22}
		Concentration of particulate material PM2,5	x_{23}
Responsible consumption and production	SDG_{12}	Percentage of solid waste used	x_{24}
Life on land	SDG_{15}	Proportion of sustainably managed agricultural land	x_{25}
Peace, justice, and strong institutions	SDG_{16}	Homicide rate	x_{26}
		First-instance case rate	x_{27}
Partnerships for the goals	SDG_{17}	Household computer ownership	x_{28}

integrates expert judgment and statistical validation, reflecting the balanced significance of economic, social, and environmental dimensions of sustainable development. By adopting this established set of weights, the study avoids subjective bias that may arise from arbitrary or locally assigned values and ensures comparability with previous international studies. Moreover, using a scientifically grounded weighting system enhances the credibility and reproducibility of the results, thereby strengthening the robustness of the city-level sustainability assessment.

Step 3: Determine the CR value for the weight matrix.

$$CR = \frac{CI}{RI}$$

where

$$CI = \frac{\lambda_{\max} - n}{n - 1}; \lambda_{\max} = \sum_i^n (w_i \times \sum_j^n a_{ij}).$$

Step 4: Evaluate the alternatives using AHP, TOPSIS, ELECTRE, and PROMETHEE methods according to the formulas and determine the ranking of the alternatives.

The analytic hierarchy process (AHP) is regarded as a flexible and effective decision-support tool that helps address complex multi-criteria problems by integrating both qualitative and quantitative data. AHP enables decision-makers to identify and synthesize key factors within problems influenced by multiple variables. This method operates based on a hierarchical model, in which

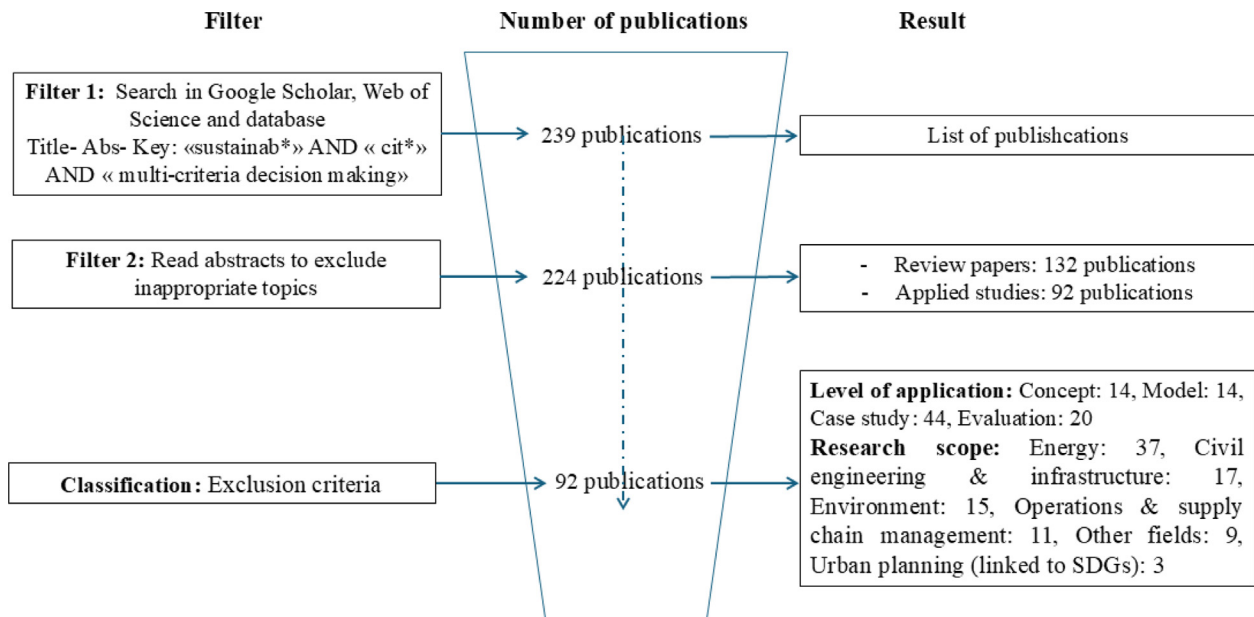


Fig. 1. Diagram of the literature selection process.

the overall goal is positioned at the highest level, followed by evaluation criteria, and finally, the set of alternatives. It provides a consistent assessment framework along with measurable priority indices to support the decision-making process [7].

The technique for order of preference by similarity to ideal solution (TOPSIS) is an MCDM method developed by Yoon and Hwang [8]. This method identifies the optimal alternative by determining the option that is closest to the positive ideal solution and farthest from the negative ideal solution [9]. According to Wang (2007), the positive ideal solution consists of the best attainable values of each criterion, whereas the negative ideal solution represents the worst attainable values. Based on the weights assigned to each criterion, both ideal solutions are defined. By comparing the distance coefficients of each alternative, their priority ranking can be determined [10].

The ELECTRE method addresses preference relations through pairwise comparisons of alternatives across individual criteria [11]. Several versions of ELECTRE (I, II, III, IV, etc.) have been developed; in this study, the ELECTRE III approach is applied for ranking alternatives.

PROMETHEE, short for Preference Ranking Organization METHod for Enrichment Evaluations, is an out-ranking-based MCDM method used to compare and select optimal alternatives in complex decision-making problems [12]. The PROMETHEE family includes PROMETHEE I, which provides a partial ranking of alternatives, and PROMETHEE II, which establishes a complete ranking. The method was originally developed by Brans and first introduced in 1982 [13]. Later, several extended versions of PROMETHEE were proposed. In this paper, the PROMETHEE II method is adopted to evaluate and rank the sustainability performance of cities in Vietnam.

The combination of the four methods is a comprehensive approach, as each method has distinct advantages that complement each other. Comparing results from multiple

methods helps verify consistency, enhances objectivity in evaluation, and provides diverse perspectives for decision-making.

Step 5: Sensitivity analysis by individual criteria using total decision and stability evaluation through Monte Carlo simulation.

3 Results

3.1 Findings from the literature review

Figure 1 provides a visual representation of the screening and selection process of publications conducted during the literature review. Among 92 studies, 14 remained at the conceptual stage of the implementation process, reflecting ongoing theoretical development of MCDM in sustainable development contexts. However, these articles lack practical models that would enable a more comprehensive understanding. Another 14 studies developed analytical models, indicating potential pathways for addressing sustainability-related issues. Notably, 44 empirical studies demonstrated specific real-world cases, suggesting a strong trend in applying MCDM methods to tackle practical problems using actual data. Only 20 studies conducted evaluative analyses — such as sensitivity analysis, scenario evaluation, or correlation testing — to verify the robustness and reliability of the proposed models. However, the number of such studies is still limited. These results indicate a certain degree of diversity in research levels but an evident imbalance between theoretical development and practical application.

In terms of research scope, the energy sector overwhelmingly dominates with 37 studies, followed by civil engineering and infrastructure (17 studies) and environmental studies (15 studies). Meanwhile, operations and supply chain management appeared in 11 studies. Other fields were addressed less frequently, accounting for only 9

studies in total. With urban planning — particularly that linked to the SDGs — being underrepresented, appearing in only 3 fragmented studies [14–16]. This underrepresentation shows a significant research gap in this area, underscoring the necessity for further research that incorporates MCDM into urban planning and sustainable development strategies.

Overall, the analysis demonstrates the growing adoption of MCDM methods in the field of sustainable development. However, there remains a lack of balance between theory and practical application. The scope of application is still skewed, failing to fully encompass social domains such as urban planning or broader sustainable development concerns. The absence primarily lies in studies that incorporate specific case scenarios followed by sensitivity analyses. This gap opens up promising avenues for future research to enhance the application of MCDM methods through more integrated and interdisciplinary frameworks in the planning and implementation of sustainable urban development policies. The current lack of interdisciplinary and multi-dimensional approaches highlights promising directions for future research. Such studies could enhance the application of MCDM by developing more integrated and cross-sectoral frameworks for sustainable urban development policymaking and implementation.

3.2 Results of the multi-criteria sustainability assessment and sensitivity analysis

Step 1: Identification of criteria and alternatives.

We constructed a parameter matrix for three alternatives, represented by three Vietnamese cities: Hanoi (A_1), Ho Chi Minh City (A_2), and Can Tho (A_3), based on a predefined set of evaluation criteria. The data were primarily collected from the General Statistics Office of Vietnam (GSO) [17–21] and several other reliable local data sources. The data collection process focused on the most recent 5-yr period (2020–2024). For each evaluation criterion, data for all three cities were collected from the same reference year to ensure data timeliness, temporal consistency, and comparability across cities within the study. This foundational step provides a basis for systematic comparison and assessment, thereby supporting a more robust and reliable decision-making process. The parameter matrix of the alternatives is presented in Table 3.

Step 2: Applying the weight set to the evaluation criteria.

Based on the weight set presented in Table 2, the relative importance of each criterion in the sustainable development assessment can be interpreted as follows.

The weight set indicates the relative importance of each criterion in the sustainable development assessment. Criteria with the highest weights (X_4, X_5, X_6, X_{23}) reflect significant concerns regarding public health and environmental pollution. Criteria related to education, such as ($X_7, X_8, X_9, X_{10}, X_{11}$), have moderate weights, indicating their important but not top-priority role. The remaining criteria have lower weights, suggesting that while they remain relevant, their impact is less significant compared to health and environmental factors. Overall, the weight set reflects

Table 2. Weights assigned to each evaluation criterion [5].

Criteria	Weight	Criteria	Weight
x_1	0.023	x_{15}	0.021
x_2	0.023	x_{16}	0.021
x_3	0.009	x_{17}	0.067
x_4	0.108	x_{18}	0.067
x_5	0.108	x_{19}	0.009
x_6	0.108	x_{20}	0.009
x_7	0.038	x_{21}	0.009
x_8	0.038	x_{22}	0.009
x_9	0.038	x_{23}	0.108
x_{10}	0.038	x_{24}	0.009
x_{11}	0.038	x_{25}	0.009
x_{12}	0.009	x_{26}	0.01
x_{13}	0.021	x_{27}	0.01
x_{14}	0.021	x_{28}	0.021

Table 3. Parameter matrix of the alternatives.

	A_1	A_2	A_3
x_1	0.43	0.57	1.26
x_2	0	0	0.09
x_3	4.6 [17]	5.8 [17]	7.6 [17]
x_4	83.6 [17]	94.7 [17]	89.7 [17]
x_5	12,79 [18]	11,89 [18]	13 [18]
x_6	0,98 [18]	0.56 [18]	4,07 [18]
x_7	77.16 [18]	76.73 [18]	92.09 [18]
x_8	86.93 [18]	99 [18]	94.23 [18]
x_9	70.81	71	50.25
x_{10}	25.87	26.53	21.56
x_{11}	0.61 [18]	1.18 [18]	3.18 [18]
x_{12}	19.7	43.62	18.89
x_{13}	100 [18]	100 [18]	96.2 [18]
x_{14}	100 [18]	100 [18]	97 [18]
x_{15}	100 [19]	98.6 [19]	99.7 [19]
x_{16}	6081.39 [19]	5969.28 [19]	4313.5 [19]
x_{17}	2.2 [18]	3.8 [18]	4.0 [18]
x_{18}	0.64 [18]	1.76 [18]	2.29 [18]
x_{19}	50 [21]	27.41 [21]	21.94 [21]
x_{20}	0.35 [18]	0.31 [18]	0.33 [18]
x_{21}	88 [17]	93 [17]	88 [17]
x_{22}	46.4 [20]	30.6 [20]	77.35 [20]
x_{23}	59	37	14.2
x_{24}	94.9 [18]	91 [18]	93.3 [18]
x_{25}	27.4	16	26.55
x_{26}	0.69	0.62	0.32
x_{27}	7.520 [18]	4.949 [18]	883 [18]
x_{28}	55 [18]	54 [18]	28.4 [18]

Table 4. Calculation steps of the AHP method.

Criteria	Weight	A_1	A_2	A_3
x_1	0.023	0.0043	0.0057	0.0126
x_2	0.023	0	0	0.0009
x_3	0.009	0.046	0.058	0.076
x_4	0.108	0.836	0.947	0.897
x_5	0.108	0.93	1	0.915
x_6	0.108	0.571	1	0.138
x_7	0.038	0.7716	0.7673	0.9209
x_8	0.038	0.8693	0.99	0.9423
x_9	0.038	0.7081	0.71	0.5025
x_{10}	0.038	0.833	0.813	1
x_{11}	0.038	0.0061	0.0118	0.0318
x_{12}	0.009	0.197	0.4362	0.1889
x_{13}	0.021	1	1	0.962
x_{14}	0.021	1	1	0.97
x_{15}	0.021	1	0.986	0.997
x_{16}	0.021	1	0.982	0.709
x_{17}	0.067	0.022	0.038	0.04
x_{18}	0.067	0.0064	0.0176	0.0229
x_{19}	0.009	0.5	0.2741	0.2194
x_{20}	0.009	0.891	1	0.937
x_{21}	0.009	0.88	0.93	0.88
x_{22}	0.009	0.464	0.306	0.7735
x_{23}	0.108	0.241	0.384	1
x_{24}	0.009	0.949	0.91	0.933
x_{25}	0.009	0.274	0.16	0.2655
x_{26}	0.01	0.464	0.516	1
x_{27}	0.01	0.117	0.178	1
x_{28}	0.021	0.55	0.54	0.284
Total score		0.543	0.627	0.594

a clear prioritization in the evaluation process, emphasizing factors that directly affect quality of life and sustainable development.

Step 3: Calculating the consistency index for the weight set:

$$CR = \frac{CI}{RI} = 0.0112 < 10\% .$$

The consistency ratio $CR = 0.0112$ indicates a very high level of consistency in the weight set. Despite conducting simultaneous comparisons among 28 criteria, the CR remains exceptionally low, demonstrating that the evaluation of the criteria is both objective and reliable. Therefore, adopting the weight set from previous research is entirely appropriate. This approach not only saves time but also ensures scientific rigor in the analysis.

Step 4: Evaluating alternatives using various methods.

Using the weight set and the parameter matrix collected by the team, we proceeded to rank the alternatives according to four methods. In this process,

Table 5. Ranking of alternatives based on AHP.

Alternative	Total score	Ranking
A_2	0.627	1
A_3	0.594	2
A_1	0.543	3

the weights of the criteria were adopted from Londoño-Pineda et al. (2021), representing the relative importance of economic, social, and environmental dimensions. Meanwhile, the performance values of the alternatives (A_1, A_2, A_3) were calculated by the research team based on the collected parameter matrix [Table 4](#).

– AHP method

After calculating the total score for each alternative, we determined the ranking of the alternatives as presented in [Table 5](#).

Table 6. Normalization of the decision matrix.

	A_1	A_2	A_3
x_1	0.3	0.39	0.87
x_2	0	0	1
x_3	0.43	0.55	0.72
x_4	0.54	0.61	0.58
x_5	0.59	0.55	0.72
x_6	0.23	0.13	0.96
x_7	0.54	0.538	0.646
x_8	0.537	0.61	0.582
x_9	0.63	0.633	0.448
x_{10}	0.6	0.619	0.5
x_{11}	0.18	0.34	0.92
x_{12}	0.38	0.85	0.37
x_{13}	0.58	0.58	0.56
x_{14}	0.583	0.583	0.566
x_{15}	0.58	0.57	0.579
x_{16}	0.637	0.625	0.452
x_{17}	0.37	0.64	0.67
x_{18}	0.22	0.59	0.77
x_{19}	0.82	0.45	0.36
x_{20}	0.61	0.54	0.58
x_{21}	0.6	0.54	0.589
x_{22}	0.554	0.3	0.776
x_{23}	0.83	0.52	0.2
x_{24}	0.59	0.56	0.58
x_{25}	0.7	0.41	0.58
x_{26}	0.7	0.63	0.33
x_{27}	0.83	0.547	0.098
x_{28}	0.67	0.657	0.346

– TOPSIS method

Based on the parameter matrix in Table 3, the decision matrix was normalized. The results are as follows by Table 6.

After obtaining the normalized matrix, the necessary parameters were calculated, and the results are as follows by Table 7.

Based on the calculated results above, the ranking of the alternatives can be clearly determined as follows by Table 8.

– ELECTRE III method

The steps for determining thresholds, the concordance matrix, and the discordance matrix are provided in Appendix (Tabs. A2, A3, and A4).

From there, the credibility matrix was determined as follows by Table 9.

The construction of the Z_1 sequence and the Z_2 sequence were carried out using the descending and ascending distillation processes, respectively.

With $\gamma = 0.6$, we obtain the matrix T_1 :

To rank the alternatives, the strengths and weaknesses of each alternative are calculated to determine the differences, which are then used to establish the ranking.

From the difference values, the Z_1 sequence can be arranged as $B \rightarrow C \rightarrow A$.

With $\beta = 0.8$, we obtain the matrix T_2 :

Similarly, the strength and weakness differences between the alternatives are calculated.

From the difference values, the Z_2 sequence can be arranged as $B \rightarrow C \rightarrow A$.

From the two sequences, the rankings of the alternatives are determined as follows.

– PROMETHEE method

First, the preference functions for each pair of alternatives were determined and are attached in Appendix (Tab. A5).

After identifying the preference functions for each pair, these values were aggregated to provide an overall view of the priority level of each alternative compared to the others.

– Result analysis

After performing the calculations using the four methods, the consolidated results are presented in the following Table 17.

The research findings, as presented in Table 18, indicate that Ho Chi Minh City (A_2) ranks highest under three methods (AHP, TOPSIS, and ELECTRE), whereas Hanoi (A_1) achieves the top position according to the PROMETHEE method. The relative positions of Can Tho (A_3) and Hanoi vary depending on the specific MCDM technique applied, demonstrating that the analytical logic inherent to each method influences the final ranking outcomes. The primary factors contributing to these differences include the initial criterion weights, data-processing mechanisms, and the ranking principles distinctive to each method.

First, regarding the weight matrix and the three cities' dataset, the high prioritization of economic and social criteria provides Ho Chi Minh City with a substantial advantage in several methods, as the city performs exceptionally well in growth, employment, and health-education indicators. For instance, its strong performance in child vaccination rates (x_4), child mortality rates (x_5), and notably HIV/AIDS mortality rates (x_6) yields significant benefits in methods that rely heavily on criterion weights and distance measures, such as AHP and TOPSIS. Thus, x_4 , x_5 , and x_6 can be considered the most sensitive criteria, exerting major influence on the ranking of the three cities. Moreover, the environmental criterion with the highest weight — PM2.5 concentration (x_{23}) — creates a sharp differentiation among the three cities: Can Tho (A_3) exhibits the best value, followed by Ho Chi Minh City (A_2), while Hanoi (A_1) records the highest PM2.5 levels. This disparity largely contributes to Hanoi's lower rankings under methods such as AHP and ELECTRE.

Table 7. Calculation steps of the TOPSIS method.

	Weighted normalized matrix			$A +$	$A -$
	A_1	A_2	A_3		
x_1	0.0069	0.009	0.02	0.0069	0.02
x_2	0	0	0.023	0	0.023
x_3	0.0039	0.005	0.006	0.0039	0.006
x_4	0.058	0.066	0.063	0.066	0.058
x_5	0.064	0.059	0.078	0.059	0.078
x_6	0.0248	0.014	0.104	0.014	0.104
x_7	0.0205	0.02	0.024	0.024	0.02
x_8	0.02	0.023	0.022	0.023	0.02
x_9	0.024	0.024	0.017	0.024	0.017
x_{10}	0.028	0.0235	0.019	0.019	0.028
x_{11}	0.0068	0.0129	0.035	0.0068	0.035
x_{12}	0.0034	0.0077	0.0033	0.0077	0.0033
x_{13}	0.01218	0.01218	0.0117	0.0121	0.0117
x_{14}	0.0122	0.0122	0.0119	0.0122	0.0119
x_{15}	0.01218	0.01197	0.0121	0.0121	0.0119
x_{16}	0.0134	0.0131	0.0095	0.0134	0.0095
x_{17}	0.025	0.043	0.045	0.025	0.045
x_{18}	0.015	0.0395	0.0516	0.015	0.0516
x_{19}	0.0074	0.00405	0.0032	0.0032	0.0074
x_{20}	0.0055	0.0049	0.0052	0.0049	0.0055
x_{21}	0.0054	0.0049	0.0053	0.0054	0.0049
x_{22}	0.005	0.0027	0.007	0.007	0.0027
x_{23}	0.09	0.056	0.0216	0.0216	0.09
x_{24}	0.0053	0.005	0.0052	0.0053	0.005
x_{25}	0.0063	0.0037	0.0052	0.0063	0.0037
x_{26}	0.007	0.0063	0.0033	0.0033	0.007
x_{27}	0.0083	0.0055	0.0009	0.0009	0.0083
x_{28}	0.014	0.014	0.0073	0.0073	0.014
S_{i+}	0.0717	0.0479	0.1086		
S_{i-}	0.0989	0.1054	0.0704		
C_i	0.58	0.688	0.39		

Table 8. Ranking of alternatives based on TOPSIS.

Alternative	Total score	Ranking
A_2	0.688	1
A_1	0.58	2
A_3	0.39	3

Table 9. Credibility matrix.

	A_1	A_2	A_3
A_1	1	0	0
A_2	1	1	0
A_3	0	0	1

Second, employment-related indicators such as the unemployment rate (x_{17}) and underemployment rate (x_{18}) — which receive the second-highest weight in the weighting scheme — contribute to Hanoi (A_1) attaining the top position in PROMETHEE. The city’s lower unemployment and underemployment levels, compared to Ho Chi Minh City (A_2) and Can Tho (A_3), increase the positive outranking flows for A_1 . This explains why

A_1 rises to the highest rank in PROMETHEE, even though it occupies relatively lower positions in AHP and TOPSIS.

In terms of data-processing mechanisms and ranking principles, the AHP method employs a relatively straightforward approach by aggregating the weighted scores of alternatives across all criteria. As a result, the final rankings are heavily influenced by the criteria groups

Table 10. Matrix T1.

	A_1	A_2	A_3
A_1	1	0	0
A_2	1	1	0
A_3	0	0	1

Table 11. Strength and weakness differences based on T1.

	W	S	Difference
A_1	2	1	-1
A_2	1	2	1
A_3	1	1	0

Table 12. Matrix T2.

	A_1	A_2	A_3
A_1	1	0	0
A_2	1	1	0
A_3	0	0	1

Table 13. Strength and weakness differences based on T2.

	W	S	Difference
A_1	2	1	-1
A_2	1	2	1
A_3	1	1	0

Table 14. Ranking of alternatives based on ELECTRE.

Alternative	Ranking
A_2	1
A_3	2
A_1	3

assigned higher weights. In this study, the healthcare sector received a high weight, which favored Ho Chi Minh City — an urban center with well-developed medical infrastructure — leading it to outperform the other two cities in the ranking.

TOPSIS is sensitive to the presence of extreme values (both maximum and minimum); therefore, a criterion with an exceptionally high or low value can significantly affect the ranking results. In this study, TOPSIS continued to rank Ho Chi Minh City first, owing to its well-balanced performance across all economic, infrastructural, and development-related criteria. Hanoi ranked second due to its higher scores in certain aspects such as quality of life and social development, placing it closer to the ideal solution compared to Can Tho. Given these characteristics, both AHP and TOPSIS are suitable for comprehensive

Table 15. Aggregated preference function matrix.

	A_1	A_2	A_3
A_1	0	0.0773	0.1228
A_2	0.0257	0	0.1183
A_3	0.0443	0.0686	0

Table 16. Preference flow for the alternatives.

Alternative	Φ_+	Φ_-	Φ
A_1	0.2001	0.07	0.1301
A_2	0.144	0.1459	-0.0019
A_3	0.1129	0.2411	-0.1282

Table 17. Ranking of alternatives based on PROMETHEE.

Alternative	Total score	Ranking
A_1	0.1301	1
A_2	-0.0019	2
A_3	-0.1282	3

Table 18. Summary of results.

	AHP	TOPSIS	PROMETHEE	ELECTRE
A_1	3	2	1	3
A_2	1	1	2	1
A_3	2	3	3	2

evaluations that involve multiple criteria, especially in complex decision-making contexts where criterion weights significantly influence the outcomes and a balance among economic, social, and environmental dimensions is required.

In the ELECTRE method, Ho Chi Minh City remained the top-ranked alternative; however, unlike TOPSIS, this method is based on the principle of outranking and emphasizes the dominance relationships between alternatives rather than establishing an absolute ranking. Ho Chi Minh City secured the leading position because, in most pairwise comparisons, it outperformed both Hanoi and Can Tho in several key criteria, such as GDP and infrastructure investment. Specifically, A_2 shows a higher tertiary education enrollment rate (x_9) compared to the other two cities, reflecting a superior quality of human capital. The city also performs strongly in household computer ownership (x_{28}) and Internet coverage (x_{21}), both of which carry substantial weights and directly strengthen pairwise dominance relations in ELECTRE. In addition, its lower agricultural land ratio (x_{22}) indicates a higher degree of urbanization, giving Ho Chi Minh City an advantage over Can Tho when evaluating cost-type criteria. Consequently, Ho Chi Minh City achieves higher

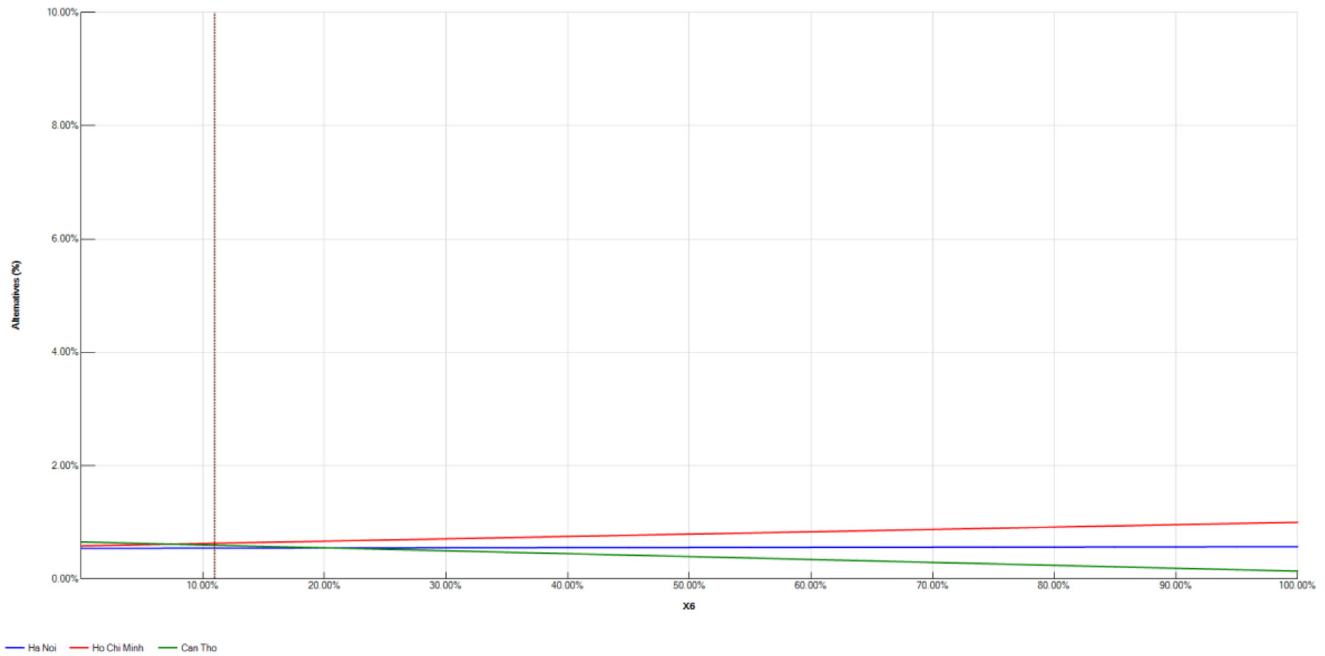


Fig. 2. Sensitivity analysis results for criterion x_6 .

concordance levels in most pairwise comparisons, allowing ELECTRE to rank it first, despite Hanoi and Can Tho exhibiting individual strengths in certain other criteria. Since ELECTRE focuses primarily on outranking relationships, it is particularly well-suited for applications such as tender evaluation, investment project selection, and strategic decision-making — contexts in which criteria may not be directly comparable and vary in terms of influence.

PROMETHEE was the only method that ranked Hanoi as the top alternative. This outcome is attributed to the fact that PROMETHEE not only considers proximity to an ideal solution but also incorporates preference functions to assess the dominance between alternatives, placing higher importance on criteria such as quality of life and environmental conditions, areas where Hanoi performs relatively well. As a result, Ho Chi Minh City did not maintain the leading position under this method. This suggests that PROMETHEE is more sensitive to criteria with lower weights, particularly environmental factors, which leads to a shift in rankings compared to other methods. PROMETHEE is therefore more suitable for urgent or specialized decision-making contexts such as environmental impact assessments, resource allocation, and policy formulation, where criteria have varying levels of priority and must be evaluated according to specific contextual needs.

Based on the above results, it is evident that no single method can be considered universally optimal; rather, the choice of method should depend on the specific characteristics of the problem and the decision-making requirements.

Step 5: Sensitivity analysis by individual criteria using total decision software and stability evaluation through Monte Carlo simulation.

– Sensitivity analysis by criterion

After analyzing the sustainability ranking results of the three cities, a sensitivity analysis was conducted for 28 criteria using the Total Decision Software. This software enables the assessment of the impact of each of the 28 criteria on the ranking outcomes of alternatives within the AHP ranking method. Based on the extent of change observed among the alternatives, the sensitivity analysis chart indicated that criterion X_6 (mortality rate for HIV–AIDS) is the most sensitive, exerting the greatest influence on the ranking results.

According to [Figure 2](#) above:

- The Y-axis represents the scores of the alternatives.
- The X-axis shows the variation in the weight of criterion x_6 , ranging from 0% to 100%.
- The initial ranking of the alternatives is indicated by the vertical red dashed line.

As the weight of criterion x_6 increases, the score of Ho Chi Minh City tends to rise significantly, whereas Can Tho's score noticeably decreases, and Hanoi's score is relatively less affected. Consequently, the intersection point occurs at a weight of 20%, representing the threshold at which the rankings of Hanoi and Can Tho switch.

When the weight of x_6 decreases, the scores of Hanoi and Can Tho slightly increase, while Ho Chi Minh City's score tends to decline. The crossover point at a weight of 8% marks the threshold where the rankings of Ho Chi Minh City and Can Tho change. These findings further confirm that criterion x_6 is highly sensitive to weight variations and plays a critical role in assessing the sustainability levels of the cities.

Another reason for the high sensitivity of x_6 is that it belongs to the group of criteria with relatively large weights in the overall AHP structure. However, sensitivity in this

	X6/X1	X6/X2	X6/X3	X6/X4	X6/X5	X6/X7	X6/X8	X6/X9	X6/X10	X6/X11	X6/X12	X6/X13	X6/X14	X6/X15
PHƯƠNG ÁN	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1
0.1	0.543923	0.543923	0.544002	0.543996	0.543996	0.548185	0.550043	0.546977	0.549352	0.533627	0.537236	0.552515	0.552515	0.552515
0.2	0.543926	0.543926	0.544003	0.544006	0.544006	0.5468	0.548045	0.545991	0.547583	0.537044	0.539414	0.549728	0.549728	0.549728
0.3	0.543929	0.543929	0.544004	0.544017	0.544017	0.546076	0.547	0.545476	0.546657	0.538837	0.540551	0.548273	0.548273	0.548273
0.4	0.543932	0.543932	0.544005	0.544027	0.544027	0.545631	0.546358	0.545159	0.546088	0.539942	0.54125	0.547379	0.547379	0.547379
0.5	0.543936	0.543936	0.544006	0.544036	0.544036	0.545331	0.545923	0.544946	0.545703	0.540691	0.541723	0.546775	0.546775	0.546775
0.6	0.543939	0.543939	0.544007	0.544046	0.544046	0.545115	0.54561	0.544793	0.545426	0.541233	0.542065	0.546339	0.546339	0.546339
0.7	0.543942	0.543942	0.544008	0.544055	0.544055	0.544952	0.545374	0.544678	0.545217	0.541644	0.542323	0.546011	0.546011	0.546011
0.8	0.543945	0.543945	0.544009	0.544064	0.544064	0.544825	0.54519	0.544588	0.545055	0.541966	0.542526	0.545755	0.545755	0.545755
0.9	0.543948	0.543948	0.54401	0.544073	0.544073	0.544724	0.545043	0.544517	0.544924	0.542225	0.542689	0.545549	0.545549	0.545549
1	0.543951	0.543951	0.544011	0.544082	0.544082	0.544641	0.544922	0.544458	0.544818	0.542439	0.542822	0.545381	0.545381	0.545381
2	0.54398	0.54398	0.54402	0.544159	0.544159	0.544256	0.544355	0.544192	0.544319	0.543481	0.543471	0.544586	0.544586	0.544586
3	0.544008	0.544008	0.544029	0.544221	0.544221	0.544134	0.544168	0.544112	0.544155	0.543871	0.54371	0.544316	0.544316	0.544316
4	0.544034	0.544034	0.544038	0.544273	0.544273	0.544082	0.544082	0.544082	0.544082	0.543837	0.543837	0.54419	0.54419	0.54419
5	0.54406	0.54406	0.544047	0.544316	0.544316	0.544058	0.544038	0.544071	0.544045	0.544219	0.543918	0.544121	0.544121	0.544121
6	0.544085	0.544085	0.544056	0.544353	0.544353	0.544048	0.544014	0.54407	0.544026	0.544317	0.543975	0.544082	0.544082	0.544082
7	0.544109	0.544109	0.544065	0.544385	0.544385	0.544045	0.544001	0.544074	0.544018	0.544392	0.544018	0.54406	0.54406	0.54406
8	0.544132	0.544132	0.544073	0.544413	0.544413	0.544047	0.543995	0.544081	0.544015	0.544452	0.544053	0.544047	0.544047	0.544047
9	0.544154	0.544154	0.544081	0.544437	0.544437	0.544052	0.543994	0.544089	0.544015	0.544502	0.544082	0.544042	0.544042	0.544042
	X6/X16	X6/X17	X6/X18	X6/X19	X6/X20	X6/X21	X6/X22	X6/X23	X6/X24	X6/X25	X6/X26	X6/X27	X6/X28	
PHƯƠNG ÁN	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	
0.1	0.534052	0.534052	0.533759	0.543039	0.550523	0.55261	0.544252	0.538335	0.551575	0.538654	0.542326	0.535687	0.543921	
0.2	0.537483	0.537483	0.537291	0.54335	0.548426	0.549841	0.544173	0.54049	0.549121	0.540359	0.54286	0.538364	0.543926	
0.3	0.539298	0.539298	0.53916	0.543513	0.547332	0.548396	0.544132	0.541652	0.547841	0.541249	0.54314	0.539762	0.54393	
0.4	0.540423	0.540423	0.540317	0.543614	0.54666	0.547509	0.544108	0.542381	0.547056	0.541796	0.543313	0.540621	0.543934	
0.5	0.541189	0.541189	0.541106	0.543682	0.546206	0.54691	0.544091	0.542882	0.546525	0.542167	0.54343	0.541203	0.543937	
0.6	0.541745	0.541745	0.541678	0.543731	0.545879	0.546477	0.54408	0.543249	0.546142	0.542436	0.543515	0.541623	0.543941	
0.7	0.542168	0.542168	0.542113	0.543769	0.545631	0.546151	0.544071	0.543529	0.545854	0.542639	0.543579	0.541941	0.543944	
0.8	0.5425	0.5425	0.542455	0.543799	0.545438	0.545895	0.544065	0.543751	0.545628	0.542798	0.54363	0.542191	0.543947	
0.9	0.542768	0.542768	0.542731	0.543823	0.545283	0.545691	0.54406	0.543932	0.545447	0.542926	0.543671	0.542391	0.54395	
1	0.542989	0.542989	0.542959	0.543843	0.545156	0.545522	0.544056	0.544082	0.545299	0.543031	0.543705	0.542556	0.543953	
2	0.544082	0.544082	0.544082	0.543943	0.54455	0.544719	0.544042	0.544842	0.544595	0.543547	0.543876	0.543356	0.543981	
3	0.544502	0.544502	0.544513	0.543985	0.544338	0.544437	0.544042	0.54515	0.544352	0.543742	0.543945	0.543651	0.544008	
4	0.544735	0.544735	0.544751	0.544011	0.544234	0.544296	0.544047	0.545328	0.544235	0.54385	0.543988	0.543809	0.544034	
5	0.544888	0.544888	0.544908	0.54403	0.544173	0.544213	0.544053	0.545448	0.54417	0.543922	0.544018	0.54391	0.544058	
6	0.544999	0.544999	0.545022	0.544045	0.544135	0.544161	0.54406	0.545536	0.54413	0.543975	0.544043	0.543983	0.544082	
7	0.545085	0.545085	0.54511	0.544059	0.54411	0.544125	0.544067	0.545605	0.544106	0.544017	0.544064	0.544038	0.544105	
8	0.545155	0.545155	0.54518	0.544071	0.544094	0.5441	0.544075	0.54566	0.544091	0.544052	0.544082	0.544082	0.544127	
9	0.545212	0.545212	0.545239	0.544082	0.544082	0.544082	0.544082	0.545706	0.544082	0.544082	0.544099	0.544119	0.544148	

Fig. 3. Alternative A₁ – Hanoi.

context should be interpreted carefully. Although ranking reversals are theoretically observed at the 8% and 20% weight levels, these values represent theoretical sensitivity thresholds rather than practically attainable conditions.

The results presented in Figure 2 indicate that if the weight of the criterion x_6 reaches the threshold levels of 8% or 20%, the rankings of certain alternatives may be reversed. However, the weights currently adopted in this study are well below these threshold values. Therefore, in practical terms, the rankings remain unchanged. This also explains why the Excel-based tests presented below show no variation in the rankings when only minor adjustments are made to the weight of x_6 (the results are presented in Figures 3, 4, and 5). To substantiate this claim, several analyses based on the obtained results are presented as follows.

As calculated, the initial ranking scores of Hanoi, Ho Chi Minh City, and Can Tho are 0.543, 0.627, and 0.594, respectively.

– At the 8% weight threshold

The ranking scores of Hanoi, Ho Chi Minh City, and Can Tho are 0.555, 0.600, and 0.610, respectively.

Compared with the baseline scores, Hanoi increases by 0.012 (corresponding to a maximum increase), Ho Chi Minh City decreases by 0.027 (corresponding to a maximum decrease), and Can Tho increases by 0.016 (corresponding to a maximum increase).

– At the 20% weight threshold

The ranking scores of Hanoi, Ho Chi Minh City, and Can Tho are 0.554, 0.695, and 0.570, respectively.

Compared with the baseline scores, Hanoi increases by 0.011 (corresponding to a maximum increase), Ho Chi Minh City increases by 0.068 (corresponding to a maximum increase), and Can Tho decreases by 0.024 (corresponding to a maximum decrease).

Subsequently, an analysis was conducted using Excel by adjusting the values in the original decision matrix to the minimum and maximum levels of the Saaty scale and observing the resulting variations in the ranking scores of the three cities.

The analysis results show in Figures 3, 4, 5:

The results are summarized as follows:

- Hanoi: The lowest score relative to the baseline is 0.534 (a decrease of 0.009), while the highest score relative to the baseline is 0.553 (an increase of 0.01).

	X6/X1	X6/X2	X6/X3	X6/X4	X6/X5	X6/X7	X6/X8	X6/X9	X6/X10	X6/X11	X6/X12	X6/X13	X6/X14	X6/X15
PHƯƠNG ÁN	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2
0.1	0.626626	0.626626	0.627035	0.626788	0.626788	0.6289309	0.633166	0.627841	0.6298	0.614564	0.623161	0.633512	0.633512	0.633168
0.2	0.626658	0.626658	0.627051	0.626974	0.626974	0.628179	0.631017	0.627449	0.628761	0.618551	0.624426	0.631304	0.631304	0.631072
0.3	0.626691	0.626691	0.627066	0.627155	0.627155	0.6278097	0.629916	0.627268	0.628242	0.620665	0.625093	0.630165	0.630165	0.629991
0.4	0.626723	0.626723	0.627081	0.627331	0.627331	0.6276022	0.629258	0.627176	0.627942	0.621987	0.625509	0.629476	0.629476	0.629339
0.5	0.626755	0.626755	0.627097	0.627503	0.627503	0.6274781	0.628828	0.627131	0.627755	0.622899	0.625795	0.629021	0.629021	0.628907
0.6	0.626787	0.626787	0.627112	0.627671	0.627671	0.6274025	0.628532	0.627112	0.627634	0.623572	0.626006	0.6287	0.6287	0.628605
0.7	0.626819	0.626819	0.627127	0.627835	0.627835	0.6273575	0.628332	0.627111	0.627555	0.624092	0.626169	0.628466	0.628466	0.628383
0.8	0.626851	0.626851	0.627142	0.627995	0.627995	0.627333	0.628165	0.627119	0.627504	0.624511	0.6263	0.628289	0.628289	0.628217
0.9	0.626883	0.626883	0.627157	0.628151	0.628151	0.6273229	0.62805	0.627136	0.627472	0.624857	0.626408	0.628153	0.628153	0.628089
1	0.626914	0.626914	0.627173	0.628303	0.628303	0.6273233	0.627964	0.627158	0.627455	0.62515	0.626499	0.628047	0.628047	0.62799
2	0.627221	0.627221	0.627322	0.629652	0.629652	0.6275652	0.627791	0.627507	0.627612	0.6268	0.627016	0.627689	0.627689	0.627665
3	0.627516	0.627516	0.627469	0.630745	0.630745	0.627928	0.628005	0.627908	0.627944	0.627668	0.627295	0.627743	0.627743	0.627731
4	0.6278	0.6278	0.627613	0.631649	0.631649	0.6283031	0.628303	0.628303	0.628303	0.628303	0.628303	0.627901	0.627901	0.627894
5	0.628072	0.628072	0.627754	0.632409	0.632409	0.6286689	0.628622	0.628681	0.628659	0.628827	0.627689	0.628095	0.628095	0.628092
6	0.628333	0.628333	0.627892	0.633057	0.633057	0.6290194	0.628941	0.62904	0.629003	0.629285	0.627856	0.628303	0.628303	0.628303
7	0.628585	0.628585	0.628028	0.633616	0.633616	0.6293531	0.629252	0.629379	0.629332	0.629695	0.628012	0.628516	0.628516	0.628518
8	0.628828	0.628828	0.628161	0.634103	0.634103	0.6296699	0.629552	0.6297	0.629646	0.63007	0.62816	0.628728	0.628728	0.628731
9	0.629061	0.629061	0.628291	0.634532	0.634532	0.6299705	0.629839	0.630004	0.629944	0.630415	0.628303	0.628938	0.628938	0.628942
	X6/X16	X6/X17	X6/X18	X6/X19	X6/X20	X6/X21	X6/X22	X6/X23	X6/X24	X6/X25	X6/X26	X6/X27	X6/X28	
PHƯƠNG ÁN	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2	
0.1	0.615285	0.615285	0.614901	0.620057	0.633952	0.632038	0.620668	0.622126	0.632209	0.617852	0.624587	0.618121	0.624731	
0.2	0.619282	0.619282	0.619031	0.62232	0.631743	0.6304453	0.622734	0.624078	0.630555	0.620819	0.625364	0.620985	0.625377	
0.3	0.621441	0.621441	0.62126	0.623509	0.630598	0.6296214	0.62382	0.625208	0.629699	0.622374	0.625278	0.622489	0.62573	
0.4	0.622813	0.622813	0.622675	0.624245	0.6299	0.6291213	0.624493	0.625976	0.629179	0.623336	0.626042	0.62342	0.625959	
0.5	0.623776	0.623776	0.623668	0.624747	0.629433	0.6287879	0.624953	0.626553	0.628833	0.623991	0.626225	0.624057	0.626124	
0.6	0.624499	0.624499	0.624412	0.625114	0.629101	0.6285516	0.62529	0.627015	0.628587	0.624468	0.626363	0.624521	0.626252	
0.7	0.625069	0.625069	0.624998	0.625396	0.628853	0.6283767	0.625547	0.627402	0.628405	0.624833	0.626471	0.624876	0.626356	
0.8	0.625535	0.625535	0.625476	0.625619	0.628663	0.6282433	0.625752	0.627737	0.628266	0.625121	0.62656	0.625158	0.626445	
0.9	0.625927	0.625927	0.625878	0.625801	0.628513	0.628139	0.62592	0.628034	0.628158	0.625356	0.626635	0.625389	0.626522	
1	0.626264	0.626264	0.626224	0.625953	0.628392	0.628056	0.626061	0.628303	0.628071	0.625551	0.6267	0.625581	0.62659	
2	0.628303	0.628303	0.628303	0.626763	0.62789	0.6277346	0.626813	0.630213	0.627734	0.62657	0.627107	0.6266	0.627074	
3	0.629481	0.629481	0.629496	0.627147	0.627803	0.6277128	0.627176	0.631508	0.627708	0.62703	0.627365	0.627079	0.62743	
4	0.630368	0.630368	0.63039	0.627413	0.627827	0.6277703	0.627432	0.632516	0.627764	0.627336	0.627581	0.627407	0.627742	
5	0.631098	0.631098	0.631125	0.627629	0.627896	0.6278589	0.627641	0.633339	0.627853	0.627578	0.627777	0.627672	0.628031	
6	0.631724	0.631724	0.631753	0.627818	0.627985	0.6279621	0.627825	0.634029	0.627957	0.627784	0.62796	0.627902	0.628303	
7	0.632272	0.632272	0.632304	0.62799	0.628086	0.6280727	0.627994	0.634618	0.628069	0.62797	0.628135	0.62811	0.628561	
8	0.632761	0.632761	0.632794	0.628151	0.628193	0.628187	0.628153	0.635128	0.628185	0.628142	0.628303	0.628303	0.628808	
9	0.6332	0.6332	0.633234	0.628303	0.628303	0.6283031	0.628303	0.635574	0.628303	0.628303	0.628466	0.628485	0.629045	

Fig. 4. Alternative A₂ – Ho Chi Minh.

- Ho Chi Minh City: The lowest score relative to the baseline is 0.615 (a decrease of 0.012), whereas the highest score relative to the baseline is 0.636 (an increase of 0.009).
- Can Tho: The lowest score relative to the baseline is 0.586 (a decrease of 0.008), while the highest score relative to the baseline is 0.605 (an increase of 0.011).

These results demonstrate that even under extreme perturbations of expert judgments, the score variations of the alternatives do not reach the critical ranges required to trigger ranking reversals (at the 8% and 20% weight thresholds). Consequently, although criterion x_6 is theoretically the most sensitive criterion, its impact on the final ranking is limited in practice, and the overall ranking structure remains stable.

This analysis further confirms that the AHP-based evaluation framework employed in this study provides a robust and reliable ranking system.

At the same time, the results indicate that the use of inherited (exogenous) weights does not have a significant influence on the final ranking outcomes of the Vietnamese cities considered in this study. Therefore, within the scope of the present research, the applied weighting scheme can be regarded as methodologically appropriate and does not introduce bias into the ranking results.

– Monte Carlo analysis

To further examine the stability and reliability of the sustainability ranking results, we applied and analyzed the Monte Carlo simulation for the three cities. Below are the results obtained from the Monte Carlo analysis for the alternatives.

From Figure 6, it can be observed that the distribution is symmetrical with a clear peak, highly concentrated around the mean value. Hanoi has the lowest mean value among the three alternatives, indicating a lower priority according to the AHP model. However, the narrow confidence interval suggests good stability. Therefore, Hanoi exhibits a high level of stability but is not the optimal alternative in terms of performance.

In the chart for Ho Chi Minh City (Fig. 7), the mean and P-value are the highest, indicating that it is the most superior alternative. The confidence interval is also noticeably wider, resulting in a slightly right-skewed distribution, yet it remains concentrated around the mean. The combination of high reliability and narrow distribution makes this alternative the most effective and stable. Therefore, Ho Chi Minh City is prioritized as the top alternative in the sensitivity analysis.

	X6/X1	X6/X2	X6/X3	X6/X4	X6/X5	X6/X7	X6/X8	X6/X9	X6/X10	X6/X11	X6/X12	X6/X13	X6/X14	X6/X15
PHƯƠNG ÁN	A3	A3	A3	A3	A3	A3	A3	A3	A3	A3	A3	A3	A3	A3
0.1	0.597555	0.597555	0.597003	0.597514	0.597514	0.603903	0.60431	0.595946	0.605407	0.586995	0.588924	0.604292	0.604445	0.604961
0.2	0.597516	0.597516	0.596985	0.597271	0.597271	0.601882	0.602155	0.59655	0.60289	0.590551	0.591502	0.602071	0.602174	0.602522
0.3	0.597477	0.597477	0.596967	0.597034	0.597034	0.600789	0.600992	0.596833	0.601537	0.592381	0.592839	0.600891	0.600968	0.601229
0.4	0.597438	0.597438	0.596949	0.596804	0.596804	0.60009	0.600249	0.59698	0.600678	0.593481	0.593654	0.600151	0.600212	0.600419
0.5	0.597399	0.597399	0.596932	0.596579	0.596579	0.599593	0.599723	0.597057	0.600072	0.594204	0.594199	0.599638	0.599688	0.599858
0.6	0.597361	0.597361	0.596914	0.596359	0.596359	0.599215	0.599324	0.597094	0.599616	0.594707	0.594587	0.599257	0.599299	0.599443
0.7	0.597322	0.597322	0.596896	0.596145	0.596145	0.598913	0.599006	0.597105	0.599255	0.595071	0.594877	0.598959	0.598996	0.59912
0.8	0.597284	0.597284	0.596879	0.595936	0.595936	0.598662	0.598742	0.597099	0.598957	0.595341	0.595099	0.598719	0.598751	0.598859
0.9	0.597246	0.597246	0.596861	0.59732	0.59732	0.598447	0.598517	0.597081	0.598705	0.595545	0.595274	0.598518	0.598546	0.598642
1	0.597208	0.597208	0.596844	0.595533	0.595533	0.598259	0.59832	0.597055	0.598486	0.595701	0.595415	0.598347	0.598372	0.598457
2	0.596837	0.596837	0.59667	0.593768	0.593768	0.597026	0.597048	0.596602	0.597107	0.596125	0.596003	0.597335	0.597346	0.597382
3	0.596481	0.596481	0.5965	0.592338	0.592338	0.596209	0.596216	0.596065	0.596236	0.595903	0.596106	0.596751	0.596756	0.596775
4	0.59614	0.59614	0.596333	0.591156	0.591156	0.595533	0.595533	0.595533	0.595533	0.595533	0.59608	0.596293	0.596296	0.596305
5	0.595812	0.595812	0.59617	0.590162	0.590162	0.594934	0.594929	0.595022	0.594917	0.59512	0.596002	0.595895	0.595896	0.5959
6	0.595496	0.595496	0.596009	0.589314	0.589314	0.594389	0.594382	0.594536	0.594361	0.594701	0.595899	0.595533	0.595533	0.595533
7	0.595192	0.595192	0.595852	0.588583	0.588583	0.593886	0.593877	0.594076	0.593851	0.594289	0.595783	0.595196	0.595195	0.595192
8	0.5949	0.5949	0.595698	0.587945	0.587945	0.593419	0.593408	0.59364	0.593377	0.593889	0.59566	0.594878	0.594877	0.594872
9	0.594618	0.594618	0.595546	0.587385	0.587385	0.592981	0.592969	0.593228	0.592935	0.593505	0.595533	0.594578	0.594576	0.594569
	X6/X16	X6/X17	X6/X18	X6/X19	X6/X20	X6/X21	X6/X22	X6/X23	X6/X24	X6/X25	X6/X26	X6/X27	X6/X28	
PHƯƠNG ÁN	A3	A3	A3	A3	A3	A3	A3	A3	A3	A3	A3	A3	A3	
0.1	0.599462	0.587142	0.586821	0.589518	0.603255	0.604078	0.600441	0.604647	0.603054	0.590276	0.604577	0.604577	0.591348	
0.2	0.59881	0.5907	0.59049	0.591908	0.601224	0.601782	0.599315	0.601704	0.601049	0.592384	0.602149	0.602149	0.593333	
0.3	0.598451	0.592517	0.592365	0.593147	0.600155	0.600575	0.598719	0.600016	0.599995	0.593476	0.600871	0.600871	0.594353	
0.4	0.598216	0.59359	0.593474	0.593901	0.599492	0.599827	0.598347	0.598879	0.599341	0.594141	0.600078	0.600078	0.594965	
0.5	0.598044	0.594278	0.594187	0.594405	0.599037	0.599315	0.598089	0.598035	0.598894	0.594585	0.599534	0.599534	0.595367	
0.6	0.597909	0.594741	0.594668	0.594764	0.598705	0.598941	0.597897	0.597365	0.598566	0.594901	0.599135	0.599135	0.595646	
0.7	0.597799	0.595063	0.595003	0.595031	0.598449	0.598654	0.597749	0.596809	0.598315	0.595136	0.598829	0.598829	0.598848	
0.8	0.597704	0.595288	0.595239	0.595236	0.598245	0.598425	0.597629	0.596331	0.598115	0.595316	0.598584	0.598584	0.595999	
0.9	0.59762	0.595447	0.595406	0.595397	0.598078	0.598238	0.597528	0.59591	0.597951	0.595458	0.598384	0.598384	0.596112	
1	0.597545	0.595556	0.595523	0.595526	0.597937	0.598082	0.597443	0.595533	0.597814	0.595571	0.598215	0.598215	0.596198	
2	0.596996	0.595533	0.595533	0.596058	0.597172	0.597238	0.596943	0.592905	0.59707	0.596035	0.597295	0.597295	0.596427	
3	0.596578	0.594927	0.594939	0.59614	0.596788	0.596827	0.596656	0.591162	0.596704	0.596101	0.596833	0.596833	0.596289	
4	0.596206	0.594239	0.594257	0.596102	0.596511	0.596536	0.596428	0.589818	0.596443	0.596063	0.5965	0.5965	0.59606	
5	0.59586	0.593565	0.593587	0.596017	0.59628	0.596296	0.596226	0.588725	0.596227	0.595982	0.596222	0.596222	0.595801	
6	0.595533	0.592931	0.592956	0.595909	0.596074	0.596084	0.59604	0.58781	0.596035	0.595881	0.595974	0.595974	0.595533	
7	0.595221	0.592343	0.592369	0.595789	0.595884	0.595889	0.595864	0.587031	0.595858	0.59577	0.595747	0.595747	0.595263	
8	0.594923	0.591799	0.591827	0.595662	0.595704	0.595706	0.595695	0.586357	0.595691	0.595653	0.595533	0.595533	0.594997	
9	0.594637	0.591297	0.591326	0.595533	0.595533	0.595533	0.595533	0.585768	0.595533	0.595533	0.595329	0.595329	0.594736	

Fig. 5. Alternative A₃ – Can Tho.

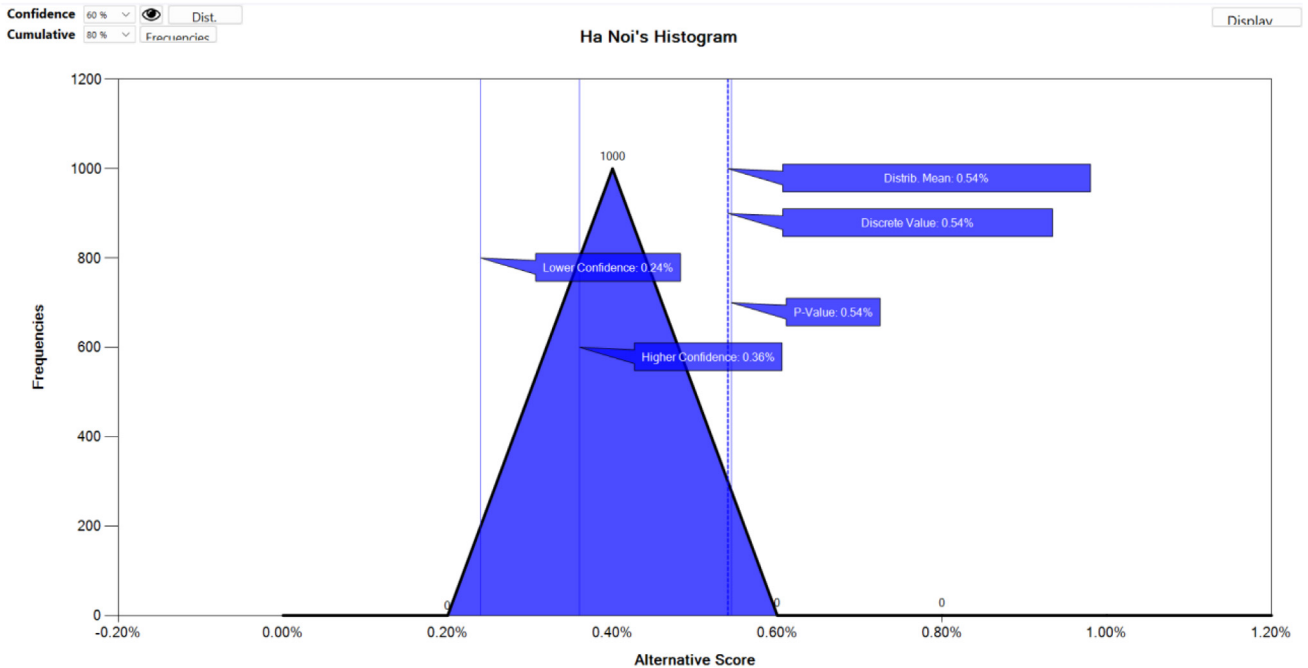


Fig. 6. Frequency distribution chart of Hanoi in the Monte Carlo simulation.

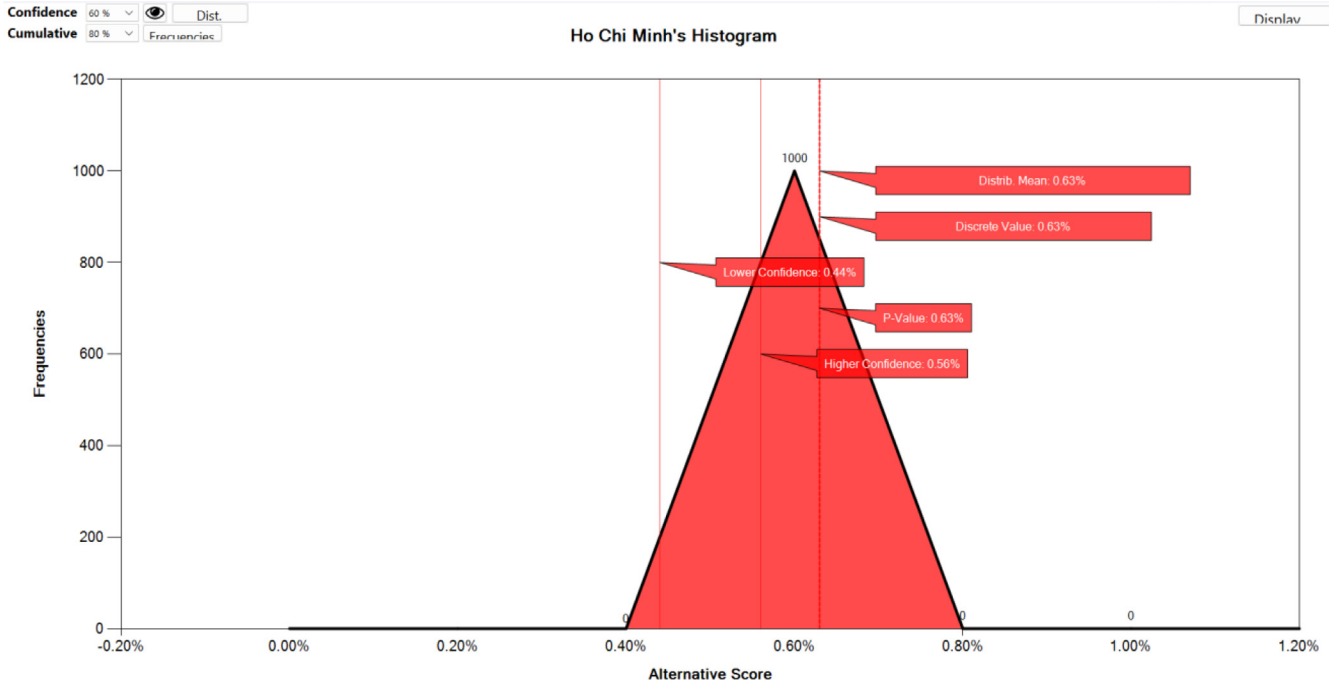


Fig. 7. Frequency distribution chart of Ho Chi Minh in the Monte Carlo simulation.

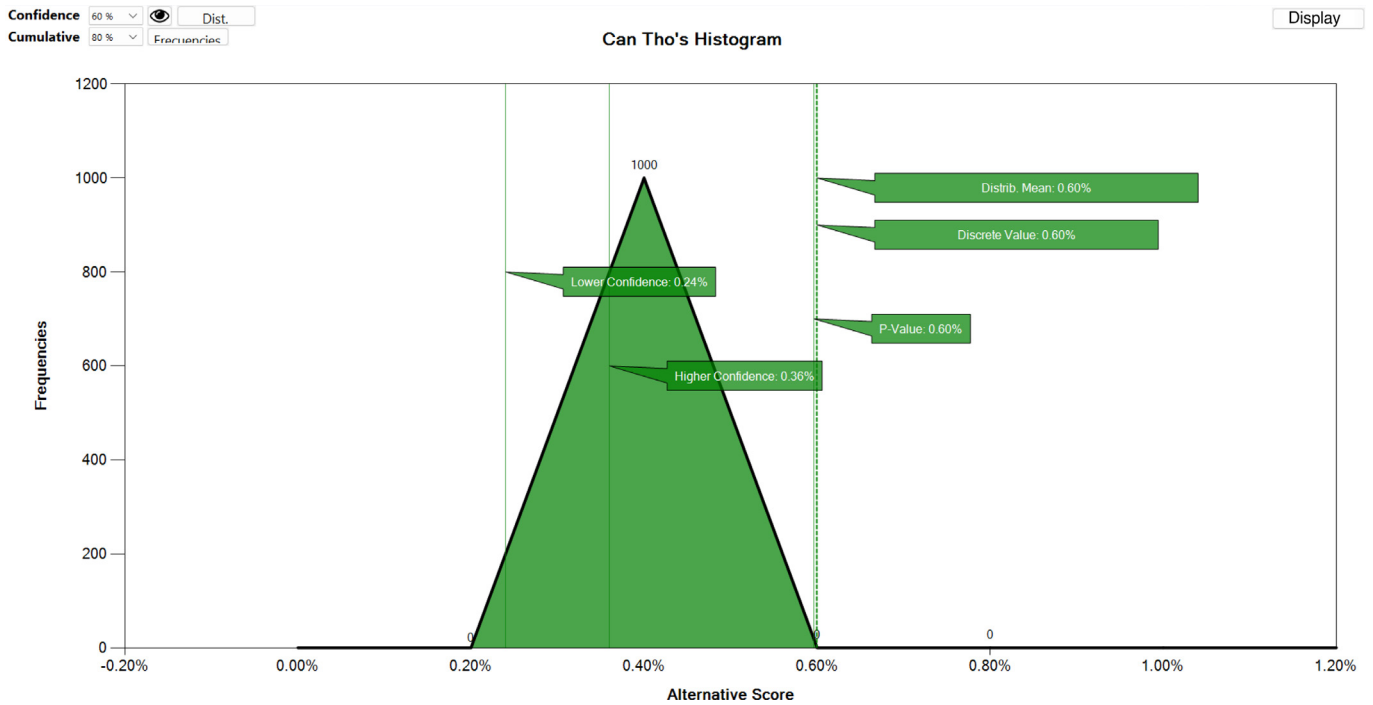


Fig. 8. Frequency distribution chart of Can Tho in the Monte Carlo simulation.

Finally, in the chart for Can Tho (Fig. 8), the mean value is higher than that of Hanoi but lower than that of Ho Chi Minh City. The confidence interval is similar to Hanoi's. Although Can Tho scores relatively high, its likelihood of achieving this performance is less certain compared to Ho Chi Minh City. Therefore, Can Tho represents an intermediate alternative with potential but lacks stability.

4 Discussion

4.1 Discussion

In the context of rapid globalization and urbanization, evaluating sustainable development can no longer rely on isolated criteria but requires MCDM methods capable of handling complex and multidimensional information.

However, a review of the literature reveals several notable research gaps. First, most existing studies focus primarily on areas such as energy, environment, or engineering projects, while urban planning and city-level sustainability assessment remain relatively limited, especially in developing countries like Vietnam. Second, the dominant use of a single MCDM method poses the risk of bias due to the specific computational nature of each tool. Finally, sensitivity analysis and robustness testing of results are often neglected, limiting the practical value of findings in public policy and sustainable investment planning.

To address these limitations, this study integrates four popular MCDM methods – AHP, TOPSIS, ELECTRE, and PROMETHEE – into a unified assessment framework, using real data from three representative Vietnamese cities: Hanoi, Ho Chi Minh City, and Can Tho. Comparing the ranking results across methods not only reveals the suitability of each tool but also reflects how each method “interprets” the concept of sustainable development from its own perspective.

AHP: Weight-oriented – emphasizing structure. AHP uses pairwise comparison matrices and predetermined weights. In this study, criteria related to healthcare and education – such as vaccination rates and school attendance – were assigned high weights, giving Ho Chi Minh City a clear advantage. However, AHP’s major drawback lies in its heavy reliance on initial weight assignment; if the weights do not adequately reflect the balance among economic, social, and environmental dimensions, the results may be skewed. Additionally, due to its additive nature, smaller criteria are often “overshadowed”.

TOPSIS: Sensitive to extremes – idealization-oriented. TOPSIS calculates the distance to an ideal and a worst-case solution. For cities with generally average performance like Ho Chi Minh City, this method produces favorable results. However, it is highly sensitive to outlier values, meaning a single very high or low indicator can distort the overall ranking. In this case, TOPSIS ranked Ho Chi Minh City highest, though this may not fully reflect Hanoi’s environmental advantages or Can Tho’s climate resilience.

Unlike AHP or TOPSIS, which rely on aggregate scores, ELECTRE compares city pairs by criterion to determine how many and to what extent one city outperforms another. Results show Ho Chi Minh City ranked highest due to its strong lead in many socio-economic indicators such as income, healthcare, and education. Can Tho ranked second, benefiting from slightly stronger economic indicators than Hanoi. Despite its environmental strengths, Hanoi ranked last because it did not sufficiently outperform other cities in pairwise comparisons. ELECTRE’s strength lies in clarifying dominance relationships between options, which is particularly useful when making competitive decisions. However, it does not reflect overall development levels and can be difficult to interpret for those unfamiliar with outranking logic.

PROMETHEE: Better criterion balance – sensitive to non-economic criteria. PROMETHEE was the only method in this study that ranked Hanoi first, reflecting its strength in highlighting environmental and quality-of-life criteria, which were underrepresented in the other methods due to lower weights. PROMETHEE employs preference functions instead of scores, making it more suitable for evaluating public policies, equitable resource allocation, and non-material values.

Conclusion: The differences in rankings across methods clearly illustrate that no single MCDM technique is universally optimal. Each method offers a different perspective on sustainable development. If a local government chooses the wrong tool, it may overlook critical aspects of sustainability – such as environmental quality in Hanoi or climate resilience in Can Tho. The findings of this study highlight that the choice of MCDM method can significantly influence policy interpretation and priority setting. Therefore, rather than relying on a single tool, policymakers should select methods that best align with their strategic objectives and data characteristics. AHP is suitable when predefined policy weights and transparent hierarchical structures are required. TOPSIS provides a clear visualization of overall performance gaps but should be complemented with sensitivity analysis to avoid distortion by extreme values. ELECTRE is useful for exploring dominance and trade-offs between alternatives, especially in comparative urban analyses. PROMETHEE, on the other hand, offers flexibility in incorporating qualitative or non-economic criteria, making it valuable for inclusive and equity-oriented planning. Finally, integrating robustness analysis across these methods can enhance result stability and strengthen decision confidence. A hybrid or ensemble MCDM framework – such as the one proposed in this study – thus represents a promising direction for achieving more balanced, evidence-based, and context-sensitive sustainability assessments.

4.2 Policy implications for urban governance

The findings of this study reveal significant disparities in the sustainability rankings of three major urban centers in Vietnam when applying different MCDM methods. This not only reflects the multidimensional nature of sustainable development but also highlights the necessity of adjusting national development policies to ensure a balanced approach across the three pillars: economic, social, and environmental.

In practice, development policies in Vietnam remain skewed toward economic growth, with insufficient attention given to social and environmental dimensions. As a result, localities with strengths in environmental quality or social well-being are often undervalued in resource allocation. This suggests that the choice of assessment tools not only affects final rankings but also influences the underlying mindset in policy formulation.

To address this issue, the national sustainability index system should be revised to better reflect regional characteristics and align with long-term strategic objectives. This includes recalibrating the weights assigned to various criteria to achieve a more balanced representation. Moreover, a policy zoning mechanism should be established based on geographic, ecological, and developmental characteristics, thereby clarifying strategic priorities for each region. Specifically:

- For large urban centers such as Ho Chi Minh City, policy should aim to balance economic development with green transition, smart mobility, and the promotion of a circular economy;
- In Hanoi, it is essential to maintain and enhance urban environmental quality and quality of life;

- For the Mekong Delta region, with Can Tho as the central hub, policies should prioritize climate change adaptation while strengthening healthcare and social infrastructure to reduce disparities with the other two cities.

Additionally, the public budgeting and investment allocation mechanisms should be reformed toward a multi-criteria integrated approach. The use of tools such as AHP, TOPSIS, ELECTRE, and PROMETHEE in project selection, urban planning, or regional prioritization will help ensure objectivity, transparency, and alignment with comprehensive development goals. In particular, PROMETHEE, with its ability to prioritize non-economic criteria, may be effectively applied in environmental impact assessments, equitable resource distribution, and social policy formulation. The government should also enhance local autonomy in sustainable strategic planning while strengthening institutional capacity, data governance, and decision-making skills based on MCDM models. Furthermore, building open data platforms for sustainable development and integrating real-time monitoring and evaluation systems will provide a robust foundation for evidence-based policymaking.

Finally, the government should pilot and scale up regionally linked sustainability assessment models, particularly in key economic zones and high-risk areas such as the Mekong Delta. These pilot models will play a crucial role in refining decision-making tools, tailoring policies to practical contexts, and institutionalizing MCDM approaches in national policy planning and oversight. Thus, the concurrent application of multiple evaluation tools in different settings will enhance the quality of decision-making, ensure regional equity, and promote a more comprehensive, flexible, and effective pathway to sustainable development in Vietnam.

5 Conclusion

This study was conducted to develop a comprehensive and scientifically grounded evaluation framework that addresses existing limitations in assessing urban sustainability by applying and comparing four widely used MCDM methods — AHP, TOPSIS, ELECTRE, and PROMETHEE — across three major Vietnamese cities, rather than relying on a single technique. The results show a certain degree of consistency among the methods despite differences in their ranking principles. This confirms that a multi-method approach generates more objective, robust, and reliable assessments of urban sustainable development. By integrating diverse decision-making logics — from weight-based methods and distance-to-ideal solutions to outranking models and preference functions — the study provides a multidimensional perspective that more accurately reflects the inherent complexity of sustainability evaluation.

Beyond methodological contributions, the findings deepen the understanding of how different sustainability criteria influence evaluation outcomes, particularly when linked to the SDG indicator framework. The analysis indicates that criteria related to SDG 3 (good health and well-being), SDG 11 (sustainable cities and communities), and SDG 13 (climate action) play pivotal roles and strongly affect the stability of rankings. Sensitivity analysis further reveals that variations in environmental quality, health-

care services, and climate adaptation capacity can shift the relative positions of the cities. These results underscore that urban areas must prioritize public health, environmental protection, and climate resilience as foundational pillars in sustainable development strategies.

The study also demonstrates the practical value of MCDM tools for policymakers by assessing the suitability of each method for the context of urban planning and sustainable development in Vietnamese cities. The comparative results provide a transparent evidence base to support strategic decisions — ranging from resource allocation and urban planning to project selection and policy performance monitoring. Integrating multiple methods reduces dependence on a single computational logic, thereby enhancing the reliability of policy recommendations and supporting evidence-based, equitable, and SDG-aligned decision-making. Policymakers may consider establishing periodic evaluation mechanisms, applying SDG-based indicator sets to monitor sustainability progress, and prioritizing policies that promote green investment, improve healthcare services, and strengthen climate resilience.

However, despite achieving its research objectives and contributing to both theory and practice, the study still has several limitations. Although focused on core pillars of sustainable development — economic, social, and environmental — the analysis does not fully incorporate other important dimensions such as political, technical, or governance factors, which are also relevant to the SDGs. Additionally, while the use of multiple MCDM methods provides more comprehensive insights, inherent differences in computational principles and decision logics may introduce discrepancies in rankings, highlighting the need for careful method selection. Moreover, the evaluation covers only three representative cities, which may not fully capture the national landscape of urban sustainability. Although sensitivity analysis was conducted to examine the influence of key criteria on ranking stability, future research could further explore criterion-level interactions of weighting scenarios. Furthermore, the effectiveness of each MCDM method depends substantially on data quality and completeness. For example, missing or low-resolution indicators can strongly influence methods such as TOPSIS and AHP, while ELECTRE may be more flexible in handling data gaps.

Based on these findings and limitations, future research can be expanded in several directions. Instead of focusing solely on three cities, subsequent studies may include a larger number of urban areas to generate a more comprehensive national assessment of sustainability. Integrating additional methods such as VIKOR or DEA may also help validate ranking robustness. Moreover, incorporating real-time data and developing dynamic evaluation systems that continuously reflect changes in sustainability conditions could provide more accurate and timely assessments. Longitudinal studies should also be conducted to track temporal variations in sustainability indicators, thereby enabling deeper analysis of long-term urban development trends. Integrating multiple MCDM methods into a unified decision-making framework may help minimize discrepancies between individual techniques and produce more balanced and objective evaluations. The findings can be used by government agencies to formulate

sustainable urban development policies, identify strategic priorities, and establish evidence-based monitoring programs that ensure progress toward greener, smarter, and climate-resilient cities. The results also offer valuable references for businesses and investors in assessing regional development potential. Importantly, tracking changes in individual indicators over time can help policymakers evaluate the effectiveness of implemented strategies and make timely adjustments to ensure future sustainability.

Overall, this study not only contributes comparative methodological insights into the application of MCDM methods but also provides a practical framework that supports policymaking, investment decisions, and sustainable urban planning in Vietnam and similar contexts, forming a foundation for evidence-based strategies that are adaptive to evolving urban challenges.

Funding

This work was supported by The University of Danang – University of Science and Technology, code number of Project: T2025-02-06.

Conflicts of interest

The authors have nothing to disclose. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability statement

This article has no associated data generated or analyzed.

Author contribution statement

Thi-Hoang-Giang TRAN: Conceptualization, Methodology, supervision, Writing – original draft.

Thi-Quynh-Giang TRAN: Investigation, Data Curation, Writing – original draft.

Le-Vi-Nhan-Tam TRAN: Investigation, Writing – review & editing.

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Cite this article as: Thi-Hoang-Giang Tran, Thi-Quynh-Giang Tran, Le-Vi-Nhan-Tam Tran, An evaluation of sustainable development levels in cities using multi-criteria decision-making methods: a case study of three major Vietnamese cities, *Int. J. Simul. Multidisci. Des. Optim.* **17**, 6 (2026), <https://doi.org/10.1051/smdo/2026001>

Appendix: A

Table A1. A synthesis of the reviewed scientific articles.

	Research title	Methods	Level of application	Scope of application
1	The Contribution of MCDM to SUMP: The Case of Spanish Cities during 2006-2021	SIMUS, WSM	Experiment	Urban planning (sustainable urban mobility)
2	Evaluating health-care waste treatment technologies using a hybrid multi-criteria decision making model	DEMATEL, fuzzy MULTIMOORA	Experiment	Environment
3	Multi criteria decision analysis to develop an optimized municipal solid waste management scenario: a case study in Ulaanbaatar, Mongolia	TOPSIS	Evaluation (scenario analysis)	Environment
4	A MCDM framework for site selection of island photovoltaic charging station based on new criteria identification and a hybrid fuzzy approach	fuzzy AHP, ENTROPY, fuzzy VIKOR	Evaluation (sensitivity analysis)	Energy
5	General model of Photovoltaic (PV) integration into existing public high-rise residential buildings in Singapore – Challenges and benefits	VIKOR	Evaluation (sensitivity analysis)	Energy
6	Evaluation of decision-support tools for coastal flood and erosion control: A multicriteria perspective	AHP, TOPSIS, PROMETHEE, ELECTRE, VIKOR, MAUT, TODAIM	Experiment	Civil engineering and infrastructure
7	Comparative analysis of multi-criteria models for decision-making in the process of building adaptation	MCDA	Concept	Civil engineering and infrastructure
8	Developing an Iranian green building assessment tool using decision making methods and geographical information system: Case study in Mashhad city	AHP, ENTROPY	Experiment	Civil engineering and infrastructure
9	Prevention/mitigation of natural disasters in urban areas	MCDM	Concept	Civil engineering and infrastructure
10	Low-carbon emission development in Asia: energy sector, waste management and environmental management system	MCDM	Concept	Energy, environment
11	Urban quality in the city of the future: A bibliometric multicriteria assessment model	AHP	Model	Urban planning (assessment of urban quality)
12	Waste to energy bio-digester selection and design model for the organic fraction of municipal solid waste	MCDA	Experiment	Environment
13	A review of multi criteria decision making (MCDM) towards sustainable renewable energy development	MCDM	Concept	Energy
14	Comparative analysis of MCDM methods for ranking renewable energy sources in Taiwan	ENTROPY SHANNON, WSM, VIKOR, TOPSIS, ELECTRE	Evaluation (sensitivity analysis)	Energy
15	Green decoration materials selection under interior environment characteristics: A grey-correlation based hybrid MCDM method	AHP, GC-TOPSIS	Evaluation (sensitivity analysis)	Civil engineering and infrastructure
16	Prioritization of renewable energy alternatives by using an integrated fuzzy MCDM model: A real case application for Turkey	fuzzy AHP, fuzzy TOPSIS	Evaluation (sensitivity analysis)	Energy
17	Development of the location suitability index for wave energy production by ANN and MCDM techniques	MCDM, ANN	Experiment	Energy
18	Sustainability evaluation of Concentrated Solar Power (CSP) projects under Clean Development Mechanism (CDM) by using Multi Criteria Decision Method (MCDM)	MCDM, MAUT	Evaluation (scenario analysis)	Energy
19	Geolocation of photovoltaic farms using Geographic Information Systems (GIS) with Multiple-criteria decision-making (MCDM) methods: Case of the Ecuadorian energy regulation	GIS, MCDM	Evaluation (correlation analysis, absolute error)	Energy

Table A1. (continued).

	Research title	Methods	Level of application	Scope of application
20	MCDM-based flood risk assessment of metro systems in smart city development: A review	MCDM, GIS	Experiment	Environment
21	Multi actor multi criteria analysis (MAMCA) as a tool to build indicators and localize sustainable development goal 11 in Brazilian municipalities	MAMCA	Experiment	Urban planning (SDGs 11)
22	Machine learning-based digital district heating/cooling with renewable integrations and advanced low-carbon transition	MCDM, ML	Model	Energy
23	An MCDM-GIS based site suitability analysis for solar power plant integration in Cameroon: Solar hybridization to optimize green electricity and hydrogen production	AHP, GIS	Evaluation	Energy
24	An ANP and fuzzy TOPSIS-based SWOT analysis for Turkey's energy planning	SWOT, ANP, fuzzy TOPSIS	Experiment	Energy
25	Analytical hierarchy process (AHP) application for reinforcement of hydropower strategy in Nepal	AHP	Experiment	Energy
26	Sustainable material selection for construction industry – A hybrid multi criteria decision making approach	MCDM	Experiment	Civil engineering and infrastructure
27	Integration of BIM and Value Model for Sustainability Assessment for application in bridge projects	MIVES+BIM	Evaluation (sensitivity analysis)	Civil engineering and infrastructure
28	Neuro-fuzzy resource forecast in site suitability assessment for wind and solar energy: A mini review	GIS, MCDM, ANFIS	Experiment	Energy
29	Evaluate the impact of COVID-19 prevention policies on supply chain aspects under uncertainty	BWM, TOPSIS	Experiment	Operations and supply chain management
30	A combined goal programming – AHP approach supported with TOPSIS for maintenance strategy selection in hydroelectric power plants	AHP, TOPSIS	Experiment	Energy
31	The development of a mining method selection model through a detailed assessment of multi-criteria decision methods	TOPSIS, TODIM, VIKOR, GRA, PROMETHEE, OCRA, ARAS, COPRAS, SAW, CP	Evaluation(sensitivity analysis, Spearman's rank correlation coefficient, Kendall's tau coefficient)	Mining
32	Monte Carlo and Fuzzy AHP with GIS for ranking hybrid solar-wind sites for electricity and hydrogen production in Cameroon	AHP, FAHP, MFAHP và GIS	Evaluation (sensitivity analysis)	Energy
33	Analysis, modelling and optimization during sustainable Dry and MQL turning of AISI 52100 steel using DF, GRA, EAMR, EDAS and FUCA methods	GRA, EAMR, FUCA và EDAS	Evaluation (Taguchi analysis)	Operations and supply chain management
34	Introducing a Novel multi-criteria Ranking of Alternatives with Weights of Criterion (RAWEC) model	RAWEC, LMAW (MCDM)	Evaluation (sensitivity analysis)	Operations and supply chain management
35	Eclectic decision for the selection of tree borne oil (TBO) as alternative fuel for internal combustion engine	AHP, MOORA, PROMETHEE	Evaluation (Spearman's rank correlation coefficient)	Energy
36	Analysis of insolation potential of Knjaževac Municipality (Serbia) using multi-criteria approach	AHP	Experiment	Energy
37	Creative trans-border cooperation in the field of operations research and sustainable development in civil engineering	MCDM	Concept	Civil engineering and infrastructure
38	Review of methods for sustainability appraisals in ship acquisition	MCDM	Concept	Procurement management
39	Integrating life cycle assessment and multi criteria decision making for sustainable waste management: Key issues and recommendations for future studies	MCDM, LCA	Concept	Environment

Table A1. (continued).

	Research title	Methods	Level of application	Scope of application
40	Material selection in the construction industry: a systematic literature review on multi-criteria decision making	MCDM-AHP	Concept	Civil engineering and infrastructure
41	Literature review: Multi-criteria decision-making method application for sustainable deep-sea mining transport plans	MCDM	Concept	Deep-sea mining.
42	Evaluating and prioritizing the healthcare waste disposal center locations using a hybrid multi-criteria decision-making method	AHP, fuzzy TOPSIS, fuzzy PROMETHEE	Experiment	Environment
43	Optimization solar site selection by fuzzy logic model and weighted linear combination method in arid and semi-arid region: A case study Isfahan-IRAN	Fuzzy logic, WLC, MCDM	Experiment	Energy
44	Assessment of biomass energy sources and technologies: The case of Central America	Fuzzy MCDM	Experiment	Energy
45	The evaluation of solar farm locations applying Geographic Information System and Multi-Criteria Decision-Making methods: Case study in southern Morocco	GIS, AHP	Experiment	Energy
46	A framework for urban pluvial flood resilient spatial planning through blue-green infrastructure	AHP, ANP	Model	Civil engineering and infrastructure
47	A hybrid novel framework for flood disaster risk control in developing countries based on smart prediction systems and prioritized scenarios	ML,DSS, TOPSIS	Experiment	Environment
48	Advances in thermal energy storage: Fundamentals and applications	MCDM	Experiment	Energy
49	Building information modelling application for developing sustainable building (Multi criteria decision making approach)	ANP	Model	Civil engineering and infrastructure
50	Assessing the critical success factors for implementing industry 4.0 in the pharmaceutical industry: Implications for supply chain sustainability in emerging economies	BWM	Model	Operations and supply chain management
51	Sustainable development of sewage sludge-to-energy in China: Barriers identification and technologies prioritization	DEMATEL	Experiment	Environment
52	Multi-objective decision-making methods for optimising CO2 decisions in the automotive industry	MOOP	Experiment	Environment, energy
53	Smart Techniques Promoting Sustainability in Construction Engineering and Management	MCDM, kỹ thuật thông minh	Concept	Civil engineering and infrastructure
54	Selection of energy performance contracting business models: A behavioral decision-making approach	TODIM	Evaluation (sensitivity analysis)	Energy
55	An approach for evaluation of the spent nuclear fuel management strategy for Brazilian nuclear power plants based on Multi-Criteria Decision-Making methodology	AHP	Model	Energy
56	A review of sustainable planning of Burundian energy sector in East Africa	MCDM-LEAP	Concept	Energy
57	Preparation, characterization, and selection of nano-assisted phase change materials for thermal management and storage applications	NePCM, MCDM	Model	Energy (SGD 7 VÀ SGD 13)
58	Technology-enhanced community forest management in tropical regions: A state of the art	MCDM,SLR,CFM	Experiment	Environment
59	Recycling of waste lubricating oil: A review of the recycling technologies with a focus on catalytic cracking, techno-economic and life cycle assessments	TEA, MCDM,LCA	Concept	Environment

Table A1. (continued).

	Research title	Methods	Level of application	Scope of application
60	Determining an optimum pattern of mixed planting from organic and non-organic crops with regard to economic and environmental indicators: A case study of cucumber in Kerman, Iran	AHP, Weighted Goal Programming	Experiment	Operations and supply chain management
61	Renewable energy in the mining industry: Status, opportunities and challenges	MCDM	Model	Energy
62	Application of multicriteria decision methods for electric supply planning in rural and remote areas	AHP, VIKOR	Experiment	Energy
63	Generating a framework to facilitate decision making in renewable energy investments	ANP	Model	Energy
64	Using Multi-Criteria Decision-Making to optimise solid waste management	AHP, MAUT, TOPSIS	Concept	Environment
65	Green Supplier Selection Based on Green Practices Evaluated Using Fuzzy Approaches of TOPSIS and ELECTRE with a Case Study in a Chinese Internet Company	fuzzy TOPSIS, fuzzy ELECTRE	Evaluation (sensitivity analysis)	Operations and supply chain management
66	Evaluation of research on CO2 trans-critical work recovery expander using multi attribute decision making methods	fuzzy AHP, TOPSIS, PROMETHEE	Concept	Energy
67	An ANP and fuzzy TOPSIS-based SWOT analysis for Turkey's energy planning	SWOT, ANP, fuzzy TOPSIS	Experiment	Energy
68	A soft computing based-modified ELECTRE model for renewable energy policy selection with unknown information	HF-M-ELECTRE (ELECTRE cải tiến)	Experiment	Energy
69	Urban flood simulation and prioritization of critical urban sub-catchments using SWMM model and PROMETHEE II approach	PROMETHEE II, SWMM model	Experiment	Civil engineering and infrastructure
70	A combined goal programming – AHP approach supported with TOPSIS for maintenance strategy selection in hydroelectric power plants	AHP, TOPSIS	Experiment	Civil engineering and infrastructure
71	Assessing organizations performance on the basis of GHRM practices using BWM and Fuzzy TOPSIS	BWM, fuzzy TOPSIS	Experiment	Human resource management
72	Investigation of feasibility study of solar farms deployment using hybrid AHP-TOPSIS analysis: Case study of India	AHP TOPSIS	Experiment	Energy
73	The spatiotemporal evolution pattern of urban resilience in the Yangtze River Delta urban agglomeration based on TOPSIS-PSO-ELM	TOPSIS	Experiment	Civil engineering and infrastructure
74	Assessing and prioritizing biogas barriers to alleviate energy poverty in Pakistan: an integrated AHP and G-TOPSIS model	DELPHI, AHP, G-TOPSIS	Experiment	Energy
75	Site selection for artificial recharge with treated wastewater with the integration of multi-criteria evaluation and ELECTRE III	AHP, ELECTRE III	Experiment	Environment
76	A decision support approach employing the PROMETHEE method and risk factors for critical supply assessment in large-scale projects	PROMETHEE II, PROMETHEE GDSS	Experiment	Operations and supply chain management
77	Evaluation of future sustainable electricity generation alternatives: The case of a Greek island	PROMETHEE II	Evaluation (sensitivity analysis)	Energy
78	Prioritization of renewable energy alternatives by using an integrated fuzzy MCDM model: A real case application for Turkey	fuzzy AHP, fuzzy TOPSIS	Evaluation (sensitivity analysis)	Energy
79	Penstock material selection in small hydropower plants using MADM methods	AHP, TOPSIS	Experiment	Civil engineering and infrastructure

Table A1. (continued).

	Research title	Methods	Level of application	Scope of application
80	Assessing the Best Supplier Selection Criteria in Supply Chain Management During the COVID-19 Pandemic	TBL, Fuzzy TOPSIS	Experiment	Operations and supply chain management
81	Evaluation on adsorption capacity of low organic matter soil for hydrophobic organic pollutant	TOPSIS	Model	Environment
82	Role prioritization of hydrogen production technologies for promoting hydrogen economy in the current state of China	fuzzy AHP, fuzzy TOPSIS	Experiment	Energy, production
83	Incorporation of management responses in the direction of soil erosion changes from the past to the future based on the RUSLE and DPSIR model	TOPSIS	Experiment	Environment
84	Sustainability in Pakistan's textile industry: analyzing barriers and strategies for green supply chain management implementation	fuzzy AHP, fuzzy TOPSIS	Experiment	Operations and supply chain management
85	Multi-objective power supply capacity evaluation method for active distribution network in power market environment	ENTROPY, TOPSIS	Experiment	Energy
86	Analysis of solar module alternatives for efficiency-based energy investments with hybrid 2-tuple IVIF modeling	DEMATEL, TOPSIS	Model	Energy
87	A general framework for sustainability assessment of manufacturing processes	MCDM	Evaluation (sensitivity analysis)	Operations and supply chain management
88	Indicator based multi-criteria decision support systems for wastewater treatment plants	DSS, fuzzy AHP, TOPSIS	Model	Environment
89	Optimization and selection of the multi-objective conceptual design scheme for considering product assembly, manufacturing and cost	TOPSIS	Model	Operations and supply chain management
90	An empirical analysis of the impact of the coupling coordination degree of the water-energy-food nexus on food security in China	TOPSIS	Experiment	Water–energy–food
91	Sustainable material selection for construction industry – A hybrid multi criteria decision making approach	DANP, TOPSIS	Experiment	Civil engineering and infrastructure
92	Social sustainability assessments in the biobased economy: Towards a systemic approach	MCDM	Model	Biobased economy

Table A2. Determination of thresholds.

	Indifference threshold (q)	Preference threshold (p)	Veto threshold (v)
x_1	0.001	0.003	0.01
x_2	0.0001	0.0003	0.001
x_3	0.005	0.015	0.05
x_4	0.01	0.03	0.1
x_5	0.01	0.03	0.1
x_6	0.05	0.1	0.3
x_7	0.01	0.03	0.1
x_8	0.01	0.03	0.1
x_9	0.05	0.1	0.3
x_{10}	0.05	0.1	0.3
x_{11}	0.001	0.003	0.01
x_{12}	0.05	0.15	0.5

Table A2. (continued).

	Indifference threshold (q)	Preference threshold (p)	Veto threshold (v)
x_{13}	0.005	0.015	0.05
x_{14}	0.005	0.015	0.05
x_{15}	0.005	0.015	0.05
x_{16}	0.05	0.15	0.5
x_{17}	0.005	0.015	0.05
x_{18}	0.001	0.003	0.01
x_{19}	0.05	0.15	0.5
x_{20}	0.05	0.15	0.5
x_{21}	0.05	0.15	0.5
x_{22}	0.05	0.15	0.5
x_{23}	0.05	0.1	0.3
x_{24}	0.05	0.15	0.5
x_{25}	0.05	0.15	0.5
x_{26}	0.1	0.3	0.7
x_{27}	0.1	0.3	0.7
x_{28}	0.05	0.15	0.5

Table A3. Concordance matrix.

	A_1/A_2	A_1/A_3	A_2/A_1	A_2/A_3	A_3/A_1	A_3/A_2	A_1/A_2
x_1	0.8	0	1	0	1	1	0.8
x_2	1	0	1	0	1	1	1
x_3	0.3	0	1	0	1	1	0.3
x_4	0	0	1	1	1	0	0
x_5	0	1	1	1	0.75	0	0
x_6	0	1	1	1	0	0	0
x_7	1	0	1	0	1	1	1
x_8	0	0	1	1	1	0	0
x_9	1	1	1	1	0	0	1
x_{10}	1	0	1	0	1	1	1
x_{11}	0	0	1	0	1	1	0
x_{12}	0	1	1	1	1	0	0
x_{13}	1	1	1	1	0	0	1
x_{14}	1	1	1	1	0	0	1
x_{15}	1	1	0.1	0.4	1	1	1
x_{16}	1	1	1	1	0	0	1
x_{17}	0	0	1	1	1	1	0
x_{18}	0	0	1	0	1	1	0
x_{19}	1	1	0	1	0	0.953	1
x_{20}	0.41	1	1	1	1	0.87	0.41
x_{21}	1	1	0.5	0.7	1	1	1
x_{22}	1	0	0	0	1	1	1
x_{23}	0	0	1	0	1	1	0
x_{24}	1	1	1	1	1	1	1
x_{25}	1	1	0.36	0.445	1	1	1
x_{26}	1	0	1	0	1	1	1
x_{27}	1	0	1	0	1	1	1
x_{28}	1	1	1	1	0	0	1

Table A4. Discordance matrix.

	A_1/A_2	A_1/A_3	A_2/A_1	A_2/A_3	A_3/A_1	A_3/A_2	A_1/A_2
x_1	0	0.757143	0	0.557143	0	0	0
x_2	0	0.857143	0	0.857143	0	0	0
x_3	0	0.428571	0	0.085714	0	0	0
x_4	1	0.442857	0	0	0	0.285714	1
x_5	0.571429	0	0	0	0	0.785714	0.571429
x_6	1	0	0	0	1	1	1
x_7	0	1	0	1	0	0	0
x_8	1	0.614286	0	0	0	0.252857	1
x_9	0	0	0	0	0.528	0.5375	0
x_{10}	0	0.335	0	0.435	0	0	0
x_{11}	0.385714	1	0	1	0	0	0.385714
x_{12}	0.254857	0	0	0	0	0.278	0.254857
x_{13}	0	0	0	0	0.657143	0.657143	0
x_{14}	0	0	0	0	0.428571	0.428571	0
x_{15}	0	0	0	0	0	0	0
x_{16}	0	0	0	0	0.402857	0.351429	0
x_{17}	0.028571	0.085714	0	0	0	0	0.028571
x_{18}	1	1	0	0.328571	0	0	1
x_{19}	0	0	0.216857	0	0.373143	0	0
x_{20}	0	0	0	0	0	0	0
x_{21}	0	0	0	0	0	0	0
x_{22}	0	0.218857	0.306857	0.954286	0	0	0
x_{23}	0.215	1	0	1	0	0	0.215
x_{24}	0	0	0	0	0	0	0
x_{25}	0	0	0	0	0	0	0
x_{26}	0	0.59	0	0.46	0	0	0
x_{27}	0	1	0	1	0	0	0
x_{28}	0	0	0	0	0.331429	0.302857	0

Table A5. Preference function for alternative pairs.

	$A_1 - A_2$	$A_1 - A_3$	$A_2 - A_3$	$A_2 - A_1$	$A_3 - A_1$	$A_3 - A_2$
x_1	0.0019	0.0083	0.0069	0	0	0
x_2	0	0.0009	0.0009	0	0	0
x_3	0.012	0.03	0.018	0	0	0
x_4	0	0	0.05	0.111	0.061	0
x_5	0.7	0	0	0	0.015	0.085
x_6	0.429	0	0	0	0.433	0.862
x_7	0.043	0	0	0	0.1493	0.1536
x_8	0	0	0.0477	0.1207	0.0739	0
x_9	0	0.2056	0.2075	0.0019	0	0
x_{10}	0	0.167	0.187	0.02	0	0
x_{11}	0.0057	0.0257	0.02	0	0	0
x_{12}	0	0.0081	0.2473	0.2392	0	0
x_{13}	0	0.038	0.038	0	0	0
x_{14}	0	0.03	0.03	0	0	0
x_{15}	0.014	0.003	0	0	0	0.011

Table A5. (continued).

	$A_1 - A_2$	$A_1 - A_3$	$A_2 - A_3$	$A_2 - A_1$	$A_3 - A_1$	$A_3 - A_2$
x_{16}	0.018	0.291	0.273	0	0	0
x_{17}	0.016	0.018	0.002	0	0	0
x_{18}	0.0112	0.0165	0.0053	0	0	0
x_{19}	0	0	0	0.2259	0.2806	0.0547
x_{20}	0.109	0.046	0	0	0	0.063
x_{21}	0.1	0.02	0	0	0	0.08
x_{22}	0.2574	0	0	0	0.2266	0.484
x_{23}	0.17	0.786	0.616	0	0	0
x_{24}	0.039	0.016	0	0	0	0.023
x_{25}	0.114	0.0085	0	0	0	0.1055
x_{26}	0.052	0.536	0.484	0	0	0
x_{27}	0.061	0.883	0.822	0	0	0
x_{28}	0.01	0.302	0.256	0	0	0