Climate Change Reports

Journal Homepage: sciencesforce.com/ccr

SCIENCES FORCE
International Academic Publisher

Climate Cha. Rep. Vol. 1 (2024) 70–78

Paper Type: Original Article

Assessment and Ranking Ecological and Water Resources of Climate Change under Fuzzy Decision Making Model

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Received: 01 Dec 2023 **Revised:** 07 Mar 2024 **Accepted:** 08 Apr 2024 **Published:** 12 Apr 2024

Abstract

This paper suggested a decision-making model for evaluating and raking the ecological and water resources under climate change. The environmental and water resources have different criteria, so multi-criteria decision-making (MCDM) is used to deal with conflict criteria. The MCDM methodology integrated with the fuzzy sets to deal with uncertainty and vague information. The weights of the requirements are computed by the average method. The VIKOR method is used to rank the alternatives. This study used 11 criteria and 10 alternatives. The results show that alternative 10 is the best and alternative 2 is the worst. The sensitivity analysis was conducted in two parts; in the first part, the criteria weights are changed into 12 cases, and then the rank of alternatives is computed to show the stability of the results. The value of v in the VIKOR method is changed in the second part, and then the rank of alternatives is computed. The results show that the rank of other options is stable in different cases.

Keywords: Decision Making; Water Resources; Ecological Resources; Climate Change; Fuzzy Sets.

1 | Introduction

Natural resources and the ecosystems that depend on them are under strain due to the unequal distribution of these resources and their poor management, particularly in areas with dry or semi-arid climates. Climate change is one element that has the potential to worsen these effects [1-3]. Environmental resources planners suggest several Water and Environmental Resources Management Scenarios (WERMSs) to mitigate the negative consequences of resource scarcity, human decision-making, and climate change. Many agents have proposed, approved, and implemented these WERMSs. Agents can assess and modify the suggested tactics based on various factors that fit their jobs and interests [4, 5].

Reliability will increase when various agent attributes—such as their powers and interests—are considered during decision-making. Multi-criteria decision-making (MCDM) is one of the instruments used for this aim that has been employed most successfully. One of the most useful MCDM techniques for Water Resources Management (WRM) is the fusion of MCDM with Multi-Objective Analysis [6, 7].

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https://doi.org/10.61356/j.ccr.2024.1221

A number of research studies have also considered climate change while evaluating MCDM. This inclusion has become increasingly noticeable, particularly in domains like MCDM-based climate change adaptation analysis for WRM [8, 9].

Both qualitative and quantitative data should be included in a robust MCDM process for decision-making problems[10, 11]. Numerous unique factors were taken into account while assessing ecological and water resources[12, 13]. The fuzzy set theory seems to be a valuable tool for offering a decision-making framework that considers the erroneous assessments that are a part of evaluating ecological and water resources[14, 15].

This research aims to devise a decision-making methodology for a problem involving multiple information sources. This methodology allows for integrating explicit and fuzzy data [16, 17], represented as triangular fuzzy numbers or linguistic variables, into the analysis. It also avoids the problematic fuzzy number ranking process, which can produce inconsistent results if applying different ranking techniques [16, 17].

The rest of this paper is organized as follows: Section 2 introduces the MCDM methodology, which uses fuzzy sets to compute the weights of criteria and rank the alternatives. Section 3 introduces the fuzzy MCDM methodology results and ranks the alternatives with sensitivity analysis. Section 4 introduces the conclusions of this paper.

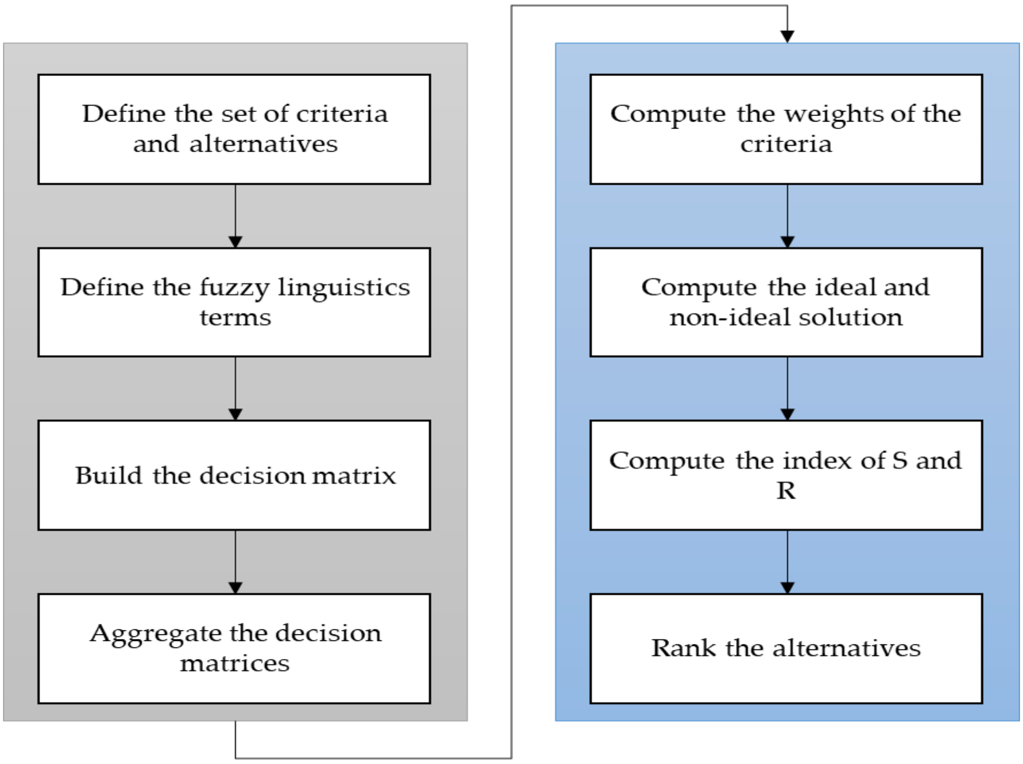

Figure 1. The steps of the fuzzy VIKOR method.

2 | MCDM Methodology

This section introduces the steps of the VIKOR method with fuzzy sets to rank the different water and ecological resources. The VIKOR method is an MCDM method used to rank the alternatives. Figure 1 shows the steps of the VIKOR method with the fuzzy sets. The fuzzy set deals with uncertainty and vague information in the assessment process of water and ecological resources.

Step 1. Define the set of criteria and alternatives.

This step invited experts to collect a set of criteria and alternatives. The criteria are the factors of water and ecological resources.

Step 2. Define the fuzzy linguistics terms.

The experts used fuzzy linguistic terms to evaluate the criteria and alternatives

Step 3. Build the decision matrix

We used fuzzy numbers to replace fuzzy linguistics to build the decision matrix between criteria and alternatives.

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}; \quad i = 1,2,\dots,m; j = 1,2,\dots,n \tag{1}$$

Step 4. Aggregate the decision matrices.

We obtain the crisp values in the decision matrices; then, we combine these matrices by the average method.

Step 5. Compute the weights of the criteria.

We used the average method to compute the weights of the criteria.

Step 6. Compute the ideal and non-ideal solution.

$$y_j^+ = \max_i x_{ij} \tag{2}$$

$$y_j^- = \min_i x_{ij} \tag{3}$$

$$y_j^+ = \min_i x_{ij} \tag{4}$$

$$y_j^- = \max_i x_{ij} \tag{5}$$

Step 7. Compute the index of S and R.

$$S_i = \sum_{j=1}^{n} w_j \frac{\left(y_j^+ - x_{ij}\right)}{\left(y_j^+ - y_j^-\right)} \tag{6}$$

$$R_i = \max_j \left[w_j \frac{\left(y_j^+ - x_{ij}\right)}{\left(y_j^+ - y_j^-\right)} \right] \tag{7}$$

Step 8. Rank the alternatives.

The alternatives are ranked based on the smallest value of Q_i.

$$Q_i = u \times \frac{(S_i - S^*)}{(S^- - S^*)} + (1 - u) \times \frac{(R_i - R^*)}{(R^- - R^*)} \tag{8}$$

$$S^* = \min_i S_i \tag{9}$$

$$S^- = \max_i S_i \tag{10}$$

$$R^* = \min_i R_i \tag{11}$$

$$R^* = \max_i R_i \tag{12}$$

Criteria	
Criteria	Water Supply
	Industrial water supply
	Participation of stakeholders
	Wastewater treatment level
	Reliability in budget allocation
	Financial Attractiveness
	Job-creation
	Cost
	Water Inflow
	The coverage of dust storm
	Agricultural water supply

Figure 2. The water and ecological resources criteria.

3 | Results

This section introduces the results of the fuzzy VIKOR method. We invited three experts who have expertise in water and ecological resources for more than 20 years.

Step 1. Define the set of criteria and alternatives.

Three experts gathered 11 criteria in this study as shown in Figure 2.

Step 2. Define the fuzzy linguistics terms.

Three experts used fuzzy linguistic terms to evaluate the criteria and alternatives.

Step 3. Build the decision matrix

Three experts used fuzzy numbers to evaluate the criteria and alternatives. Then the three decision matrices are built by using Eq. (1) as shown in Table A1-A3.

Step 4. Aggregate the decision matrices.

The average method is used to combine the decision matrices.

Step 5. Compute the weights of the criteria.

We compute the weights of criteria by average method as shown in Figure 3.

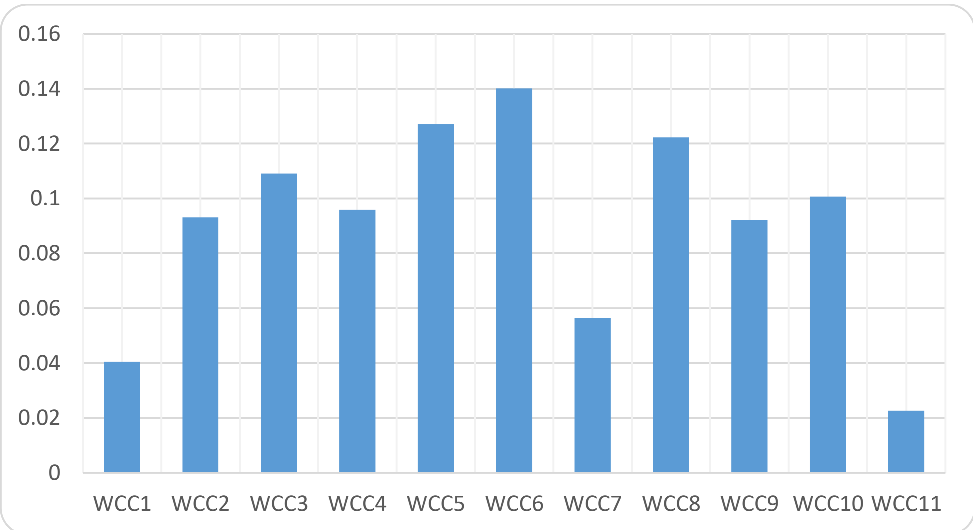

Figure 3. The weights of criteria.

Step 6. Compute the ideal and non-ideal solution by using Eqs. (2-5).

Step 7. Compute the index of S and R by using Eq. (6) and (7) as shown in Table 1.

Table 1. The values of normalized matrices.

	WCC_1	WCC_2	WCC_3	WCC_4	WCC_5	WCC_6	WCC_7	WCC_8	WCC_9	WCC_{10}	WCC_{11}
WCA_1	0.088	0.088	0.060649	0.016709	0.0352	0	0.033297	0.03119	0.077524	0.065043	0.12
WCA_2	0.072286	0.034305	0.039243	0.088	0.0704	0.088	0.088	0.061266	0.03981	0.082899	0.12
WCA_3	0.068095	0.074576	0.054703	0.072405	0.0528	0.063631	0.082054	0.036759	0.053429	0.048464	0.098571
WCA_4	0.03981	0.076068	0.022595	0.046785	0.0528	0.069046	0.076108	0.051241	0.068095	0.058667	0.06
WCA_5	0.04819	0.026847	0.054703	0.021165	0.0704	0.056862	0.044	0.076861	0.034571	0.082899	0.021429
WCA_6	0.044	0.06861	0.044	0.05681	0.064114	0.037908	0.048757	0.010025	0.038762	0.006377	0
WCA_7	0.015714	0.01939	0	0.06238	0.086743	0.037908	0.038054	0	0.058667	0.012754	0.098571
WCA_8	0.024095	0.005966	0.048757	0.00557	0.088	0.044677	0.021405	0.00557	0	0.088	0.098571
WCA_9	0.082762	0.007458	0.088	0	0.018857	0.013538	0	0.088	0.088	0	0.06
WCA_{10}	0	0	0.076108	0	0	0.020308	0.038054	0.071291	0.088	0.01913	0.06

Step 8. Rank the alternatives.

The alternatives are ranked based on the smallest value of Q_i by using Eq. (8) as shown in Figure 4. We put the value of v with 0.5. then the alternative 10 is the best and alternatives 2 is the worst.

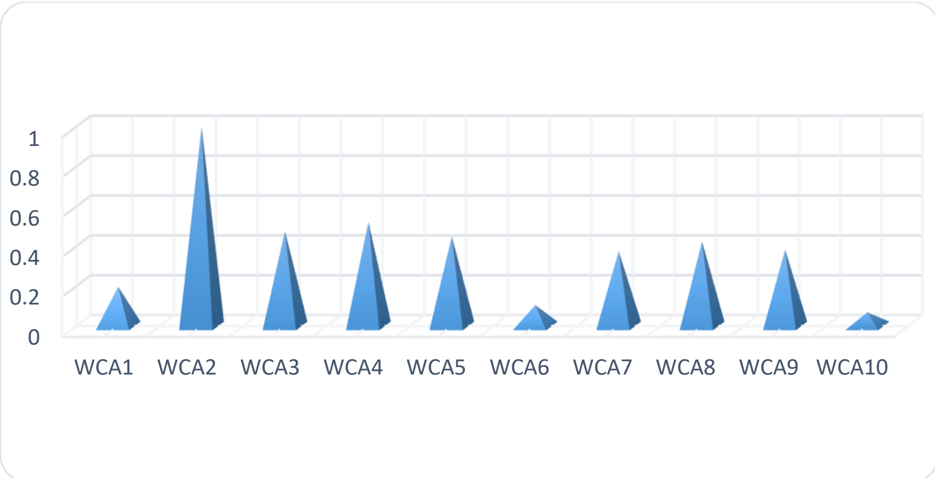

Figure 4. The values of Q_i.

3.1 | Sensitivity Analysis

This sub-section is divided into two parts. In the first part, we change the values of v between 0 and 1, then we compute the values of Q_i, then we rank the alternatives as shown in Figure 5. We show that alternative 2 is the worst in all cases. In cases 1,2,3,4 alternative 6 is the best and in other cases, alternative 10 is the best.

In the second part, we change the criteria weights and show the alternatives' rank. We proposed 12 cases in criteria weights. In the first case, we put that all criteria are equal. In the second case, we put the first criterion with 0.12 weight, and other weights are equal, as shown in Figure 6. Then, we rank the alternatives under sensitivity analysis. We show that alternative 10 is the best and alternative 2 is the worst, as shown in Figure 7.

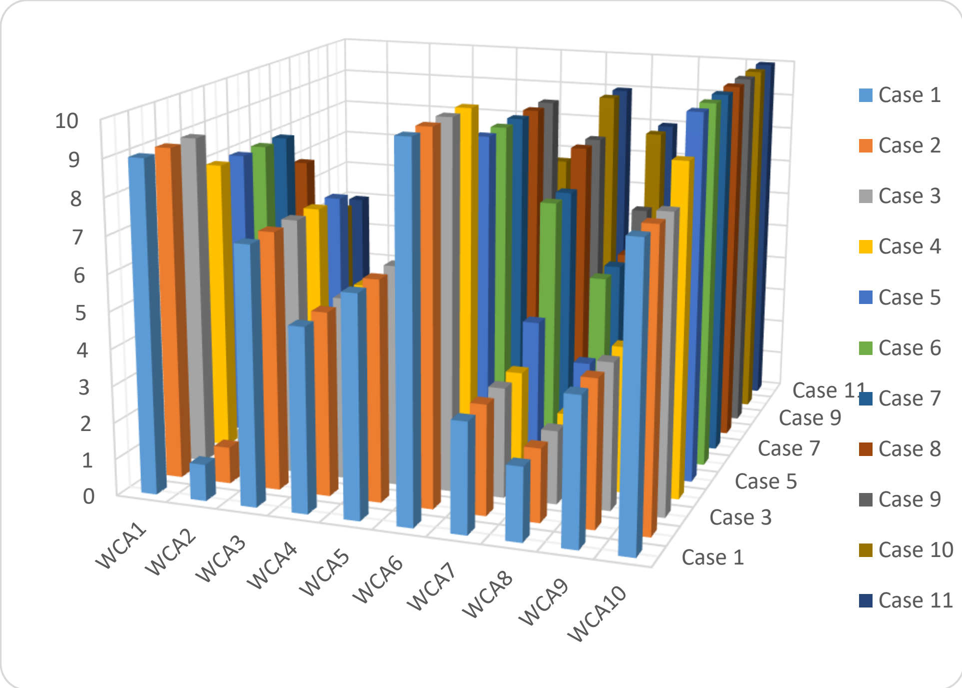

Figure 5. The rank of alternatives under sensitivity analysis with v values.

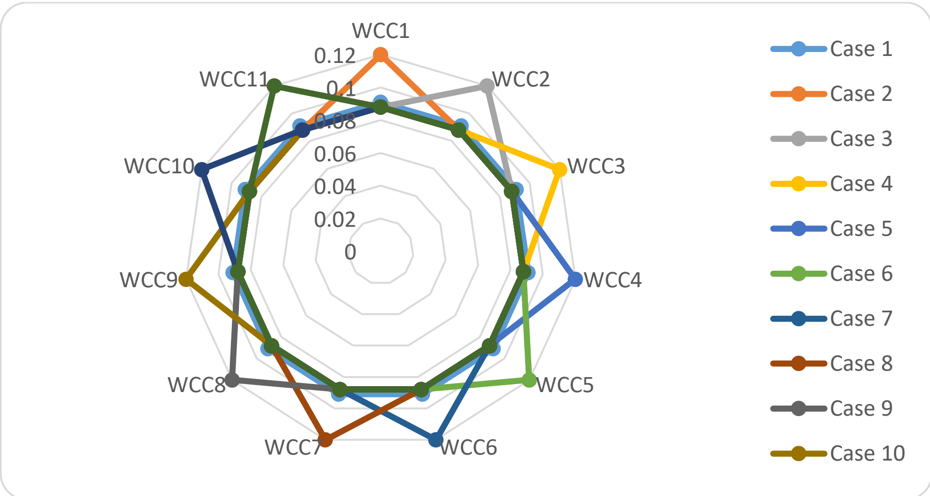

Figure 6. The weights of criteria under sensitivity analysis.

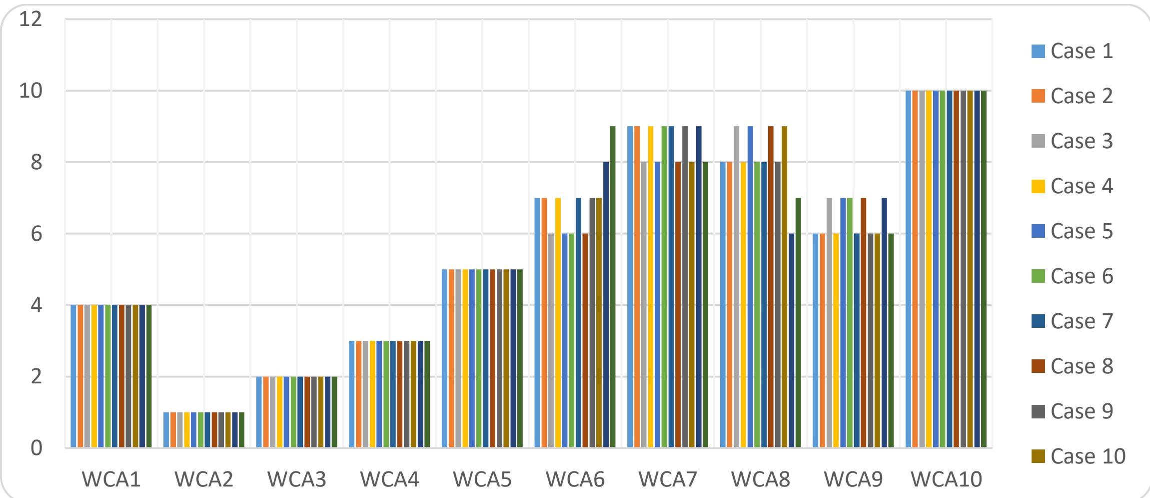

Figure 7. The rank of alternatives under sensitivity analysis.

4 | Conclusions

The fuzzy sets are used in this paper to overcome uncertainty and vague information in evaluating and ranking water and ecological resources. The MCDM methodology calculates the criteria weights and ranks the alternatives. The VIKOR method is used as an MCDM methodology to rank the alternatives. Three experts were invited to collect the set of criteria and alternatives. There are 11 criteria, and 10 alternatives are used in this study. Three experts used fuzzy linguistic terms to evaluate the criteria and alternatives; then the decision matrices were built. Then, we replaced these terms with fuzzy numbers. Then, we obtain the crisp values. Then, we compute the weights of the criteria and rank the alternatives. Alternative 10 is the best, and alternative 2 is the worst. The sensitivity analysis was conducted to show the stability of the rank. There are 12 cases are proposed with criteria weights to rank the alternatives. The results show the rank of alternatives is stable.

Other MCDM methods will be used in the future to compute the weights of criteria such as AHP, DEMATEL, BWM, etc. Various MCDM methods can be used to rank the alternatives, such as TOPSIS, WASPAS, MABAC, etc.

Acknowledgments

The author is grateful to the editorial and reviewers, as well as the correspondent author, who offered assistance in the form of advice, assessment, and checking during the study period.

Author Contribution

All authors contributed equally to this work.

Funding

This research has no funding source.

Data Availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that there is no conflict of interest in the research.

Ethical Approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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Appendix

Table A1. The first decision matrix.

	WCC_1	**WCC_2**	**WCC_3**	**WCC_4**	**WCC_5**	**WCC_6**	**WCC_7**	**WCC_8**	**WCC_9**	**WCC_{10}**	**WCC_{11}**
WCA_1	(0, 0, 0.2)	(0, 0.2, 0.4)	(0.3, 0.5, 0.7)	(0.6, 0.8, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0, 0.2, 0.4)	(0.3, 0.5, 0.7)	(0, 0, 0.2)
WCA_2	(0, 0.2, 0.4)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0, 0, 0.2)	(0.6, 0.8, 1)	(0.3, 0.5, 0.7)	(0, 0, 0.2)	(0, 0.2, 0.4)	(0.6, 0.8, 1)	(0, 0.2, 0.4)	(0, 0, 0.2)
WCA_3	(0, 0.2, 0.4)	(0, 0.2, 0.4)	(0.3, 0.5, 0.7)	(0, 0.2, 0.4)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0, 0, 0.2)	(0.6, 0.8, 1)	(0.8, 1, 1)	(0.6, 0.8, 1)	(0, 0.2, 0.4)
WCA_4	(0.6, 0.8, 1)	(0, 0, 0.2)	(0.6, 0.8, 1)	(0.3, 0.5, 0.7)	(0, 0.2, 0.4)	(0, 0.2, 0.4)	(0, 0.2, 0.4)	(0, 0.2, 0.4)	(0, 0.2, 0.4)	(0, 0.2, 0.4)	(0.3, 0.5, 0.7)
WCA_5	(0.8, 1, 1)	(0.8, 1, 1)	(0, 0.2, 0.4)	(0.6, 0.8, 1)	(0, 0, 0.2)	(0, 0, 0.2)	(0.6, 0.8, 1)	(0, 0, 0.2)	(0.6, 0.8, 1)	(0, 0, 0.2)	(0.6, 0.8, 1)
WCA_6	(0.3, 0.5, 0.7)	(0.6, 0.8, 1)	(0, 0, 0.2)	(0, 0.2, 0.4)	(0.8, 1, 1)	(0.8, 1, 1)	(0, 0.2, 0.4)	(0.8, 1, 1)	(0, 0.2, 0.4)	(0.8, 1, 1)	(0.8, 1, 1)
WCA_7	(0.6, 0.8, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0, 0, 0.2)	(0, 0.2, 0.4)	(0.3, 0.5, 0.7)	(0, 0, 0.2)	(0.8, 1, 1)	(0, 0, 0.2)	(0.6, 0.8, 1)	(0, 0.2, 0.4)
WCA_8	(0, 0.2, 0.4)	(0.8, 1, 1)	(0, 0.2, 0.4)	(0.8, 1, 1)	(0, 0, 0.2)	(0.3, 0.5, 0.7)	(0.8, 1, 1)	(0.6, 0.8, 1)	(0.8, 1, 1)	(0, 0.2, 0.4)	(0, 0.2, 0.4)
WCA_9	(0, 0, 0.2)	(0.6, 0.8, 1)	(0, 0, 0.2)	(0.8, 1, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0, 0, 0.2)	(0, 0, 0.2)	(0.8, 1, 1)	(0.3, 0.5, 0.7)
WCA_{10}	(0.8, 1, 1)	(0.6, 0.8, 1)	(0, 0.2, 0.4)	(0.8, 1, 1)	(0.8, 1, 1)	(0.6, 0.8, 1)	(0.3, 0.5, 0.7)	(0, 0.2, 0.4)	(0, 0, 0.2)	(0.6, 0.8, 1)	(0.3, 0.5, 0.7)

Table A2. The second decision matrix.

	WCC_1	WCC_2	WCC_3	WCC_4	WCC_5	WCC_6	WCC_7	WCC_8	WCC_9	WCC_{10}	WCC_{11}
WCA_1	(0, 0, 0.2)	(0, 0.2, 0.4)	(0.3, 0.5, 0.7)	(0.6, 0.8, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.6, 0.8, 1)	(0, 0.2, 0.4)	(0, 0.2, 0.4)	(0, 0.2, 0.4)	(0, 0, 0.2)
WCA_2	(0, 0.2, 0.4)	(0, 0.2, 0.4)	(0.6, 0.8, 1)	(0, 0.2, 0.4)	(0, 0.2, 0.4)	(0, 0.2, 0.4)	(0, 0, 0.2)	(0.3, 0.5, 0.7)	(0.6, 0.8, 1)	(0.3, 0.5, 0.7)	(0, 0, 0.2)
WCA_3	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0, 0, 0.2)	(0.6, 0.8, 1)	(0, 0.2, 0.4)	(0.6, 0.8, 1)	(0, 0.2, 0.4)
WCA_4	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0, 0.2, 0.4)	(0.8, 1, 1)	(0.3, 0.5, 0.7)	(0.8, 1, 1)	(0.3, 0.5, 0.7)
WCA_5	(0, 0.2, 0.4)	(0.8, 1, 1)	(0, 0.2, 0.4)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.3, 0.5, 0.7)	(0, 0.2, 0.4)	(0.6, 0.8, 1)	(0, 0.2, 0.4)	(0.6, 0.8, 1)
WCA_6	(0.3, 0.5, 0.7)	(0, 0.2, 0.4)	(0.3, 0.5, 0.7)	(0, 0.2, 0.4)	(0, 0.2, 0.4)	(0, 0.2, 0.4)	(0.6, 0.8, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)
WCA_7	(0.6, 0.8, 1)	(0.8, 1, 1)	(0.6, 0.8, 1)	(0, 0, 0.2)	(0, 0.2, 0.4)	(0.3, 0.5, 0.7)	(0.8, 1, 1)	(0.8, 1, 1)	(0, 0.2, 0.4)	(0.6, 0.8, 1)	(0, 0.2, 0.4)
WCA_8	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0, 0, 0.2)	(0.3, 0.5, 0.7)	(0, 0.2, 0.4)	(0.6, 0.8, 1)	(0.8, 1, 1)	(0, 0.2, 0.4)	(0, 0.2, 0.4)
WCA_9	(0, 0.2, 0.4)	(0.6, 0.8, 1)	(0, 0.2, 0.4)	(0.8, 1, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0, 0, 0.2)	(0, 0, 0.2)	(0.8, 1, 1)	(0.3, 0.5, 0.7)
WCA_{10}	(0.8, 1, 1)	(0.6, 0.8, 1)	(0, 0.2, 0.4)	(0.8, 1, 1)	(0.8, 1, 1)	(0.6, 0.8, 1)	(0.3, 0.5, 0.7)	(0, 0.2, 0.4)	(0, 0, 0.2)	(0.6, 0.8, 1)	(0.3, 0.5, 0.7)

Table A3. The third decision matrix.

	WCC_1	WCC_2	WCC_3	WCC_4	WCC_5	WCC_6	WCC_7	WCC_8	WCC_9	WCC_{10}	WCC_{11}
WCA_1	(0, 0, 0.2)	(0, 0.2, 0.4)	(0, 0, 0.2)	(0.6, 0.8, 1)	(0, 0, 0.2)	(0.8, 1, 1)	(0, 0, 0.2)	(0.6, 0.8, 1)	(0, 0, 0.2)	(0.3, 0.5, 0.7)	(0, 0, 0.2)
WCA_2	(0, 0.2, 0.4)	(0.6, 0.8, 1)	(0, 0, 0.2)	(0, 0, 0.2)	(0, 0, 0.2)	(0, 0, 0.2)	(0, 0, 0.2)	(0, 0.2, 0.4)	(0, 0, 0.2)	(0, 0, 0.2)	(0, 0, 0.2)
WCA_3	(0, 0, 0.2)	(0, 0.2, 0.4)	(0, 0.2, 0.4)	(0, 0, 0.2)	(0, 0.2, 0.4)	(0, 0, 0.2)	(0, 0.2, 0.4)	(0, 0, 0.2)	(0, 0, 0.2)	(0, 0, 0.2)	(0, 0.2, 0.4)
WCA_4	(0, 0, 0.2)	(0, 0, 0.2)	(0.3, 0.5, 0.7)	(0, 0.2, 0.4)	(0.3, 0.5, 0.7)	(0, 0.2, 0.4)	(0, 0, 0.2)	(0, 0, 0.2)	(0, 0, 0.2)	(0, 0.2, 0.4)	(0.3, 0.5, 0.7)
WCA_5	(0, 0.2, 0.4)	(0, 0, 0.2)	(0.6, 0.8, 1)	(0.3, 0.5, 0.7)	(0, 0, 0.2)	(0.3, 0.5, 0.7)	(0, 0, 0.2)	(0, 0.2, 0.4)	(0, 0.2, 0.4)	(0.3, 0.5, 0.7)	(0.6, 0.8, 1)
WCA_6	(0.3, 0.5, 0.7)	(0, 0, 0.2)	(0.8, 1, 1)	(0.6, 0.8, 1)	(0, 0, 0.2)	(0.6, 0.8, 1)	(0, 0.2, 0.4)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.6, 0.8, 1)	(0.8, 1, 1)
WCA_7	(0.6, 0.8, 1)	(0, 0.2, 0.4)	(0.8, 1, 1)	(0.8, 1, 1)	(0, 0.2, 0.4)	(0.8, 1, 1)	(0.3, 0.5, 0.7)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.8, 1, 1)	(0, 0.2, 0.4)
WCA_8	(0.8, 1, 1)	(0.3, 0.5, 0.7)	(0, 0.2, 0.4)	(0.6, 0.8, 1)	(0.3, 0.5, 0.7)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0, 0.2, 0.4)	(0, 0.2, 0.4)
WCA_9	(0, 0, 0.2)	(0.6, 0.8, 1)	(0, 0, 0.2)	(0.8, 1, 1)	(0.6, 0.8, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0, 0, 0.2)	(0, 0, 0.2)	(0.8, 1, 1)	(0.3, 0.5, 0.7)
WCA_{10}	(0.8, 1, 1)	(0.8, 1, 1)	(0, 0.2, 0.4)	(0.8, 1, 1)	(0.8, 1, 1)	(0.6, 0.8, 1)	(0.3, 0.5, 0.7)	(0, 0.2, 0.4)	(0, 0, 0.2)	(0.6, 0.8, 1)	(0.3, 0.5, 0.7)