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An integrated decision-making method for locating parking centers of recyclable waste transportation vehicle

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Abstract: This study is motivated by a third-party logistics company in a modern city in China that manages the transportation of recyclable waste for the municipal government. Research in the area has rarely attended to the location of recyclable waste transportation vehicle parking centers (RWTVPCs). This study develops an integrated multi-criteria decision-making (MCDM) method through the decision-making trial and evaluation laboratory (DEMATEL) approach, entropy weight (EW), and weighted aggregated sum product assessment (WASPAS) to select suitable RWTVPC sites. An interesting finding is that the MCDM method is more suitable for this task than the traditional location allocation model. A comparison of three MCDM methods verified the advantages of the proposed method in terms of stability and reliability. Moreover, we found through a sensitivity analysis that the ranking of alternatives was greatly affected by changes in the criteria weights but was not sensitive to changes in the parameters of the preferential decisions. Besides, the proposed method has advantages in terms of reducing the cost of transportation of recyclable waste and improving the efficiency of transportation. This provides a reference for the large-scale collection of urban recyclable waste. This paper provides some important implications for waste management that are useful for the implementation of the DEMATEL-EW-WASPAS method.

Keywords: Recyclable waste transportation; Multi-criteria decision-making; Circular economy; Parking lot site selection; Entropy weight

Nomenclature			
LA	Location allocation	AHP	Analytic hierarchy process
MCDM	Multi-criteria decision-making	ANP	Analytic network process
DEMATEL	Decision-making trial and evaluation laboratory	TOPSIS	Technique for order preference by similarity to an ideal solution
EW	Entropy weight	WSM	Weighted sum model
WASPAS	Weighted aggregated sum product assessment	WPM	Weighted product model
TFN	Triangular fuzzy number	VIKOR	Vlsekriterijumska optimizacija I kompromisno resenje
RWTVPC	Recyclable waste transportation vehicle parking center	TODIM	An acronym in portuguese for interactive multi-criteria decision making

1. Introduction

The rapidly increasing amount of waste not only pollutes the environment, but also causes great harm to people's health (Liu and Zheng, 2020; Rahmasary et al., 2019; Zhang et al., 2020a). If effective measures are not taken to reduce it, it is estimated that the amount of annual waste generated globally will increase from 2.01 billion tons in 2016 to 3.4 billion tons in 2050 (Kaza et al., 2018). Although many countries have developed strategies to treat recyclable waste to reduce its volume or use it, considerable work is needed to efficiently manage the transportation recyclable waste (Rene et al., 2021). China is implementing source separation, or compulsory waste sorting, to improve the environment (e.g. Shenzhen[1], Beijing[2] , Shanghai[3], and Guangzhou[4], etc), and promoting the sustainable development of the circular economy (CE). Source separation is beneficial for increasing the use of recyclable waste (Wang et al., 2021; Wang and Hao, 2020). However, the small amount of recyclable waste in each community or waste collection site poses a challenge to the efficient transportation of recyclable waste (Shao et al., 2020).

CE has more advantages than traditional economic models (Do et al., 2021; Lee et al., 2021), such as saved energy, low cost, improved economic and ecological benefits, and the ability to maintain an ecological balance. In the context of the CE, good recyclable waste management is essential for sustainable development (Zhang et al., 2019). With improvements in people's concept of the CE, managing and transporting recyclable waste in a smart and sustainable way will help promote economic growth while minimizing the impact on the environment (Yi et al., 2020). Therefore, appropriately managing the transportation and collection of recyclable waste is critical to increasing its value in a CE. Because waste sorting is the basis of the downstream value recovery business, the Chinese government has formulated a waste sorting policy to promote the development of the CE.

This paper focuses on the problem of parking vehicles used to transport recyclable waste. The literature (Albalate and Gragera, 2020; Liu et al., 2021; Lu et al., 2021) has shown that parking is an important economic activity that occupies a large amount of urban space, and optimizing the locations of parking spaces is thus important. Land in the city center is limited and the supply of parking spaces is always restricted (Van Ommeren et al., 2021; Wang et al., 2019). Thus, the selection of parking locations for vehicles used to transport recyclable waste is important for improving the efficiency of transportation and reducing costs (Winter et al., 2021). The amount of recyclable waste at each waste collection point is uncertain, and affects the efficiency of each

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[1] See http://www.gov.cn/xinwen/2020-09/01/content_5539091.htm.

[2] See http://www.beijing.gov.cn/zhengce/zhengcefagui/201912/t20191218_1256860.html.

[3] See https://www.shanghai.gov.cn/nw44388/20200824/0001-44388_58275.html.

[4] See http: //www.gz.gov.cn/zfjgzy/gzsrmzfbgt/zfxxgkml/bmwj/qtwj/content/post_4435554.html.

transportation-related activity (Akbarpour et al., 2021). Hence, making use of the economies of scale is not easy without appropriately planning the location of vehicles used to transport recyclable waste.

1.1. Motivation and purpose

This study is motivated by a third-party logistics company that manages the collection and transportation of recyclable waste for a city on behalf of its a municipal government. Due to cooperation between the company and the government, the business of recyclable waste transportation has continued to expand in the city. The company needs to select a suitable location for its recyclable waste transportation vehicle parking center (RWTVPC) to rapidly and efficiently transport recyclable waste. Consider a city (or a region) that has a third-party logistics company that collects and transports recyclable waste. The company uses many vehicles to transport recyclable waste. A large amount of recyclable waste is transported between the waste generation site and the collection site every day. The company may arrange for one or more waste transporting vehicles to collect various kinds of recyclable waste from multiple waste generation sites (or regions). The key challenge facing the company is to select the optimal location of the RWTVPCs to efficiently transport recyclable waste in the region.

RWTVPC site selection is regarded as a problem that could be resolved using the multi-criteria decision-making (MCDM) method which is widely used in many fields (Ahmad et al., 2021; Gou et al., 2020; Li et al., 2021; Lin et al., 2021). Since the importance of each criterion is different, it is necessary to assign appropriate weights to each criterion in the MCDM problem (Gou et al., 2018; Mohammadi and Rezaei, 2020). In practice, however, due to differences in the experts' knowledge and background, their understanding of the importance of a given criterion is different (Gou et al., 2021; Zhan et al., 2021). If only subjective judgment is used to assign weights to the criteria, this may introduce risks for decision makers. Considering both subjective and objective approaches to calculate criteria weights to reduce decision-making risks is thus useful (Ma et al., 1999; Ran et al., 2021; Zheng et al., 2021). This study aims to answer the following questions: (1) How do we design and implement the MCDM method to develop a strategy to determine the best location for RWTVPC? (2) How do we select the best system of evaluation indices to improve the quality of RWTVPC site selection? (3) What are the effects of the parameters in the proposed method on the results of RWTVPC site selection?

The objective of this study is to propose a method that integrates the decision-making trial and evaluation laboratory (DEMATEL) (Chang et al., 2011), entropy weight (EW) method, and weighted aggregated sum product assessment (WASPAS) to select the optimal location for the RWTVPC. The DEMATEL is used to calculate the subjective weights of the criteria, the EW method is applied to calculate their objective weights, and the WASPAS method is used to rank alternatives. We illustrate steps of the application of the proposed method by a case study. Moreover, we compared the proposed method with other MCDM methods, and the results verify its advantages. We also compared it with the location allocation (LA) optimization model, and the results show that the proposed method makes up for the limitation of traditional LA optimization whereby it cannot be used to evaluate qualitative criteria.

1.2. Research gaps

First, the location of the RWTVPC is an important issue that, however, has not been addressed sufficiently well in the literature to date. An integrated method to analyze choices of locations of RWTVPC is also not available. Although the MCDM method is widely used in many fields, it has not been used for RWTVPC site selection. Hence, this paper fills this gap in research by developing an integrated MCDM method. Second, the system of indices to assess RWTVPC site selection has an important influence on decision making. However, few studies have investigated such a system. This paper also fills this gap in research. Third, no study to date has compared the MCDM method with the traditional LA optimization model in the context of site selection. This study compares the results obtained by the MCDM with those of LA optimization, and analyzes application scenarios of both methods.

1.3. Main contributions and organizational structure

We summarize the main contributions of this paper as follows:

Firstly, to the best of our knowledge, although there are many studies on waste transportation, previous literatures have ignored the location of the RWTVPC problem. Thus, this is the first paper that defines this problem. Moreover, this study fills above research gap and positions it as the pioneering research on waste topic.

Secondly, to solve the problem of RWTVPC location, an integrated DEMATEL-EW-WASPAS method, which makes a theoretical contribution to MCDM and provides an analysis framework for the future application of the DEMATEL-EW-WASPAS method, was proposed for the first time.

Thirdly, we have provided managerial implications for relevant waste managers from a practical perspective. Besides, this study provides new insights for relevant waste transportation practitioners and scholars.

The remainder of this study is organized as follows: We present a review of the literature in Section 2, and Section 3 introduces the problem description, research methods, and decision framework of RWTVDC site selection. The system to assess indices used for RWTVPC site selection is established in Section 4. In Section 5, we apply an illustrative example to verify the applicability of the proposed method. We give the results and discussion in Section 6. Managerial implications and importance of this paper are given in Section 7. Finally, we summarize the conclusions, limitations of this study, and offer directions for future research in Section 8.

2. Literature review

This section reviews the related literature on waste transportation, CE, and parking site selection to highlight the contributions of this study.

2.1. Waste transportation

Logistics has always been a hot topic studied by scholars, such as emergency transportation (Wang et al., 2016), logistics risk management (Choi, 2021; Choi et al., 2016), and the application of new technologies in logistics (Cai et al., 2021; Choi, 2020; Dutta et al., 2020). Recently, research on waste logistics has attracted wide attention. Optimizing waste transportation can significantly improve waste management. Yang et al. (2020) integrated the problem of backhaul and time window in vehicle transportation into a vehicle routing planning model, and converted the model into a quadratic 0–1 programming model to solve it. Govinda and Gholizadeh (2021) studied the reverse logistics network of scrapped vehicles based on big data to save organizational costs. Gambella et al. (2019) developed a two-stage optimization method to reduce the total cost of transportation and provided a reasonable plan for waste transportation. Zhao et al. (2016) developed a multi-objective optimization model to solve the problems of the location of the waste facility and the transportation of hazardous waste to reduce costs and risks. To reduce risk in the transportation of medical waste, Taslimi et al. (2020) developed an optimization method based on a heuristic algorithm. This paper is related to work by Miranda et al. (2015), who used a mixed-integer programming method to study the location of waste collection sites and plan the final route of the vehicle. However, we optimize the transportation route by adding RWTVPC sites between waste collection sites. Moreover, the method of this paper is different from that used by Miranda et al. (2015).

Most studies use mathematical optimization to determine the location of waste facilities and plan the routes of vehicles. However, few have considered the problem of parking vehicles during transportation to reduce the risk due to the uncertainty in the amount of waste. Waste transportation vehicles may also encounter situations where the load is not full, or there is too much waste to be cleaned up in time. Therefore, we consider the temporary parking of vehicles transporting waste between waste collection points to improve the efficiency of transportation. In particular, we improve the routes of vehicles transporting waste to improve their efficiency of waste transportation and reduce the risk of waste in the environment.

2.2. Circular economy

Recently, CE has received extensive attention in practice and academia (Choi and Chen, 2021; Choi et al., 2020; Zhang et al., 2021). The evolution from a linear economy to a CE depends on effective waste management (Ranjbari et al., 2021; Zeller et al., 2019). Focusing on the development of the CE through waste management practices is key to achieving environmental sustainability (Fan et al., 2021). The relevant literature has examined the challenges and obstacles to the development of the CE (Zhanget al, 2019), the waste level index (Pires and Martinho, 2019), and the factors influencing e-waste in the CE (Sharma et al., 2020). In the context of the CE, appropriate waste management and realizing the value of recyclable waste are essential to transforming the entire society into a sustainable and zero-waste environment (Aghbashlo et al., 2019). Households have different preferences for different waste sorting and treatment solutions, which also affects garbage recycling and transportation (Nainggolan et al., 2019). Allevi et al. (2021) developed a sequential optimization model to study the factors influencing government departments and waste recycling companies to improve municipal solid waste management in a CE. The results of this research provide theoretical support for decision making by the government and recycling companies. Rathore and Sarmah (2020) developed a mixed-integer nonlinear model to optimize the total cost of waste management and reduce carbon emissions to achieve a CE.

The above studies have examined waste management in a CE from multiple perspectives and provide references for relevant practitioners. However, reducing carbon emissions in waste transportation management can also contribute to the CE. Therefore, our work here is different from these studies. We focus on transportation management of recyclable waste in a network, especially the problem of choosing the site for a parking lot for waste transport vehicles.

2.3. Parking lot site selection

Parking is a long-standing challenge in many large cities (Zhang et al., 2020b). Studies have shown that cruise parking increases carbon emissions and traffic congestion (Liu and Geroliminis, 2016; Van Ommerenet al, 2021). Parking is an important economic activity (Inci, 2015). To alleviate the parking problem, various methods have been proposed in the literature to improve the efficiency of parking. For the problem of choosing to cruise or paying for parking, Shoup (2006) proposed a model to help drivers make decisions. To reduce congestion due to vehicle cruises, Gu et al. (2020) developed two real-time parking pricing strategies that provided valuable insights into parking management systems using numerical research. Najmi et al. (2021) integrated a behavioral pricing formula into an agent-based simulation model to analyze parking problems in practice.

The above literature has focused on issues related to how vehicles choose parking spaces and pricing. However, this study focuses on selecting a site for a parking lot. Our research is closer to that by Jelokhani-Niaraki and Malczewski (2015), Kazazi Darani et al. (2018), and Karimi et al. (2020).

Jelokhani-Niaraki and Malczewski (2015) integrated a geographic information system and multi-criteria decision analysis into a platform to select the best location for a parking lot. By considering the economic, social, and environmental criteria for selecting a site for a parking lot, Kazazi Darani et al. (2018) applied the analytic hierarchy process and the order of preference by similarity to the ideal solution to select the location of a public parking lot. Because a public parking lot plays an important role in reducing the difficulty of parking in the city, Farzanmanesh et al. (2010) used geographic information systems and fuzzy logic to select the best location for it. After determining the criteria for site selection, Aliniai et al. (2015) applied the MCDM method to select the most suitable location for a public parking lot. Fierek et al. (2020) used the weighted average and the analytic hierarchy process to evaluate 15 candidate locations for a parking lot, and choose one based on final rankings obtained by using these two methods.

Our research is clearly different from the above-mentioned literature. First, we study the location of a parking lot for vehicles transporting waste, which is essential for improving the transportation of waste by vehicles in the context of a CE. Second, the candidate locations for each parking lot are evaluated through historical data; we thus consider environmental, economic, social, and technical criteria to select the best site for the parking lot. Finally, we consider both the subjective and objective weights of the criteria, and use the proposed DEMATEL-EW-WASPAS method to evaluate alternatives.

3. Methodology

This section introduces the problem and the method used to solve it. We assume that there are m RWTVPC sites, denoted by $A = (A_1, A_2, \cdots, A_i \cdots, A_m)$, and n evaluation criteria denoted by $C = (c_1, c_2, \cdots, c_j \cdots, c_n)$. The subjective weight vector obtained by the DEMATEL method is denoted by $W^s = (w_1^s, w_2^s, \cdots, w_j^s \cdots, w_n^s)$, and the objective weight vector obtained by the EW method by $W^o = (w_1^o, w_2^o, \cdots, w_j^o \cdots, w_n^o)$. We also assume that there are L evaluation experts, denoted by $E = (E_1, E_2, \cdots, E_l \cdots, E_L)$, and the weight vector corresponding to each expert is denoted by $W^L = (w^1, w^1, \cdots, w^l, \cdots, w^L)$.

3.1. Problem description

Consider a regional logistics network with a waste transportation company, many waste generation sites, and waste disposal centers. The company is responsible for transporting recyclable waste in a given area. To rapidly transport recyclable waste, the company usually has to collect all of it in an area within a given time window. However, because it is impossible to build a new dispatch center for vehicles transporting waste in the area, the waste generation points in the area are divided into several centers, and each center is equipped with at least one vehicle that is responsible for transporting its recyclable waste. Because the amount of recyclable waste generated is uncertain in each period, the company hopes to set-up a reasonably located RWTVPC (e.g., roadside parking lot) in this area to ensure that the recyclable waste can be removed in time. We assume that there are m waste generation sites in the urban CBD area and a recyclable waste treatment plant in the outskirts, as shown in Fig. 1.

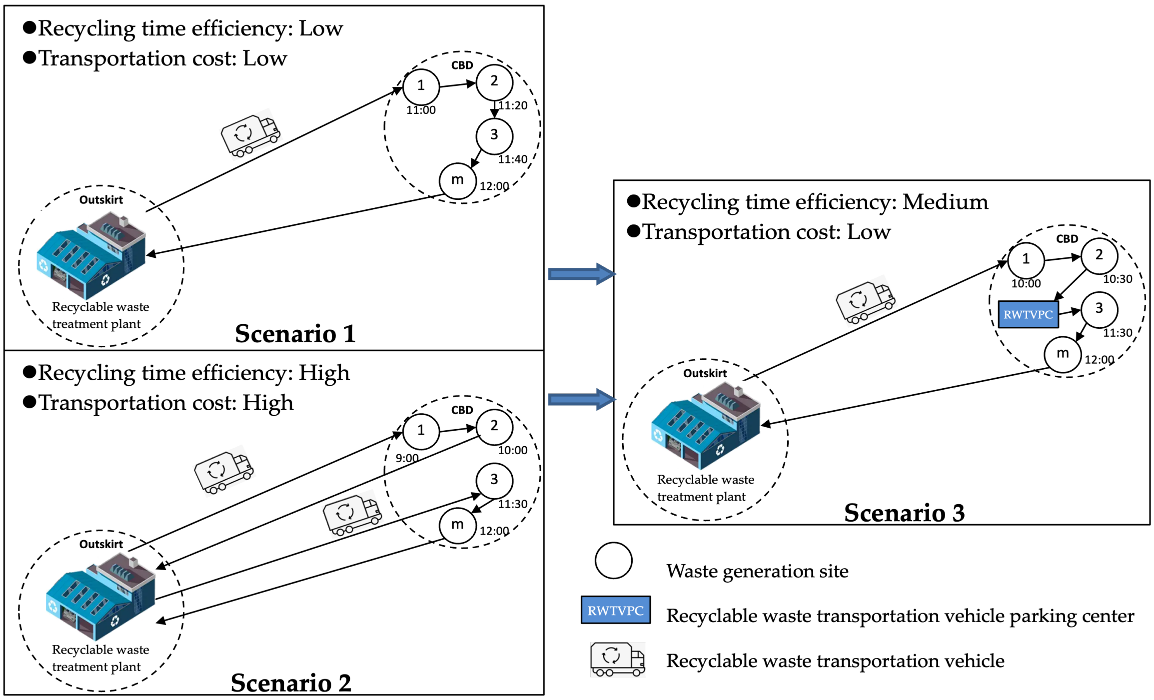

Figure 1. An illustration of managing the transportation of recyclable waste with and without the RWTVPC.

Note that waste needs to be transported from each waste generation site within a given time window. The waste transportation vehicle departs from the recyclable waste treatment plant to the waste generation point to collect waste. Residents/enterprises around the waste collection site hope that recyclable waste can be quickly removed by the waste transportation company. Thus, if the recyclable waste can be transported within a given time window, the social welfare of the surrounding residents/enterprises can be significantly improved. In other words, the efficiency of the recycling time affects the social welfare of local residents/enterprises. In scenario 1, if a small number of vehicles transporting waste are used, it is difficult to transport recyclable waste within a given time window even though the cost of transportation is low, which means that the social welfare of the surrounding residents/enterprises does not improve. In scenario 2, if the vehicles used to transport recyclable waste are appropriately added, the waste can be guaranteed to be transported within the given time window, but the cost of transportation is higher. Thus, neither scenario 1 nor scenario 2 is the best choice in terms of transportation time and cost. In scenario 3, we select the appropriate location of the RWTVPC in the city's CBD to park the vehicles transporting recyclable waste. This not only ensures that waste is removed within a given time window, but also that each vehicle fully loaded. Therefore, scenario 3 shows that a suitable location of the RWTVPC can improve the efficiency of transportation of recyclable waste and reduce the cost of transportation.

Given that the amount of recyclable waste at each waste generation site is small, if a vehicle transports a small amount of waste from each site, this increases transportation costs. Fig. 1 shows a suitable location of the RWTVPC from among multiple waste generation sites. Vehicles patrol this area to collect recyclable waste. If a vehicle's capacity cannot be filled in one cruise, it stops at the RWTVPC, and then continues to cruise in the next time window to be filled up with waste. Thus, compared with the previous network for recyclable waste transportation, this network can reduce transportation costs while improving efficiency.

3.2. DEMATEL method

The TFN can reflect the fuzziness of experts' opinions on a given criteria. This section presents steps of the DEMATEL approach (Si et al., 2018).

Step 1: Each expert determines a direct relation matrix according to the evaluation criteria. Experts assign linguistic evaluation terms to the evaluation criteria based on the correlation between them. To deal with the ambiguity of human evaluation, we divide the linguistic variable "influence" into five linguistic terms, and express it by TFNs $(z_{ij1}^l, z_{ij2}^l, z_{ij3}^l)$, as shown in Table A1 (Wu and Lee, 2007).

Step 2: Establish the evaluation-related information matrix of expert l, denote as $\left[\tilde{z}_{ij}^l\right]_{n\times n}$.

Step 3: We aggregate the decision-making information to get a direct-relation matrix of each expert, denote as $\tilde{Z} = \left[\tilde{z}_{ij}\right]_{n\times n}$.

$$\tilde{z}_{ij} = \sum_{l=1}^{L} w^l \tilde{z}_{ij}^l, \tag{1}$$

where w^l represents the weight of expert l, and $\sum_{l=1}^{L} w^l = 1$.

Step 4: Normalize direct-relation matrix $\tilde{Z}$ by the following equation.

$$\tilde{X} = \frac{\tilde{Z}}{\Delta}, \tag{2}$$

where

$$\tilde{Z} = \begin{bmatrix} \tilde{z}_{11} & \tilde{z}_{12} & \cdots & \tilde{z}_{1n} \\ \tilde{z}_{21} & \tilde{z}_{22} & \cdots & d_{2n}^l \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{z}_{n1} & \tilde{z}_{n2} & \cdots & \tilde{z}_{nn} \end{bmatrix}, \tag{3}$$

$$\Delta = \max_{i,j}[\max_{1\le i\le n} \sum_{j=1}^{n} z_{ij3}, \max_{1\le j\le n} \sum_{i=1}^{n} z_{ij3}], \tag{4}$$

Step 5: Compute the comprehensive influence matrix $\tilde{T} = \left[\tilde{t}_{ij}\right]_{n\times n}$ by

$$\tilde{T} = \tilde{X}(I - \tilde{X})^{-1}, \tag{5}$$

where I is the identity matrix, $\tilde{t}_{ij} = (t_{ij1}, t_{ij2}, t_{ij3})$ and

$$\begin{aligned} T_1 &= \left[t_{ij1}\right]_{n\times n} = X_1(I - X_1)^{-1}, \\ T_2 &= \left[t_{ij2}\right]_{n\times n} = X_2(I - X_2)^{-1}, \\ T_3 &= \left[t_{ij3}\right]_{n\times n} = X_3(I - X_3)^{-1}, \end{aligned} \tag{6}$$

where $X_1 = \left[x_{ij1}\right]_{n\times n}$, $X_2 = \left[x_{ij2}\right]_{n\times n}$, $X_3 = \left[x_{ij3}\right]_{n\times n}$.

Step 6: We use Eq. (7) to calculate the sum of rows of the matrix $\tilde{T}$, which is the degree of influence $\tilde{R}_i$; we use Eq. (8) to calculate the sum of columns of the matrix $\tilde{T}$, which is the affected degree $\tilde{C}_i$.

$$\tilde{R}_i = (\sum_{j=1}^{n} t_{ij1}, \sum_{j=1}^{n} t_{ij2}, \sum_{j=1}^{n} t_{ij3}) \tag{7}$$

$$\tilde{C}_i = (\sum_{i=1}^{n} t_{ij1}, \sum_{i=1}^{n} t_{ij2}, \sum_{i=1}^{n} t_{ij3}). \tag{8}$$

Step 7: Let Γ denote the defuzzified value of the TFN $\tilde{\Gamma} = (\alpha, \beta, \gamma)$, then

$$\Gamma = \frac{\alpha + 2\beta + \gamma}{4}. \tag{9}$$

Thus, we can use Eq. (9) to defuzzify $\tilde{R}_i$ and $\tilde{C}_i$, and obtain the crisp values $\tilde{R}_i^{def}$ and $\tilde{C}_i^{def}$.

Step 8: Obtain the center degree Q_i and cause degree U_i of each criterion by Eqs. (10) and (11).

$$Q_i = \tilde{R}_i^{def} + \tilde{C}_i^{def}, \tag{10}$$

$$U_i = \tilde{R}_i^{def} - \tilde{C}_i^{def}. \tag{11}$$

Step 9: We determine the subjective weight of each criterion by Eq. (12).

$$w_i^s = \frac{(Q_i^2 + U_i^2)^2}{\sum_{j=1}^{n}(Q_i^2 + U_i^2)^2}. \tag{12}$$

3.3. EW method

In this study, the quantitative criteria for evaluation can be expressed by using crisp values, while the qualitative criteria can be expressed by using linguistic terms (see Table A2). After defining the linguistic variables, we summarize the specific steps of the EW method (Wang et al., 2021).

Step 1: Obtain the initial hybrid matrix of decision-making information of expert l.

$$\widetilde{D}_{ij}^{l} = \begin{bmatrix} \tilde{d}_{11}^l & \tilde{d}_{12}^l & \cdots & \tilde{d}_{1n}^l \\ \tilde{d}_{21}^l & \tilde{d}_{21}^l & \cdots & \tilde{d}_{2n}^l \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{d}_{m1}^l & \tilde{d}_{m1}^l & \cdots & \tilde{d}_{mn}^l \end{bmatrix}. \tag{13}$$

Step 2: Aggregate the evaluation-related information of all experts by Eq. (14).

$$\widetilde{D} = \sum_{l=1}^{L} w^l \tilde{d}_{ij}^l, \tag{14}$$

where w^l represents the weight of expert l, and $\sum_{l=1}^{L} w^l = 1$.

Step 2: Normalize the data in matrix $\widetilde{D}$. Thus, we can obtain the normalized fuzzy matrix $\tilde{P} = [\tilde{p}_{ij}]_{m\times n}$

$$\tilde{p}_{ij} = (x_{ij}^l, x_{ij}^m, x_{ij}^u) = \begin{cases} \left(\frac{d_{ij}^l}{d_{\max j}^u}, \frac{d_{ij}^m}{d_{\max j}^u}, \frac{d_{ij}^u}{d_{\max j}^u}\right) \; for \text{ benefit type} \\ \left(\frac{d_{\min j}^l}{d_{ij}^u}, \frac{d_{\min j}^l}{d_{ij}^m}, \frac{d_{\min j}^l}{d_{ij}^l}\right) \; for \text{ cost type} \end{cases}, \tag{15}$$

where $d_{\max j}^u = \max\{d_{ij}^u | i = 1,2,\cdots,m\}$ and $d_{\min j}^l = \min\{d_{ij}^l | i = 1,2,\cdots,m\}$.

Step 3: Calculate the fuzzy entropy of each criterion e_j.

$$\tilde{h}_{ij} = \frac{\tilde{p}_{ij}}{\sum_{i=1}^{m} \tilde{p}_{ij}}, \tag{16}$$

$$\tilde{e}_j = -\frac{1}{\ln m} \sum_{i=1}^{m} \tilde{h}_{ij} \ln \tilde{h}_{ij}. \tag{17}$$

If $p_{ij} = 0$, then $p_{ij} \ln p_{ij} = 0$.

Step 4: Determine the fuzzy objective weight of each criterion $\widetilde{w}_j = (w_j^l, w_j^m, w_j^u)$.

$$\widetilde{w}_j = \frac{1 - e_j}{n - \sum_{j=1}^{n} e_j}. \tag{18}$$

Step 5: Determine the final objective weight of each criterion.

$$w_j^o = \frac{w_j^l + 2w_j^m + w_j^u}{4}. \tag{19}$$

3.4. Determining the comprehensive weight

This paper uses a linear weighting method to calculate global weights, that can be flexibly adjusted to obtain a satisfactory comprehensive weight (Wen et al., 2021). The comprehensive weight can be determined by Eq. (20):

$$w_j = \theta w_j^s + (1 - \theta) w_j^o, \tag{20}$$

where $0 \le \theta \le 1$, and $w_j \ge 0, \sum_{j=1}^{n} w_j = 1$. θ represents the decision-maker's preference among the subjective weights, and $1 - \theta$ represents their preference among objective weights.

3.5. WASPAS method

The WASPAS method is applied to rank the alternatives, and its steps are summarized as follows:

Step 1: A matrix of the evaluations of experts $F = [f_{ij}]_{m\times n}$ is obtained by

$$d_{ij}^{l} = \frac{1}{4}\left(\alpha_{ij}^{l} + 2\beta_{ij}^{l} + \gamma_{ij}^{l}\right), \tag{21}$$

$$f_{ij} = \sum_{l=1}^{L} w^{l} d_{ij}^{l}. \tag{22}$$

Step 2: The decision-making matrix is normalized.

$$\bar{f}_{ij} = \begin{cases} \dfrac{f_{ij}}{\max\limits_{i} f_{ij}}, \text{for benefit type} \\ \dfrac{\min\limits_{i} f_{ij}}{f_{ij}}, \quad \text{for cost type} \end{cases}. \tag{23}$$

Step 3: The relative importance of the alternatives is computed by using the WSM (P_i^{WSM}) and WPM (P_i^{WPM}) methods.

$$P_i^{WSM} = \sum_{j=1}^{n} w_j \bar{f}_{ij}, \tag{24}$$

$$P_i^{WPM} = \prod_{j=1}^{n} (\bar{f}_{ij})^{w_j}. \tag{25}$$

Step 4: Linear weighting is used to calculate the final relative importance of the alternatives.

$$P_i = \lambda P_i^{WSM} + (1-\lambda) P_i^{WPM}, \tag{26}$$

where λ represents the decision preference of the decision makers between the WSM and WPM methods, and $\lambda \in [0,1]$. When $\lambda = 1$ and $\lambda = 0$, the WASPAS method is completely converted into the WSM and WPM methods, respectively. Therefore, the WASPAS method has the advantages of both the WSM and the WPM methods.

3.6. Decision framework of RWTVPC site selection

To select the RWTVPC site, a comprehensive framework of analysis is proposed, as shown in Fig. 2. It is divided into the following stages:

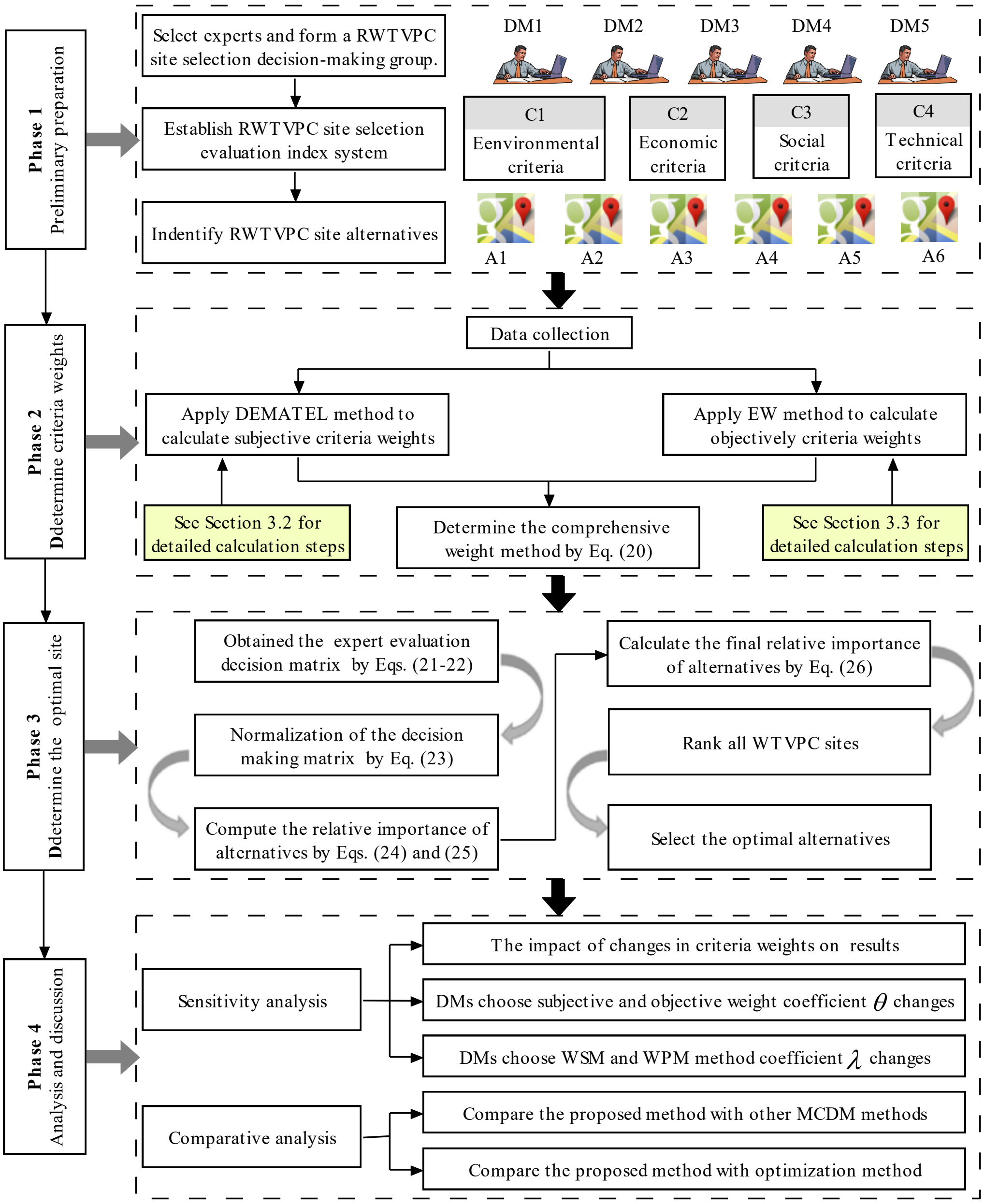

Figure 2. Decision framework for RWTVPC site selection.

Phase 1: In the stage of preliminary preparation, determine the alternative locations and evaluation criteria. The management department of the company should invite experts in related fields, such as environmental management, vehicle transportation service, and public relations management, to study the government's waste management and transportation policies, and investigate feasible alternatives in the region. After determining these alternatives, it is necessary to collect information on RWTVPC site selection from three sources, the literature, project feasibility analysis report, and field investigation, to establish a scientific and reasonable evaluation index.

Phase 2: Determine comprehensive criteria weights. The subjective criteria weights are determined by the DEMATEL method described in Section 3.2; while the objective criteria weights are determined by the EW method described in Section 3.3.

Phase 3: Select the best site by applying the WASPAS method, described in Section 3.5.

Phase 4: Conduct a comparative study and sensitivity analysis. Regarding the former, first, the proposed method is compared with other MCDM methods and its effectiveness is verified. Second, a comparison is made on the basis of maintaining the dimensions of the evaluation consistent with those of traditional optimization methods to illustrate the advantages of the proposed method. Regarding the latter, first, due to the subjectivity and uncertainty of the decision makers, the criteria weights may change. Second, the decision makers may also have an impact on the research results in terms of choosing subjective and objective weight coefficients. Finally, the decision makers' preferences for the WSM or the WPM method may also have an impact on the results. Hence, a sensitivity analysis is needed to verify the robustness of the chosen parameters.

4. System of evaluation indicators for RWTVPC site selection

To ensure the scientificity of the constructed index system, a process to analyze its design to assess the indices used for RWTVPC site selection was carried out. The main steps were as follows: i) the company's management department invited five experts from different companies to form the decision-making committee for RWTVPC site selection; ii) the company screened out potential evaluation criteria from the academic literature and project feasibility analysis reports. Five experts reviewed the initial evaluation index system based on their experience and professional knowledge, and ranked them according to importance; and iii) the experts conducted multiple rounds of discussion to reach a consensus, and built the final system of indices to evaluate RWTVPC site selection.

According to the analysis above, a comprehensive system to assess the indices used for RWTVPC site selection (containing 12 sub-criteria), including environmental, economic, social, and technical criteria, was established, and each criterion is detailed in Table 1.

Table 1. System to assess indices used for RWTVPC site selection.

Criteria	Subcriteria	Description	Reference
Environmental (C1)	Impact on residents' health (C11)	Because vehicles transporting waste may emit odors, dust, etc., they affect the local residents' health (Younger et al., 2008). Although the company uses strict measures to control pollution, there is still a potential risk.	(Pamuar et al., 2021)
	Impact on the open environment (C12)	The RWTVPC is generally located in an open environment, which may have an impact on society and urban life.	
	Pollution in the environment (C13)	Due to certain conditions, the RWTVPC sites cannot use new energy-based vehicles, and the pollutants emitted by vehicles run on fossil fuels will affect the environment.	
Economic (C2)	Operation cost (C21)	Only the costs of renting and managing the RWTVPC site need to be considered.	

	Unit transportation cost (C22)	The location of the RWTVPC determines the route and distance for vehicle transportation, which may affect unit transportation costs.	
	Service capability (C23)	Service capacity measures the number of waste collection points that each site can serve. Different locations of the RWTVPCs affect this capacity.	(Pamuaret al, 2021)
Social (C3)	Public satisfaction (C31)	Because the public may be worried about the smell of waste transport vehicles, or that they might affect the beauty of the city, residents may have objections.	(Rabbani et al., 2020)
	Government support (C32)	Government management departments determine the waste generation points in the area, and strengthened cooperation with the government can help obtain more support.	(Sagnak et al., 2021)
	Coordination with planning (C33)	The location of the RWTVPC cannot affect the regional environment and beauty.	
Technical (C4)	Service convenience (C41)	Service convenience measures the convenience of location of the RWTVPC to each waste collection site.	(Rabbaniet al, 2020)
	Mutual distance (C42)	Mutual distance refers to the distance between the RWTVPC and the recyclable waste treatment plant.	
	Scalability (C43)	Scalability means that as the amount of waste increases, the number of transportation vehicles may increase, and RWTVPC sites can be appropriately expanded to meet the transportation requirements.	

5. Application of proposed method

To clearly illustrate the effectiveness of the proposed method and the applicability of the analytical framework, we use an example of its use in this section.

5.1. Background

Although source separation or compulsory waste sorting is conducive to the recycling of recyclable waste, the recycling value of waste determines the type of recycling and transportation mode needed, which limits its use. To encourage enterprises to recycle low-value recyclable waste, some local governments have introduced corresponding incentives, including subsidies, recyclables' recycling guides, and low-value recyclables' inventories. Although these policies provide institutional guarantees for the large-scale collection and transportation of recyclable waste, the current transportation of recyclable waste still faces challenges, such as the high cost of transportation and a lack of economies of scale. Thus, the transportation network for recyclable waste needs to be improved to reduce transportation costs.

Owing to the limited land resources in the city, it is difficult to find a piece of land that can be used to build a dispatch center for waste transport vehicles. In addition, the company is hesitant to build large-scale vehicle dispatch centers because of high land prices. Thus, it is important to select a suitable RWTVPC site in the planned area. The company H needs to select two suitable RWTVPC sites from among six alternatives $A = (A_1, A_2, A_3, A_4, A_5, A_6)$ in an area. Company H invited five decision makers $E = (E_1, E_2, E_3, E_4, E_5)$ from different fields to form a decision-making committee, and assigned different weights $W^L = (0.15, 0.25, 0.15, 0.2, 0.25)$ according to each decision maker's professional background and experience. The proposed method was then applied to select the best alternative.

5.2. Determining criteria weights

Step 1: Use DEMATEL method to determine the subjective weights. First, each expert assigned values to the matrix of direct relationship among the criteria according to Table A1, as shown in Tables A3–A7 in the Appendix A. Second, the linguistic terms in Tables A3 to A7 are converted into TFNs, and aggregated the fuzzy matrices of all experts and normalize them by Eqs. (1)–(4). Third, we determine the degree of influence $\tilde{R}_i$ and the affected degree $\tilde{C}_i$ by Eqs. (5)–(8). Fourth, we use the Eq. (9) to defuzzify $\tilde{R}_i$ and $\tilde{C}_i$. Finally, the subjective weights are calculated by Eqs. (10)–(12), and the results are given in Table A8.

Step 2: Use EW method to calculate the objective weights. First, we obtain the hybrid evaluation information of each expert on the criteria (see Tables A9 and A10 in the Appendix A), in which C21, C22, C23, and C42 are quantitative criteria, and the rest are qualitative criteria. We then aggregate the evaluation information of all experts by Eqs. (13) and (14). Second, we use Eqs. (15)–(17) to calculate the fuzzy entropy values. Third, we apply Eq. (18) to compute the fuzzy entropy weights, and finally we use Eq. (19) to defuzzify, and the results are shown in Table A8.

Step 3: Use linear weighting method to determine global weights. After obtaining the subjective and objective weights, let $\theta = 0.5$, and we use Eq. (20) to determine the comprehensive criteria weights. The final weights are given in Table A12 and Fig. 3. Criterion C22 had the largest weight and C41 had the smallest. Moreover, the experts believe that environmental criteria had the greatest impact on RWTVPC site selection, followed by economic criteria.

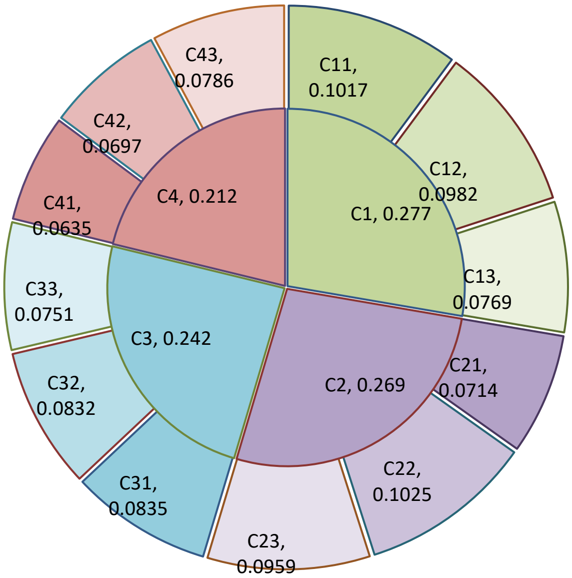

Figure 3. Distribution of the comprehensive criteria weights.

5.3. Determining optimal sites

First, we aggregate the initial evaluation information in Table A10 by Eqs. (21) and (22), and the results are shown in Table A12. Second, we apply Eq. (23) to normalize the matrix of evaluation information. Third, we use Eqs. (24)-(25) to calculate the relative importance of each alternative. Finally, we let $\lambda = 0.5$, and use linear weighting method to calculate the final relative importance of each criterion. We obtain the final ranking results, shown in Table 2, as A5>A1>A3>A2>A6>A4. A1 and A5 are thus selected as the optimal alternatives.

Table 2. Comprehensive ranking results of alternatives.

Alternatives	A1	A2	A3	A4	A5	A6
WSM method	0.8521	0.8282	0.8440	0.7735	0.8608	0.7902
WPM method	0.8400	0.8152	0.8259	0.7544	0.8350	0.7626
Comprehensive result	0.8460	0.8217	0.8350	0.7640	0.8479	0.7764
Ranking	2	4	3	6	1	5

6. Results and discussion

To further verify the robustness and advantages of the proposed method, we conducted necessary result analysis and discussion.

6.1. Comparative analysis with optimization method

To illustrate the advantages of the proposed MCDM method in terms of evaluating the qualitative and quantitative criteria, it was compared with the LA optimization method that considers only quantitative criteria. The aim is to show that the MCDM method can reflect more attributes of evaluation by decision makers about alternatives. The model is in fact a special type of the classic location–allocation model that is NP-hard; however, our proposed LA method does not require such a large amount of calculation. We constructed the following LA optimization model:

$$\min \sum_{k=1}^{K} \sum_{j=1}^{N} c_j d_{kj} x_{kj}, \tag{27}$$

$$\sum_{j=1}^{N} x_{kj} = 1, \tag{28}$$

$$x_{kj} \leq y_j, \tag{29}$$

$$\sum_{j=1}^{N} y_j = 2, \tag{30}$$

$$\sum_{j=1}^{N} T_j y_j \leq 13000, \tag{31}$$

$$x_{kj}, y_j \in \{0,1\}, \tag{32}$$

where c_j represents the unit transportation cost of alternative j, T_j represents the monthly operational cost, and d_{kj} represents the distance between alternative j and waste generation point k. x_{kj} is the 0-1 variable; if waste generation point k is served by alternative j, then $x_{kj} = 1$; otherwise, $x_{kj} = 0$. y_j is also a 0-1 variable; if alternative j is selected, then $y_j = 1$; otherwise, $y_j = 0$. The objective function in Eq. (27) is used to minimize the transportation cost. Constraint (28) ensures that each waste generation point is connected to only one alternative. Constraint (29) ensures that only nodes selected in the set of alternative nodes can establish connections with waste generation points, Constraint (30) ensures that the number of alternatives is two, and Constraint (31) ensures that the annual operating capital is within the budget.

Assume that there are eight waste generation points ($K = 8$) and six alternatives ($N = 6$). The distance between each alternative and waste generation site is shown in Table A13. To reduce errors, the data on the parameters T_j and c_j are consistent with the data on criteria C21 and C22, as shown in Table A14. Finally, we solve the model by using Linggo11.0, and the results show that alternatives A3 and A5 were the best choices.

The LA optimization model proposed here considers the economic criteria of the alternatives. To verify that it is compatible with the characteristics of the optimization model, we use the DEMATEL-EW-WASPAS method to evaluate only the economic criteria of the alternatives. Let the weights of the cost of operation, unit transportation cost, and service capacity be 0.3, 0.4, and 0.3, respectively. The results of the evaluation are shown in Table A15. A3 and A5 are the best choices if only the economic criteria of the alternatives are considered.

An interesting finding is that the DEMATEL-EW-WASPAS approach is more compatible than the above LA optimization model. Indeed, traditional optimal site selection models often struggle to capture the qualitative criteria of alternatives, but in terms of quantitative criteria for evaluating alternatives, the LA optimization model is also trustworthy. In conclusion, when evaluating multiple attributes of alternatives (such as qualitative and quantitative criteria), it is better to use the MCDM method; and if only the quantitative criteria of alternatives need to be evaluated, the traditional LA optimization model is also a good choice.

6.2. Comparison with other MCDM methods

To highlight the effectiveness of the proposed DEMATEL-EW-WASPAS method, it was compared with three other MCDM methods: TOPSIS (Sagnaket al, 2021), VIKOR (Sennaroglu and Celebi, 2018), and TODIM (Pan et al., 2021). The results of the comparison are given in Table 3.

Table 3. Comparison results with other MCDM methods.

A_i	TOPSIS		VIKOR		TODIM		WASPAS	
	Result	*Ranking*	*Result*	*Ranking*	*Result*	*Ranking*	*Result*	*Ranking*
A_1	0.5809	1	0.0932	2	0.9046	2	0.8460	2
A_2	0.5310	3	0.4652	4	0.6797	4	0.8217	4
A_3	0.5256	4	0.4649	3	0.7810	3	0.8350	3
A_4	0.4168	6	1.0000	6	0.0000	6	0.7640	6
A_5	0.5658	2	0.0438	1	1.0000	1	0.8479	1
A_6	0.4261	5	0.4700	5	0.1158	5	0.7764	5

We analyzed the results from two perspectives. First, the results in Table 3 verified the correctness of the proposed method. Although only the results obtained by the TOPSIS method were different those of the other three methods, the results of all methods placed alternatives A1 and A5 in the top two. Second, the WASPAS method combines two well-known MCDM methods, and the other three are common, single MCDM methods. Therefore, the WASPAS method has an advantage over the other three MCDM methods in terms of the accuracy of the results.

6.3. Sensitivity analysis

We conducted a sensitivity analysis from the three perspectives of changes in the criteria weights, parameter θ, and parameter λ changes.

6.3.1. Sensitivity analysis of changes in criteria weights

The weight of a sub-criterion depends heavily on the criteria weight. We changed criteria weights to determine whether the results changed significantly. In each scenario, we let one criteria weight increase, let the other one decrease, and kept the other two unchanged. We obtained the changes in weights in different scenarios, as shown in Table A16 in the Appendix. The ranking of alternatives in each scenario is shown in Fig. 4. Changes in the criteria weights had a significant impact on the ranking of alternatives, and different criteria weights corresponded to different rankings. Therefore, choosing appropriate criteria weight is essential for reducing the risk in decision making for site selection.

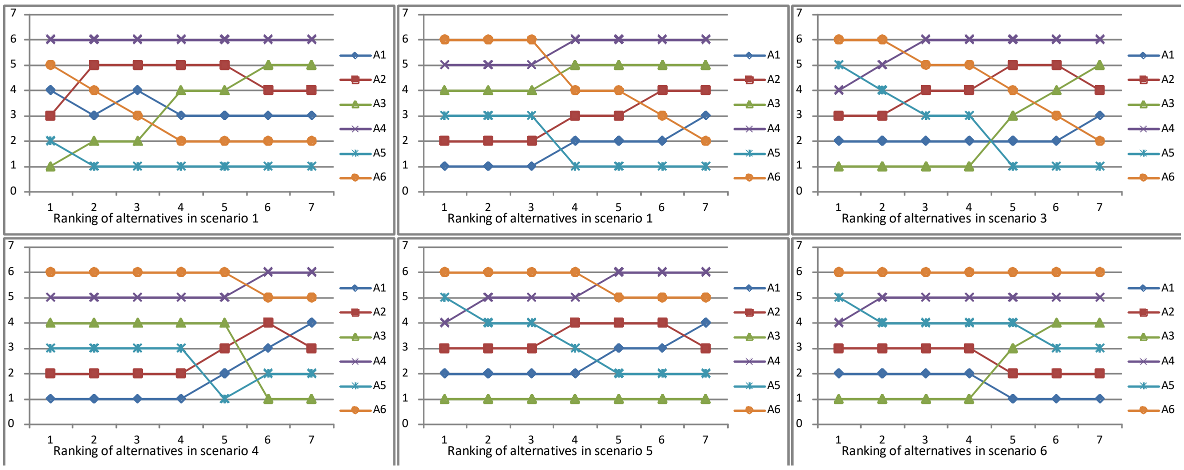

Figure 4. Ranking of alternatives with varying weights in different scenarios.

6.3.2. Sensitivity analysis of changes in parameter θ

The decision maker's preference for selecting subjective weights is θ, and the preference for selecting objective weights is $1-\theta$. Fig. 5(A) shows the impact on the results of the decision when the decision preference θ changes from zero to one.

Fig. 5(a) shows that when θ gradually increased from zero to one, the values of all alternatives will increase, except alternative A3. When the decision preference θ was in the interval [0.2, 0.3] and [0.9,1], the ranking of the alternatives was different; when the decision preference θ was in the interval [0.3, 0.9], the ranking of the alternatives did not change (see Fig. 5(b)). When θ was in the interval [0.3, 1], the top two alternatives were always A1 and A5, which shows the stability of the proposed method.

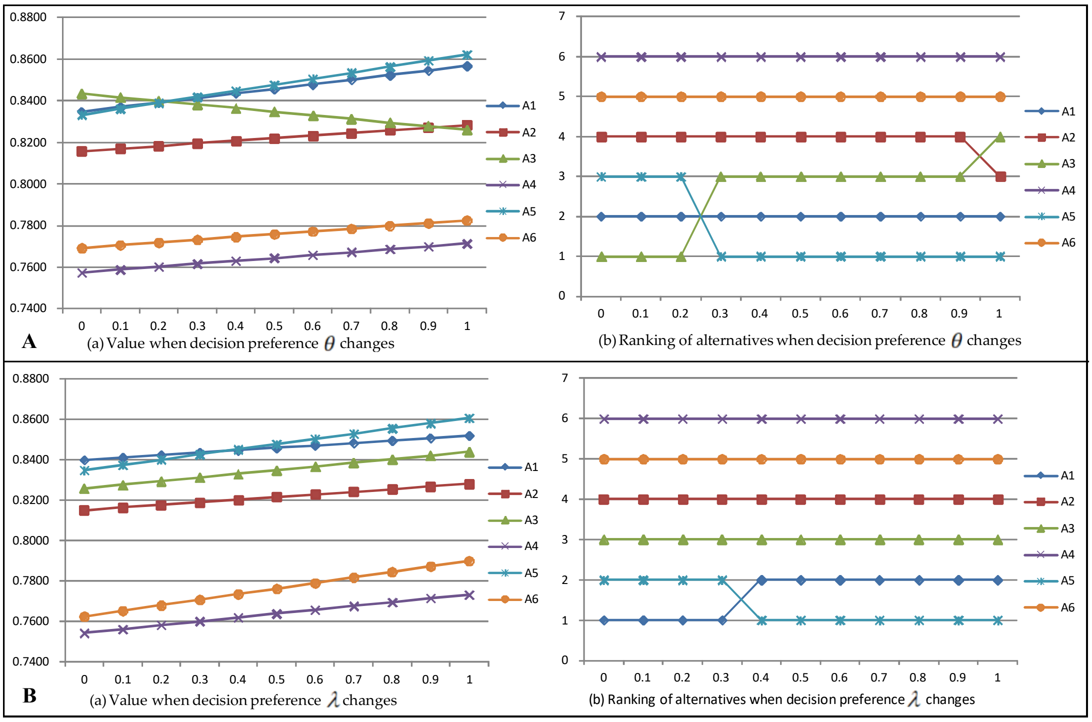

Figure 5. The effects of changes in decision preferences θ and λ on the results.

6.3.3. Sensitivity analysis of changes in parameter λ

The decision maker's preference for the WSM method is λ, and the preference for the WPM method is $1-\lambda$. We conducted a sensitivity analysis of the decision makers' preference λ for choosing WSM and WPM methods to verify the stability of the proposed method. Fig. 5(B) shows the impact on the results when the decision preference λ changed from zero to one.

When the decision preference λ was in the interval [0, 0.3] and [0.4, 1], the ranking of all alternatives remained unchanged; when the value of decision preference λ was in the interval [0.3, 0.4], only the ranking of alternatives A1 and A5 changed. In conclusion, decision preference λ was not sensitive to the results of the decision, and the top two alternatives were always A1 and A5 (see Fig. 5(d)), which illustrates the stability and robustness of the method proposed in this paper.

Note that the parameters θ and λ of decision preference have an impact on the results. In practice, ways of choosing θ and λ to reduce risk requires sufficient attention from managers. If the selected evaluation expert has a sound theoretical foundation and rich practical experience, the subjective weights of θ should be greater than its objective weight; otherwise, it should rely more on the objective weight. In addition, because the parameter λ of decision preference has a minor effect on the result, we can set λ to 0.5. As the MCDM method often uses experts for evaluation, where they might have different opinions due to differences in knowledge and experience, different experts should be assigned different weights to reduce ambiguity in their evaluations.

6.4. Advantages of the proposed method

We summarize some advantages of the proposed method as follows:

First, the risk for decision makers can be reduced using it. The WASPAS is a hybrid MCDM method that improves the accuracy of the results of decision making. Studies have shown that the hybrid MCDM method can make up for the shortcomings of a single method (Tian et al., 2018). In addition, our WASPAS uses linear weighting to aggregate these two methods. Decision makers can thus flexibly adjust their preferences for the two methods to reduce the risk of failure of site selection.

Second, stable decision-making results can be obtained using the proposed method. Table A8 shows that there was a difference between the criteria weights obtained by the DEMATEL method and the EW method. Table A17 shows the advantages and disadvantages of DEMATEL and EW methods. Fig. 4 shows that the criteria weights were sensitive to the results of the decision. Therefore, if the decision makers consider only a single objective or a subjective method to calculate weights, the best alternative may not be obtained. This paper integrates subjective and objective methods to calculate weights, where this can reduce the decision-related risk that may be caused by the inappropriate selection of criteria weights.

Third, the proposed DEMATEL-EW-WASPAS method has a visual calculation process. The intuitive visualization can help decision makers discover possible deficiencies in the evaluation. The calculation of the WASPAS approach is also relatively simple, and decision makers can analyze the gap between criteria based on the results.

7. Managerial implications and importance of this paper

In densely populated cities, the removal and transportation of recyclable waste faces daunting challenges, especially in areas where land resources are limited and dispatch centers for waste transportation vehicles cannot be built. In view of this, this is the first paper that defines and studies the RWTVPC problem. In view of problems that might occur in practice, some implications for management are given below to provide guidelines for managers in practical scenarios. Moreover, we also discuss the importance of this study from a practical perspective.

7.1. Managerial implications

First, this paper constructed a system of evaluation indices for RWTVPC containing four criteria and 12 sub-criteria. This is suitable for choosing the site for parking centers for recyclable waste-carrying vehicles. Owing to different objectives of evaluation, however, the criteria may not objectively reflect the psychological preferences of decision makers. Hence, managers should dynamically adjust the evaluation index in practice. Fortunately, the process of analysis of the design of the system to assess indices used for RWTVPC site selection proposed here provides an effective tool for managers to construct an index system.

Second, the improved transportation network for recyclable waste management proposed here can reduce the cost of transportation. Previously proposed methods involve transporting recyclable waste on fixed transportation routes, which can lead to situations where the vehicles are not fully loaded or the waste along the route cannot be all picked up. However, the proposed method is dedicated to solving the above-mentioned shortcomings, and logistics operations managers will benefit from its low transportation cost and transportation efficiency. In addition, the proposed method requires less capital investment, has strong operability and flexibility, and requires only that the logistics operations managers find a suitable location of the RWTVPC along the route of the vehicle transporting waste.

Third, this study contributes to the literature by improving the network of recyclable waste transportation. The recycling of waste promotes the sustainable development of the CE. However, the current transportation of recyclable waste faces unique challenges, such as the small amount of recyclable waste at each collection site. Thus, this study proposed a sustainable solution to recyclable waste transportation to achieve economies of scale, thereby reducing the cost of transportation and improving the efficiency of regional recyclable waste. We can also reduce transportation costs and improve efficiency by adding locations of RWTVPCs to the recyclable waste transportation network. In addition, in the context of the economies of scale for recyclable waste in the future, the proposed method will more significantly improve transportation efficiency.

7.2. Importance of this paper

On a practical level, the importance of this paper is mainly reflected in the following.

First, this paper provides a location plan for a third-party logistics company that collects and transports recyclable waste on behalf of the city. Traditionally, waste transportation service companies need to invest a large amount of money to build dispatch centers for waste transportation vehicles. However, due to the city's limited land resources and high rental costs, it is impossible to build a dispatch center for vehicles transporting waste in relatively developed urban areas. In view of this, we considered roadside parking lots or idle spaces and other resources to park vehicles used to transport recyclable waste. When instructed, the vehicles depart from this location to the waste collection point to collect the waste. This is the first study to define and propose the RWTVPC problem. Besides, the solution to it offered here is more advantageous than investing in the construction of a new vehicle dispatch center for the following reasons: i) it reduces the risk of investment and saves investment funds; ii) it is more flexible; the location of the RWTVPC can be adjusted and its capacity increased at any time according to the volume of recyclable waste at the waste generation site; iii) it enhances the efficiency of recyclable waste transportation services. Importantly, our simplified RWTVPC problem is also easy to understand and implement.

Second, criteria weights are very sensitive to the results of the decision. If a more accurate weight cannot be determined by using a suitable method, the risk of failure of site selection increases. In addition, when the decision maker chooses different values of the parameters of decision preference, this has an impact on the results of calculation of the alternatives. However, we used a comprehensive weight that integrates subjective and objective methods to render the obtained criteria weights more in line with practical needs. Moreover, we applied the well-known WASPAS method to select the optimal alternative to improve the accuracy of evaluation. We also constructed a framework for decision-making analysis for RWTVPC-related issues to provide clear ideas. While our method is suitable for RWTVPC site selection, the analysis and methods provided herein can also be used for similar site selection problems.

Third, the RWTVPC issue proposed here is important in three ways: i) Compared with traditional transfer stations, the parking center for transportation vehicles proposed here is cheaper, more flexible, and maneuverable. ii) Compared with kitchen waste and medical chemical waste, vehicles used to transport recyclable waste have a lower negative impact on the environment when they are parked. iii) The RWTVPC can ensure that recyclable waste in the area is transported in time, thereby improving the social welfare of surrounding residents/enterprises.

8. Conclusions

To promote the development of the CE, recyclable waste transportation management has gradually attracted people's attention. Motivated by a third-party logistics company, this paper studied how the company selects the best location for an RWTVPC in a given area, and established an integrated framework of analysis for the problem of identifying this location. To make the criteria weights more reasonable, we used the DEMATEL-EW method to obtain them and applied the WASPAS approach to obtain the results. The results show that the DEMATEL-EW-WASPAS method is reliable in terms of obtaining reasonable criteria weights and alternative rankings, and can reduce the risks in decision making. Moreover, the MCDM proposed here is more compatible than the traditional LA location allocation method in terms of solving the problem of identifying the location of the RWTVPC, and can handle qualitative criteria whereas LA allocation cannot. Due to its flexibility, it can also be applied to similar problems with appropriate adjustments.

Although the results here verify that the proposed method is viable and effective, it has some limitations. First, the preference parameters for decision making used here are directly given by the decision makers. Thus, no scientific method is available to reduce the subjectivity of the decision maker's judgment. Second, the criteria weights should be flexible and dynamically adjusted as the decision-making environment changes. Third, considering the amount of waste at each waste collection point is beneficial for improving waste transportation management. In future work, we should consider the method to use to determine the weights of expert opinions to reduce the influence of experts who have different backgrounds and experience on the results of decision making. It will be interesting to consider improving waste transportation through an intelligent vehicle transportation management platform as well. In addition, an important direction of research in the future is to examine how the government affects the transportation of recyclable waste through such measures as subsidies and policy preferences. This may be an effective way to achieve economies of scale in the transportation of recyclable waste.

Appendix A

Table A1. Linguistic scale and the corresponding TFNs.

Linguistic terms scale	Very high influence (VH)	High influence (H)	Low influence (L)	Very low influence (VL)	No influence (N)
TFNs	(0.75,1.0,1.0)	(0.5,0.75,1.0)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0,0.25)

Table A2. Linguistic evaluation terms of experts.

Linguistic terms	Very good (VG)	Good (G)	Slightly good (SG)	Fair (F)	Slightly poor (SP)	Poor (P)	Very poor (VP)
TFNs	(0.90,1.0,1.0)	(0.75,0.85,0.9)	(0.5,0.6,0.75)	(0.4,0.5,0.6)	(0.2,0.3,0.5)	(0.1,0.2,0.35)	(0,0.1,0.2)

Table A3. Linguistic terms of criteria provided by experts.

	Criteria	C1	C2	C3	C4		Criteria	C1	C2	C3	C4		Criteria	C1	C2	C3	C4
E1	C1	N	VL	VH	L	E2	C1	N	VL	H	L	E3	C1	N	VL	VH	L
	C2	VH	N	L	H		C2	H	N	L	H		C2	VH	N	L	VH
	C3	VL	L	N	VL		C3	VL	L	N	VL		C3	VL	L	N	VL
	C4	L	VL	VL	N		C4	L	VL	VL	N		C4	VH	VL	H	N
E4	C1	N	VL	VH	L	E5	C1	N	H	VH	L						
	C2	VH	N	L	VH		C2	VH	N	L	VH						
	C3	VH	L	N	VL		C3	VH	L	N	VL						
	C4	L	VL	H	N		C4	L	L	H	N						

Table A4. Linguistic terms of environmental criteria provided by experts.

	Criteria	C11	C12	C13		Criteria	C11	C12	C13		Criteria	C11	C12	C13
E1	C11	N	VL	VH	E2	C11	N	VH	VH	E3	C11	N	VL	VH
	C12	VH	N	L		C12	VH	N	VH		C12	H	N	L
	C13	VL	L	N		C13	VL	L	N		C13	VL	L	N
E4	C11	N	VL	VH	E5	C11	N	VL	VH					

	C12	H	N	L		C12	H	N	L
	C13	VL	VL	N		C13	H	VL	N

Table A5. Linguistic terms of economic criteria provided by experts.

	Criteria	C21	C22	C23		Criteria	C21	C22	C23		Criteria	C21	C22	C23
	C21	N	L	VH		C21	N	H	L		C21	N	VL	L
E1	C22	VH	N	L	E2	C22	VH	N	VH	E3	C22	H	N	L
	C23	VL	VL	N		C23	VH	L	N		C23	VL	N	N
	C21	N	VL	L		C21	N	H	VL					
E4	C22	H	N	L	E5	C22	H	N	L					
	C23	H	H	N		C23	VH	H	N					

Table A6. Linguistic terms of social criteria provided by experts.

	Criteria	C31	C32	C33		Criteria	C31	C32	C33		Criteria	C31	C32	C33
	C31	N	L	VH		C31	N	H	L		C31	N	L	H
E1	C32	L	N	L	E2	C32	VH	N	VH	E3	C32	H	N	L
	C33	VL	VL	N		C33	VH	VL	N		C33	VL	L	N
	C31	N	VL	L		C31	N	H	VL					
E4	C32	VH	N	H	E5	C32	VH	N	L					
	C33	VH	H	N		C33	H	H	N					

Table A7. Linguistic terms of technical criteria provided by experts.

	Criteria	C41	C42	C43		Criteria	C41	C42	C43		Criteria	C41	C42	C43
	C41	N	VL	H		C41	N	L	L		C41	N	H	H
E1	C42	H	N	L	E2	C42	H	N	L	E3	C42	H	N	VH
	C43	VL	VL	N		C43	VH	H	N		C43	VH	L	N
	C41	N	VL	VL		C41	N	VL	L					
E4	C42	H	N	VL	E5	C42	VH	N	H					
	C43	VH	H	N		C43	VH	H	N					

Table A8. Subjective and objective weights calculated by DEMATEL and EW method.

DEMATEL method					EW method				
Criteria	Weight	Sub-criteria	Local weight	Global weight	Criteria	Weight	Sub-criteria	Local weight	Global weight
		C11	0.338	0.102			C11	0.396	0.100
C1	0.301	C12	0.329	0.099	C1	0.253	C12	0.380	0.096
		C13	0.333	0.100			C13	0.223	0.057
		C21	0.336	0.092			C21	0.194	0.051
C2	0.274	C22	0.339	0.093	C2	0.265	C22	0.421	0.112
		C23	0.325	0.089			C23	0.385	0.102
C3	0.242	C31	0.336	0.081	C3	0.241	C31	0.355	0.086
		C32	0.338	0.082			C32	0.351	0.085

		C33	0.327	0.079			C33	0.294	0.071
		C41	0.331	0.061			C41	0.269	0.065
C4	0.183	C42	0.335	0.061	C4	0.240	C42	0.323	0.078
		C43	0.335	0.061			C43	0.408	0.098

Table A9. Linguistic terms objectively provided by experts based on criteria data.

	A_i	C1	C2	C3	C4		A_i	C1	C2	C3	C4		A_i	C1	C2	C3	C4
E1	A1	G	SG	SG	F	E2	A1	G	F	VG	F	E3	A1	G	F	SG	F
	A2	VG	G	SP	G		A2	SG	G	F	G		A2	SG	P	F	VG
	A3	F	SG	G	G		A3	F	SG	G	VG		A3	VG	SG	G	VG
	A4	VG	G	F	G		A4	VG	G	VG	G		A4	VG	G	P	G
	A5	SG	F	SP	SG		A5	SG	SG	G	SG		A5	SG	SG	G	SG
	A6	F	G	VP	VG		A6	F	G	VP	G		A6	P	G	VP	SG
E4	A1	G	F	SG	F	E5	A1	G	P	SG	F						
	A2	SG	VG	F	VG		A2	SG	VG	F	VG						
	A3	VG	SG	G	G		A3	VG	VG	SG	SG						
	A4	VG	G	P	G		A4	G	SG	P	G						
	A5	SG	SP	G	SG		A5	SG	F	G	SG						
	A6	P	G	P	G		A6	G	F	SG	F						

Table A10. Linguistic terms of criteria for all alternatives provided by experts.

Experts	Alternatives	C11	C12	C13	C21	C22	C23	C31	C32	C33	C41	C42	C43
E1	A1	VG	VG	G	6000	100	19	VG	VG	G	G	20	G
	A2	G	VG	G	6400	95	20	SG	VG	G	F	16	SG
	A3	VG	G	VG	5800	90	23	SG	G	F	G	25	G
	A4	VG	VG	G	6000	100	19	G	G	G	SP	30	G
	A5	G	VG	VG	6000	98	24	F	G	F	F	27	SP
	A6	VG	G	G	6250	96	22	G	VG	SP	G	20	SG
E2	A1	G	G	G	6000	100	19	VG	G	VG	G	20	F
	A2	G	VG	G	6400	95	20	G	VG	G	SG	16	SG
	A3	VG	G	P	5800	90	23	F	F	F	G	25	G
	A4	G	F	G	6000	100	19	SG	G	G	SP	30	F
	A5	G	VG	VG	6000	98	24	VG	G	F	F	27	SP
	A6	VG	VG	SP	6250	96	22	P	VG	SP	SG	20	P
E3	A1	G	G	G	6000	100	19	G	G	VG	G	20	F
	A2	VG	VG	G	6400	95	20	VG	VG	G	SG	16	SG
	A3	VG	SP	SG	5800	90	23	G	VG	F	G	25	G
	A4	SG	F	G	6000	100	19	SG	G	SG	SP	30	F
	A5	G	VG	VG	6000	98	24	VG	F	VG	F	27	SP
	A6	VG	G	F	6250	96	22	SG	VG	SP	SG	20	VP

E4	A1	G	SG	G	6000	100	19	SG	VG	VG	G	20	SP
	A2	SG	P	G	6400	95	20	VG	VG	G	SG	16	SG
	A3	VG	SP	SG	5800	90	23	G	G	SG	G	25	G
	A4	SG	F	G	6000	100	19	SG	G	SG	SP	30	SP
	A5	G	VG	VG	6000	98	24	VG	F	VG	F	27	SP
	A6	VG	G	VG	6250	96	22	SG	VG	SP	P	20	VP
E5	A1	SG	SG	G	6000	100	19	VG	VG	SG	G	20	P
	A2	SG	P	G	6400	95	20	VG	VG	G	F	16	SG
	A3	G	SP	SG	5800	90	23	G	G	SG	G	25	G
	A4	SG	F	G	6000	100	19	SG	G	SG	SP	30	F
	A5	G	VG	G	6000	98	24	VG	SG	VG	F	27	SP
	A6	VG	G	VG	6250	96	22	SG	VG	F	SG	20	G

Table A11. Comprehensive weights.

Criteria	Weight	Subcriteria	Local comprehensive weight	Global comprehensive weight	Ranking
C1	0.277	C11	0.367	0.1017	2
		C12	0.355	0.0982	3
		C13	0.278	0.0769	8
C2	0.270	C21	0.265	0.0714	10
		C22	0.380	0.1025	1
		C23	0.355	0.0959	4
C3	0.242	C31	0.345	0.0835	5
		C32	0.344	0.0832	6
		C33	0.311	0.0751	9
C4	0.212	C41	0.300	0.0635	12
		C42	0.329	0.0697	11
		C43	0.371	0.0786	7

Table A12. Aggregating the evaluation information of all experts.

A_i	C1	C2	C3	C4	C11	C12	C13	C21	C22	C23	C31	C32	C33	C41	C42	C43
A1	0.838	0.445	0.703	0.500	0.802	0.757	0.838	6000	100	19	0.882	0.920	0.864	0.838	20	0.444
A2	0.667	0.806	0.474	0.920	0.757	0.632	0.838	6400	95	20	0.886	0.975	0.838	0.568	16	0.613
A3	0.785	0.703	0.781	0.836	0.941	0.530	0.567	5800	90	23	0.719	0.774	0.551	0.838	25	0.838
A4	0.941	0.781	0.446	0.838	0.723	0.571	0.838	6000	100	19	0.646	0.835	0.703	0.325	30	0.516
A5	0.613	0.510	0.761	0.613	0.838	0.975	0.941	6000	98	24	0.904	0.663	0.785	0.500	27	0.325
A6	0.484	0.753	0.251	0.740	0.975	0.872	0.721	6250	96	22	0.546	0.975	0.369	0.566	20	0.389

Table A13. Distance from alternatives to each waste generation point.

Distance	A1	A2	A3	A4	A5	A6
Waste generation point 1	2	5	2	6	2	3

Waste generation point 2	2	2	4	3	2	5
Waste generation point 3	3	1	5	2	3	3
Waste generation point 4	1	5	4	2	1	2
Waste generation point 5	1	3	1	6	1	3
Waste generation point 6	2	2	2	4	2	6
Waste generation point 7	3	4	3	6	3	5
Waste generation point 8	2	3	4	6	2	2

Table A14. Other parameter values.

Alternatives	A1	A2	A3	A4	A5	A6
T_j	6000	6400	5800	6000	6000	6250
c_j	100	95	90	100	98	96

Table A15. The comprehensive ranking of alternatives considering only economic criteria.

Alternatives	A1	A2	A3	A4	A5	A6
WSM method	0.8875	0.9008	0.9875	0.8875	0.9573	0.9284
WPM method	0.8848	0.8996	0.9873	0.8848	0.95673	0.9284
Comprehensive result	0.8861	0.9002	0.9874	0.8861	0.9570	0.9284
Ranking	5	4	1	5	2	3

Table A16. Weight combination.

	Scenario 1							Scenario 2							Scenario 3						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
C1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.1	0.2	0.3	0.4	0.5	0.6	0.7
C2	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
C3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
C4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.7	0.5	0.4	0.3	0.2	0.1	0.1
	Scenario 4							Scenario 5							Scenario 6						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
C1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
C2	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.1	0.1	0.1	0.1	0.1	0.1	0.1
C3	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.7
C4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.7	0.6	0.5	0.4	0.3	0.2	0.1

Table A17. The advantages and disadvantages of DEMATEL and EW methods.

Method	Type	Advantages	Disadvantages
DEMATEL	Subjective	Simplify the relationship between system elements, and rely on expert experience for	It cannot objectively reflect the attributes of the data; difficult to analyze large and complex systems

		analysis	
EW	Objective	The accuracy is high, and the weight can be modified appropriately	Depending on the accuracy of the data, once the data has a large error, the weights obtained are not accurate

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