Sustainable Resilient Recycling Partner Selection for Urban Waste Management: Consolidating Perspectives of Decision-makers and Experts

Gholamreza Haseli [a], Ali Ebadi Torkayesh [b], Mostafa Hajiaghaei-Keshteli [a*], Sandra Venghaus [b,c]

[a] Tecnologico de Monterrey, Escuela de Ingeniería y Ciencias, Puebla, Mexico

[b] School of Business and Economics, RWTH Aachen University, 52072 Aachen, Germany

[c] Institute of Energy and Climate Research – Systems Analysis and Technology Evaluation (IEK-STE), Forschungszentrum Jülich, Wilhelm-Johnen-Straße, 52428 Jülich, Germany

* mostafahaji@tec.mx (Corresponding author)

Abstract

The selection of recycling partners is an important decision-making issue in sustainable waste supply chains. Waste supply chains have undergone many fundamental modifications as a result of the rise of concepts such as sustainability, circular economy, and resilience. To overcome the current shortcomings of the literature on recycling partner selection only based on sustainability aspects, an evaluation framework is developed to address recycling partner selection by considering both sustainability and resilience factors. In spite of the fact that developing a sustainable, resilient evaluation framework improves the process of selecting recycling partners, the problem becomes very complex, and multidimensional decision-makers require reliable and accurate tools to make informed decisions. Multi-criteria decision-making (MCDM) methods are useful decision-making tools with high reliability to address problems under uncertainty. Although previous studies have developed several MCDM methods based on various uncertainty sets, the capability to support efficient and accurate group decision-making by decision-makers' opinions and experts' judgments has been a major disadvantage. Therefore, this study develops a novel decision-making approach using Z^E-numbers based best-worst method (Z^E-BWM) and a combined compromise solution (Z^E-CoCoSo). The proposed novel approach for addressing a sustainability and resilience management problem in an urban setting is demonstrated in a real-life case study using Tabriz, Iran as a case study. According to the results, the most important criteria are net profit and the robustness of the waste supply chain.

Keywords: Recycling Partner Selection; Sustainability; Waste Management; Circularity; Multi-Criteria Decision Making.

1. Introduction

1.1. Sustainability, Resilience, and Circular Economy in Supply Chains

In recent years, waste management systems have undergone a number of green and environmental transformations due to the introduction of concepts such as sustainability, resilience, and circular economy. Sustainability is an increasing concern in all sectors dealing with products and services, aiming to decrease social, economic, and environmental impacts [[1], [2], [3]]. Municipal waste management systems are one of the important urban systems to adopt sustainability practices; however, there exist several issues with maintaining a completely sustainable municipal waste management system [4], [5]. One of the main issues with current municipal waste management systems is their capacity limitation due to the high waste generation rate. Population growth and high household consumption are two major reasons for increasing waste in big cities. According to Figure 1, waste generation worldwide (in million metric tons) is expected to increase between 2016 and 2050 (in million metric tons). As shown in Figure 1, the waste generation rate is projected to increase for the next several decades based on information provided by the World Bank [6]. It is no longer possible to manage waste efficiently and sustainably under traditional systems.

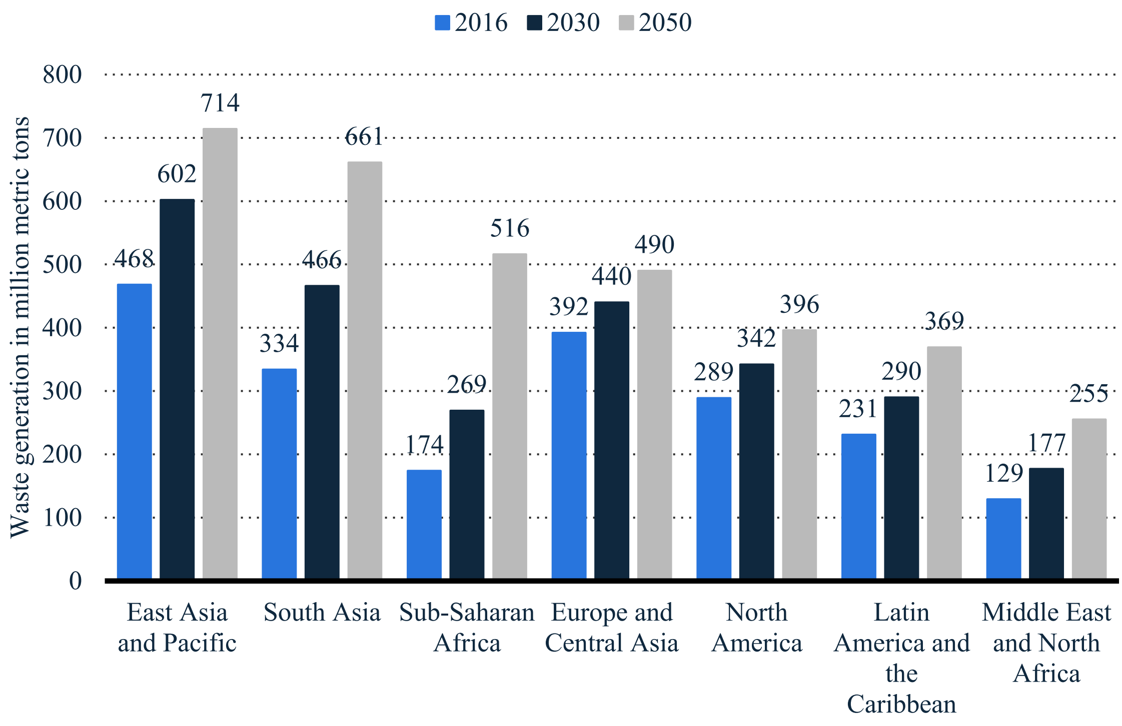


Figure 1. Projection of waste generation worldwide in 2016, 2030, and 2050 (million metric tons) [6].

Thus, sustainability and circular economy concepts are currently being considered to address existing issues and mitigate current systems' drawbacks [7], [8]. As one of the key concepts supporting sustainability, circular economy emphasizes the role of recyclability in the waste supply chain. Recycling is one of the most important operations in today's waste supply chain for reducing environmental pollutants associated with landfilling and other unsanitary disposal methods. Social, environmental and economic advantages have attracted governmental sectors and private organizations to invest more in recycling [9], [10].

While sustainability practices have provided useful solutions for the waste supply chain, they still require modifications to fundamental functions and operations. One of the major issues with the waste supply chain is its vulnerability to risks, unexpected changes, and disruptions [11]. It is important to note that any disruption in the waste supply chain can have expensive and, in some cases, irreversible social, environmental, and economic consequences. Thus, resilience measures are highly significant for the waste supply chain to ensure that the system would continue to work in case of disruptions. Robustness, flexibility, and agility of the waste supply chain should be intensified to develop resilient systems [[12], [13], [14]].

As an example, the COVID-19 pandemic was one of the most significant and critical events that occurred recently and had an immediate impact on the world. The pandemic negatively affected many industries and supply chains worldwide, specifically in the very early days of 2020 [15], [16]. Thus, a number of industries were unable to continue to operate, or at least their ability to operate was greatly impacted by the severe limitations and difficult circumstances. Like other supply chains, the pandemic also affects the waste supply chain in several ways [15], [17]. One of the most critical issues in the waste supply chain since the beginning of the pandemic has been the exponential increase in waste generation rate (household waste). Thus, the high waste generation rate has put high pressure on the supply chain network, specifically on facility plants such as collection, treatment, and recycling which now have to deal with more waste than their infrastructural and technological capabilities. In such circumstances, the circular economy plays a crucial role in waste management by promoting recycling. Therefore, the waste supply chain's robustness and agility are highly significant for preventing any failure in waste management systems under any unexpected changes or disruptions [19], [20]. After the pandemic, waste management managers learned the importance of meeting resilience, sustainability, and circular economy standards in the post-pandemic period [21, 22].

1.2. Decision-Making in Waste Recycling Supply Chain Management

In order to increase their capabilities and operations, recycling facilities and companies have sought to cooperate with other companies to handle large municipal waste during the pandemic. In addition to their expertise in processing specific waste types such as plastic, paper, and glass, recycling companies are increasingly collaborating with each other. Evaluation and selection of the best recycling partner has become a complex process due to factors such as sustainability and resilience.

Multi-criteria decision-making (MCDM) methods are useful tools for addressing complicated and multi-dimensional problems with straightforward soft computing [[23], [24], [25], [26], [27]]. With a user-friendly structure, MCDM methods are considered very reliable tools for handling two major tasks in the waste supply chain: determining weight coefficients and evaluating alternatives. Another advantage of MCDM methods for recycling partner selection (RPS) is their capability to incorporate uncertain information for performance evaluation through various uncertainty sets, such as fuzzy sets using linguistic terms [[28], [29], [30]]. A summary of the most recent studies on RPS using MCDM is as follows.

Recent studies have proposed a variety of techniques to address this issue under different conditions. Wibowo and Deng [31] applied a fuzzy MCDM approach to investigate the performance of recycling program for e-waste. Zho et al. [32] developed a decision-making approach based on the fuzzy DEMATEL (decision-making trial and evaluation laboratory), AEW (anti-entropy weighting), and VIKOR (VlseKriterijuska Optimizacija I Komoromisno Resenje) to evaluate recycling partners in small-and-medium enterprises considering sustainability factors. Kumar et al. [33] used an MCDM framework based on AHP and VIKOR under the type-1 fuzzy set to address RPS in waste electrical and electronic equipment considering environmental and green factors. Chauhan et al. [34] developed an analytical approach using DEMATEL and interpretive structural modeling (ISM) to investigate the barriers of waste recycling in India where results indicated that the lack of funds, input material, and subsidy are the most influential barriers. Rani et al. [35] suggested a novel approach by combining Pythagorean TOPSIS (a technique for order preference by similarity to ideal solution) and similarity measure based on the trigonometric function to rank recycling partners according to sustainability aspects in India. Later in 2020, Rani and Mishra [10] integrated a similarity measure, and CoCoSo (combined compromise solution) under the single-valued Neutrosophic set for RPS for waste electrical and electronics equipment. To analyze the interrelation between evaluation factors for RPS, Li et al. [36] utilized DEMATEL based on probabilistic linguistics under the hesitant fuzzy linguistic set. Mishra and Rani [26] proposed an evaluation model using entropy with discrimination measures and ARAS (additive ratio assessment) methods under the q-rung repair fuzzy set for a real case study of RPS in India. Deshpande et al. [37] used multi-attribute value theory (MAVT) to evaluate the degree of sustainability of end-of-life options (in-land recycling, export recycling, incineration, and landfilling) for waste plastics in Norway. Results showed that in-land recycling is the best option for Norway. Karagoz et al. [38] developed an intuitionistic fuzzy based CODAS to address location selection of a dismantling facility within electric vehicles recycling supply chain in Turkey. To address the same problem in more comprehensive way, Karagöz et al. [39] introduced a new decision-making model using interval type-2 Fuzzy ARAS to locate a recycling facility for the end-of-life vehicles. In order to consider possible impacts of the potential future scenarios on locating recycling facility, Torkayesh and Simic [40] suggested a decision model based on the concept of stratification for healthcare plastic waste in Turkey.

In light of current disruptions, uncertainties, and strict global environmental standards, sustainability and resilience have become critical concepts in waste supply chains. Consequently, research into developing novel techniques and methodologies to address various waste supply chain problems has gained increased attention. It has been discussed previously that RPS is a significant issue faced by large recycling companies. Due to this, RPS is no longer a simple decision-making process based on technical and economic factors. To maintain standards of a sustainable municipal waste management system, RPS must also address environmental, social and resilience factors. Integrating sustainability and resilience factors into RPS increases the complexity of the problem's complexity; thus, more advanced techniques are required to address the problem accurately.

However, most of the studies in the literature have developed MCDM approaches utilizing different versions of fuzzy sets; however, all of these approaches use their input data only by decision makers. Due to their backgrounds, professions, and expectations, decision-makers' opinions are prone to bias and subjectivity. No study in the RPS literature has not addressed this issue so far.

1.3. Contributions & Novelties

In MCDM problems, the decision-makers determine coefficient weights and alternative ranking based on the evaluations of several criteria [41], [42]. Real-world decision-making problems, however, are uncertain and complex. As a result, decision-makers are unable to accurately express their preferences in uncertain environments. This problem was partially solved with the introduction of fuzzy sets [43]. Various fuzzy sets were developed to improve the traditional ones in the following years. However, most traditional fuzzy sets cannot consider the reliability of decision-makers' preferences. To overcome this limitation and consider the reliability of decision makers' preferences, Z-numbers were introduced by Zadeh [44]. Since then, different MCDM methods have been developed based on the Z-numbers in various fields [45], [46]. However, an important shortcoming of Z-numbers, like other uncertainty sets, is their structure in addressing MCDM problems which only consider decision-makers' opinions. To address this shortcoming, Tian et al. [47] extended Z-numbers and proposed Z^E-numbers for group decision-making to increase the reliability of decision-makers' decisions by considering the experts' judgments. The Z^E-numbers approach enables the preferences of decision-makers and experts to be analyzed in two separate stages in order to generate highly reliable solutions.

Although several studies have addressed the RPS problem with various approaches, several research gaps exist. According to the literature review in Section 1.2, none of the previous studies on RPS consider sustainability and resilience factors simultaneously to evaluate recycling partners. The first major research gap in the literature is related to integrating the resilience factors within the RPS problem. The present study is the first to develop a comprehensive evaluation framework based on sustainability and resilience factors for RPS. As waste management systems are fundamental in urban areas, great attention is paid to their transformation into sustainable, resilient, and circular systems. Recycling and circular economies play an important role in transforming traditional waste management systems into sustainable ones. A sustainable waste management system would maximize the efforts to achieve a sustainable urban area by considering sustainability and resilience factors.

In this regard, this study develops a novel decision-making approach using Best-Worst Method (BWM), and CoCoSo based on Z^E-numbers to address sustainable, resilient RPS. To address the RPS, BWM and CoCoSo as two of the well-known methods among MCDM techniques are used. This study develops novel BWM and CoCoSo based on Z^E-numbers labeled as Z^E-BWM, and Z^E-CoCoSo. Z^E-BWM is used to determine the optimal weight coefficients of decision criteria (factors), while Z^E-CoCoSo is used to prioritize recycling partners based on the sustainability and resilience factors. The main motivation to develop novel extensions of BWM and CoCoSo under Z^E-numbers is due to the superiority of Z^E-numbers compared to other uncertainty sets such as traditional fuzzy sets, and Z-numbers. Z^E-numbers provide a reliable and flexible decision-making environment and improve the group decision-making process for important real-life problems with several decision-makers. Z^E-numbers are improved version of the Z-numbers where experts' judgments are consolidated with decision-makers' opinion for more reliable solutions. In other words, unlike Z-numbers and other uncertainty sets such as triangular fuzzy set, and interval-valued fuzzy set where only decision-makers are considered in the decision-making process, Z^E-numbers also involve experts to incorporate the effects of their judgments on decision-makers' opinions. In an exemplary case within organizational structure of a company, decisions made by mid-level professionals usually go through upper-level managers where feedback and judgments are reflected accordingly. In this way, the decision-making model will provide more reliable solutions than previous approaches in the literature. An additional contribution of this study is the integration of Z^E-BWM and Z^E-CoCoSo as an integrated decision-making approach to address the RPS for a real-life case study. In order to demonstrate the applicability and effectiveness of the proposed approach in a decision-making problem, a case study is conducted in Tabriz, Iran for the RPS under sustainability and resilience aspects.

1.4. Organization & Structure

The rest of the paper is organized as follows. In section 2, you will find an overview of the background and preliminary information of the proposed approach. The case study and context definition are given in Section 3. In Section 4, the results of the weight coefficients, ranking of recycling partners, sensitivity analysis, and comparative analysis are presented. Section 5 presents a discussion and managerial insight. Finally, the conclusions are provided in Section 6.

2. Methodology

This section presents Z^E-numbers, and two new methods called Z^E-BWM and Z^E-CoCoSo.

2.1. Preliminaries of Z^E-numbers

Zadeh [43] introduced fuzzy set theory as a powerful method to express ambiguous information and subjective in various fields. A fuzzy set is a set of membership elements between [0, 1]. The U is a set of numbers and m: $U \rightarrow [0,1]$ is the membership function $\tilde{\mu}_s(x)$. Triangular Fuzzy Numbers (TFNs) are special fuzzy numbers that express the relative importance of each membership element in the same hierarchy. A TFN can be denoted by three elements (l, m, u), which indicate the lower value, the center, and the upper, respectively. The membership functions of TFNs are defined as Eq. (1), where $l < m < u$.

$$\tilde{\mu}_s(x) = \begin{cases} 0, & x < l \\ \dfrac{x-l}{m-l}, & l \le x \le m \\ \dfrac{u-x}{u-m}, & m \le x \le u \\ 0, & x > u \end{cases} \tag{1}$$

Let $\tilde{S}_1 = (l_1,, m_1, u_1)$ and $\tilde{S}_2 = (l_2, m_2, u_2)$ be two TFNs. For more details and familiarization with how to calculate different operators and the graded mean integration representation (GMIR) for the TFNs, refer to see [48].

Zadeh [44] proposed Z-numbers as a generalized version of the uncertainty theory for calculating preliminary reliable numbers [49]. A Z-number is a pair of fuzzy numbers denoted as $Z = (A, B)$ where the A component indicates the variable of the fuzzy restriction of the domain X, and B component indicates a reliability measure of A by triangular fuzzy numbers (TFNs). The fuzzy restriction $(R(X): X \ is \ A)$ is a probabilistic constraint, which indicates the possible distribution. This restriction can be described in Eq. (2).

$$R(X): X \ is \ A \rightarrow Poss \ (X = u) = u_A(u) \quad (2)$$

In Eq. (2), u is the general value of X and u_A is a membership function of A which can be considered as a constraint associated with $R(X)$. In fact, the degree of satisfaction of u is satisfied by $u_A(u)$. So, X is a random variable with the probability distribution $R(X)$ and plays the potential restriction role on X. The probability distribution $R(X)$ is described as Eq (3).

$$R(X): X \ is \ p \rightarrow Prob \ (u \leq x \leq u + du) = p(u)du \quad (3)$$

Eq. (4) is used to convert the reliability component of Z-numbers into a crisp number.

$$\alpha = \frac{\int x\mu_B dx}{\int \mu_B dx} \quad (4)$$

Due to the original concept of the Z-numbers [44], Z-numbers are not simple pair components. A and B components are linked by hidden probability. Eq. (5) indicates this restriction.

$$\sum_{i=1}^{n} \mu_A(x_i) \, . p_{x_A}(x_i) \rightarrow \ b_i \quad (5)$$

For objective reliability, the information obtained from Z-number decision-makers should be as objective as possible. Tian et al. [47] proposed Z^E-numbers to determine group decision-making reliabilities by improving Z-numbers. The form of Z^E-numbers is defined as Eq. (6),

$$ZE = ((A, B), E) \quad (6)$$

To determine the reliability of group decision-making, Tian et al. [47] utilized the voting method. According to Eq. (7), in the voting method for group decision-making, Y indicates the number of experts who agree with evaluated Z-numbers, N indicates the number of experts who disagree, and θ indicates the number of experts who have a neutral opinion.

$$Evaluation - number = (Y, N, \theta) \quad (7)$$

The E component in Eq. (8) is $Evaluation - number$, which indicates individual evaluation by group voting to determine the credibility of decisions. The E component represents the credibility of the A and B components. For transforming a Z-number to a Z^E-number, Eqs. (8-9) can be used.

$$M = \begin{cases} b_i^* = b_i * (1 + R) & . \quad R < 0 \\ b_i^* = b_i & . \quad R = 0 \\ b_i^* = 1 - (1 - b_i) * (1 - R) & . \quad R > 0 \end{cases} \quad (8)$$

$$R = \frac{Y - N}{n - \theta} \tag{9}$$

where b_i^* indicates the modified value of b_i and b_i is b of B component in Z-numbers, and n denotes total number of participants.

2.2. Group Z^E-BWM

Rezaei [50] introduced BWM as a powerful method for determining optimal weight coefficients for criteria through the use of an optimization model. BWM evaluates the relative importance of criteria using pairwise comparisons. This method is based on a vector-based structure and performs fewer pairwise comparisons than other MCDM methods such as AHP. Guo and Zhao [48] extended BWM by TFNs (F-BWM) to fuzzy environments. To improve the BWM for group decision-making, Hafezalkotob and Hafezalkotob [51] introduced fuzzy group BWM. One year later, Aboutorab et al. [49] used the Z-numbers to develop Z-BWM to improve fuzzy BWM by considering reliability values. Haseli et al. [52] proposed an approach for group BWM to involve many decision-makers' opinions with fewer constraints. Torkayesh et al. [53] suggested a new form of BWM under stratification theory to include impacts of scenarios and events in weight coefficients. Due to its high efficiency in handling the MCDM problem, BWM and its extensions have been used numerously in different applications such as waste management, energy planning [54], supply chain management [55], recycling and remanufacturing [29], risk evaluation [56] and sustainability [57]. Although various extensions have been developed so far, none of these extensions can consider experts' judgments on decision-makers' opinions.

This section describes the Z^E-BWM as a novel extension of the Z-BWM. Z^E-BWM can be used based on the following steps.

Steps 1: Specify a set of decision criteria, decision-makers, and experts.

In this step, a set of criteria, number of decision-makers, and a group of experts should be defined.

Steps 2: Determine the best and worst criteria by decision-makers.

Steps 3: Determine the relative importance of pairwise comparisons.

In this step, perform pairwise comparisons between best-to-others and others-to-worst criteria using the fuzzy linguistic terms (Table 1, Table 2) to determine the relative importance of the criteria. Decision-makers select the linguistic variables in Table 1 to assign the value of pairwise comparisons. Also, linguistic variables of reliabilities in Table 2 are chosen to express the level of reliabilities. The Z-number for preferences of pairwise comparisons is calculated by merging membership function and TFNs of reliability. First, the α value is calculated. To find the α value for Eq. (10), the crisp number for TFN of reliability is calculated according to Eq. (4). Second, the calculated crisp number of reliabilities is multiplied by each of the membership function elements according to Eq. (10).

$$Z - number\left(l_{Z(ij)}, m_{Z(ij)}, u_{Z(ij)}\right) = \left(l_j \times \sqrt{\alpha},\ m_j \times \sqrt{\alpha},\ u_j \times \sqrt{\alpha}\right) \tag{10}$$

Preferences of the pairwise comparison vector of the best-to-others criteria based on Z-numbers will follow Eq. (11).

$$\tilde{A}_B = \left((l_{Z(B1)}, m_{Z(B1)}, u_{Z(B1)}), (l_{Z(B2)}, m_{Z(B2)}, u_{Z(B2)}), \cdots, (l_{Z(Bn)}, m_{Z(Bn)}, u_{Z(Bn)})\right) \tag{11}$$

where (l_{Bj}, m_{Bj}, u_{Bj}) indicates the relative importance of the best criterion to criterion j using Z-numbers. Also, Eq. (12) indicates the vector of the fuzzy relative importance of the criterion j to the worst criterion.

$$\tilde{A}_w = \left((l_{Z(1w)}, m_{Z(1w)}, u_{Z(1w)}), (l_{Z(2w)}, m_{Z(2w)}, u_{Z(2w)}), \cdots, (l_{Z(nw)}, m_{Z(nw)}, u_{Z(nw)})\right) \tag{12}$$

where (l_{jw}, m_{jw}, u_{jw}) denote the relative importance of the criterion j over the worst criterion using Z-numbers.

Table 1. Linguistic variables and Consistency Index (CI) [58].

Linguistic variables	Membership function	CI
Equally Important (EI)	(1,1,1)	3.00
Weakly important (WI)	(2/3,1, 3/2)	3.8
Fairly important (FI)	(3/2,2,5/2)	5.29
Important (I)	(5/2,3,7/2)	6.69
Very important (VI)	(7/2,4,9/2)	8.04
Absolutely important (AI)	(9/2,5,11/2)	9.35

Table 2. Transformation rules of linguistic variables of reliabilities [49].

Linguistic variables	Very low (VL)	Low (L)	Medium (M)	High (H)	Very High (VH)
TFNs	(0,0,0.3)	(0.1,0.3,0.5)	(0.3,0.5,0.7)	(0.5,0.7,0.9)	(0.7,1.0,1.0)

Steps 4: Obtain the Z^E-numbers by experts voting for preferences of pairwise comparisons vectors.

Each expert votes for each decision makers' vectors of pairwise comparison preferences in this step. After voting, three statutes may occur for R. In all three statutes, the new b_i^* is calculated according to Eq. (8).

According to the Z^E-numbers concepts, the final preferences of the best-to-others and other-to-worst criteria based on Z^E-numbers will be as follows.

$$(l_{Z^E(Bj)}, m_{Z^E(Bj)}, u_{Z^E(Bj)}) = \begin{cases} ZE = \left((l_{B1}, m_{B1}, u_{B1}), (l_R, m_R, u_R), E_1\right) \\ ZE = \left((l_{B2}, m_{B2}, u_{B2}), (l_R, m_R, u_R), E_2\right) \\ ZE = \left((l_{B3}, m_{B3}, u_{B3}), (l_R, m_R, u_R), E_3\right) \\ \cdots \\ ZE = \left((l_{Bn}, m_{Bn}, u_{Bn}), (l_R, m_R, u_R), E_n\right) \end{cases} \tag{13}$$

$$\left(l_{Z^E(jw)}, m_{Z^E(jw)}, u_{Z^E(jw)}\right) = \begin{cases} ZE = \left((l_{1w}, m_{1w}, u_{1w}), (l_R, m_R, u_R), E_1\right) \\ ZE = \left((l_{2w}, m_{2w}, u_{2w}), (l_R, m_R, u_R), E_2\right) \\ ZE = \left((l_{3w}, m_{3w}, u_{3w}), (l_R, m_R, u_R), E_3\right) \\ \cdots \\ ZE = \left((l_{Bn}, m_{Bn}, u_{Bn}), (l_R, m_R, u_R), E_n\right) \end{cases} \tag{14}$$

Steps 5: Obtain the optimal weights of the criteria.

The optimal criteria weight value is the one where for each pairwise comparison (for all j) of the $(l_B^w, m_B^w, u_B^w)/(l_j^w, m_j^w, u_j^w)$ and $(l_j^w, m_j^w, u_j^w)/(l_w^w, m_w^w, u_w^w)$, there are the $(l_B^w, m_B^w, u_B^w)/(l_j^w, m_j^w, u_j^w) = \left(l_{Z^E(Bj)}, m_{Z^E(Bj)}, u_{Z^E(Bj)}\right)$ and $(l_j^w, m_j^w, u_j^w)/(l_w^w, m_w^w, u_w^w) = \left(l_{Z^E(jw)}, m_{Z^E(jw)}, u_{Z^E(jw)}\right)$. Since the criteria weights are considered aggregated and non-negative, the mathematical model should be written as Eq. (15) to obtain a solution for minimizing the maximum absolute differences $\left|\left((l_B^w, m_B^w, u_B^w)/(l_j^w, m_j^w, u_j^w)\right) - \left(l_{Z^E(Bj)}, m_{Z^E(Bj)}, u_{Z^E(Bj)}\right)\right|$ and $\left|(l_j^w, m_j^w, u_j^w)/(l_w^w, m_w^w, u_w^w) - \left(l_{Z^E(jw)}, m_{Z^E(jw)}, u_{Z^E(jw)}\right)\right|$. As mentioned in Eq. (15), the sum of the crisp values of criteria weights must be equal to 1.

Min $\sum_{k=1}^{p} \lambda_k \xi_k$

$$\begin{cases} \left|\dfrac{(l_B^w, m_B^w, u_B^w)}{(l_j^w, m_j^w, u_j^w)} - \left(l_{Z^E(Bj)}, m_{Z^E(Bj)}, u_{Z^E(Bj)}\right)\right| \le (\xi_k, \xi_k, \xi_k) \\ \left|\dfrac{(l_j^w, m_j^w, u_j^w)}{(l_w^w, m_w^w, u_w^w)} - \left(l_{Z^E(jw)}, m_{Z^E(jw)}, u_{Z^E(jw)}\right)\right| \le (\xi_k, \xi_k, \xi_k) \\ \sum_{j=1}^{n} \dfrac{\left(l_j^w + 4 * m_j^w + u_j^w\right)}{6} = 1 \\ l_j^w \le m_j^w \le u_j^w \\ l_j^w \ge 0 \; for \; all \; j \end{cases} \tag{15}$$

By solving the mathematical model of Eq. (15) for the pairwise comparisons value of all j, the optimal criteria weights are obtained.

Consistency ratio in pairwise comparisons is very important in decision-making. Rezaei [50] proposed the consistency index to evaluate the preference information under crisp values. Obviously, the proposed consistency index for crisp values is unsuitable for fuzzy values. Therefore, Aboutorab et al. [49] proposed new consistency indexes for the BWM under Z-numbers. The consistency ratio is determined by replacing the values of the consistency index and ξ in Eq. (16).

$$Consistency\ Ratio = \frac{\xi}{Consistency\ Index} \tag{16}$$

The fuzzy pairwise comparisons will be fully consistent if the value of ξ is equal to zero.

2.3. Z^E-CoCoSo

CoCoSo is one of the new MCDM ranking methods introduced by Yazdani et al. [59]. CoCoSo is the result of combining ideas of multiplicative exponential weighting (MEW), simple additive weighting (SAW), and weighted aggregated sum product assessment (WASPAS) methods.

In recent years, CoCoSo has been developed using various fuzzy sets in uncertain environments, such as fuzzy CoCoSo [60], interval-valued fuzzy soft CoCoSo [61], intuitionistic fuzzy soft CoCoSo [62], hesitant fuzzy CoCoSo [63], Neutrosophic fuzzy CoCoSo [64], Pythagorean fuzzy CoCoSo [24], [65], and Spherical fuzzy CoCoSo [30]. Considering its high applicability in real-life problems, CoCoSo has been used for decision-making problems in various fields such as waste management [65], [66], and transportation management [67].

Z^E-CoCoSo can be applied based on the following steps.

***Step 1**:* Define the initial decision matrix based on the set of the sub-criteria and alternatives.

Eq. (17) shows the form of the initial decision matrix and its elements based on the *n* criteria and *m* alternatives. Each of the initial decision matrix elements indicates the value of the alternative than the corresponding criterion.

$$DE = \begin{bmatrix} x_{11} & x_{12} & x_{13} & \cdots & x_{1n} \\ x_{21} & x_{22} & x_{23} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ x_{m1} & x_{m2} & x_{m3} & \cdots & x_{mn} \end{bmatrix} \tag{17}$$

***Step 2**:* Form the fuzzy decision matrix based on the membership functions.

In this step, the DMs are asked to assign values for each element of the initial decision matrix based on the terms of the linguistic variable provided in Table 1.

$$DE_{MF} = \begin{bmatrix} (l_{11}, m_{11}, u_{11}) & (l_{12}, m_{12}, u_{12}) & (l_{13}, m_{13}, u_{13}) & \cdots & (l_{1n}, m_{1n}, u_{1n}) \\ (l_{21}, m_{21}, u_{21}) & (l_{22}, m_{22}, u_{22}) & (l_{23}, m_{23}, u_{23}) & \cdots & (l_{2n}, m_{2n}, u_{2n}) \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ (l_{m1}, m_{m1}, u_{m1}) & (l_{m2}, m_{m2}, u_{m2}) & (l_{m3}, m_{m3}, u_{m3}) & \cdots & (l_{mn}, m_{mn}, u_{mn}) \end{bmatrix} \tag{18}$$

***Step 3**:* Form the fuzzy decision matrix based on the reliability functions.

In this step, the DMs are asked to assign reliability values for each element of the initial decision matrix based on the terms of the linguistic variable provided in Table 2.

$$DE_{RF} = \begin{bmatrix} (l_{11}, m_{11}, u_{11}) & (l_{12}, m_{12}, u_{12}) & (l_{13}, m_{13}, u_{13}) & \cdots & (l_{1n}, m_{1n}, u_{1n}) \\ (l_{21}, m_{21}, u_{21}) & (l_{22}, m_{22}, u_{22}) & (l_{23}, m_{23}, u_{23}) & \cdots & (l_{2n}, m_{2n}, u_{2n}) \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ (l_{m1}, m_{m1}, u_{m1}) & (l_{m2}, m_{m2}, u_{m2}) & (l_{m3}, m_{m3}, u_{m3}) & \cdots & (l_{mn}, m_{mn}, u_{mn}) \end{bmatrix} \tag{19}$$

***Step 4**:* Obtain the Z^E-numbers by experts voting for elements of each alternative row in the decision matrix.

In this step, expert voting is collected for each alternative. Then, the Z^E-number is determined based on Eq. (8-9). According to votes, the decision matrix based on Z^E-numbers is as follows (Eq. 20).

$$DE_{Z^E} = \begin{bmatrix} (l_{Z^E(11)}, m_{Z^E(11)}, u_{Z^E(11)}) & (l_{Z^E(12)}, m_{Z^E(12)}, u_{Z^E(12)}) \cdots & (l_{Z^E(1n)}, m_{Z^E(1n)}, u_{Z^E(1n)}) \\ (l_{Z^E(21)}, m_{Z^E(21)}, u_{Z^E(21)}) & (l_{Z^E(22)}, m_{Z^E(22)}, u_{Z^E(22)}) \cdots & (l_{Z^E(2n)}, m_{Z^E(2n)}, u_{Z^E(2n)}) \\ \vdots & \vdots & \vdots \\ (l_{Z^E(m1)}, m_{Z^E(m1)}, u_{Z^E(m1)}) & (l_{Z^E(m2)}, m_{Z^E(m2)}, u_{Z^E(m2)}) \cdots & (l_{Z^E(mn)}, m_{Z^E(mn)}, u_{Z^E(mn)}) \end{bmatrix} \quad (20)$$

***Step 5**:* Normalize the elements of the Z^E-numbers matrix.

The Z^E-number elements $(l_{Z^E(ij)}, m_{Z^E(ij)}, u_{Z^E(ij)})$ of the normalized Z^E-numbers matrix (N) are determined as follows (Eq. 21):

$$Normalize\,(l_{Z^E(ij)}, m_{Z^E(ij)}, u_{Z^E(ij)}) = \begin{cases} Nl_{Z^E(ij)} = \dfrac{l_{Z^E(ij)}}{\max(u_{Z^E(j)})};\; Nm_{Z^E(ij)} = \dfrac{m_{Z^E(ij)}}{\max(u_{Z^E(j)})};\; Nu_{Z^E(ij)} = \dfrac{u_{Z^E(ij)}}{\max(u_{Z^E(j)})} \\ Nl_{Z^E(ij)} = \dfrac{\min(l_{Z^E(j)})}{u_{Z^E(ij)}};\; Nm_{Z^E(ij)} = \dfrac{\min(l_{Z^E(j)})}{m_{Z^E(ij)}};\; Nu_{Z^E(ij)} = \dfrac{\min(l_{Z^E(j)})}{l_{Z^E(ij)}}; \end{cases} \quad (21)$$

***Step 6**:* Calculate the weighted normalized Z^E-numbers matrix.

In this step, the normalized elements of the Z^E-numbers matrix are multiplied to the weight coefficients obtained by Z^E-BWM. Later, WSM (Eq. 22) and WPM (Eq. 23) are used to calculate completely compensatory performance values of the i*th* alternative ($S_{i(Z^E)}$) and incompletely compensatory performance values of the i*th* alternative ($P_{i(Z^E)}$).

$$S_{i(Z^E)} = \sum_{j=1}^{n}\left((l_{Z^E(j)}, m_{Z^E(j)}, u_{Z^E(j)}) \times N(l_{Z^E(ij)}, m_{Z^E(ij)}, u_{Z^E(ij)})\right) \quad (22)$$

$$P_{i(Z^E)} = \sum_{j=1}^{n}\left(N(l_{Z^E(ij)}, m_{Z^E(ij)}, u_{Z^E(ij)})^{(l_{Z^E(j)}, m_{Z^E(j)}, u_{Z^E(j)})}\right) \quad (23)$$

The $S_{i(Z^E)}$ value as a sum of the weighted comparability sequence for each alternative is obtained based on the grey relational generation approach. Also, the $P_{i(Z^E)}$ value as the amount of the power weight of comparability sequences for each alternative is obtained based on the WASPAS multiplicative attitude.

***Step** 7:* Calculate the relative weights of the alternatives using the three aggregated appraisal scores (Eqs. 24-26).

$$M_{ia(Z^E)} = \frac{P_{i(Z^E)} + S_{i(Z^E)}}{\sum_{i=1}^{m}\left(P_{i(Z^E)} + S_{i(Z^E)}\right)} \quad (24)$$

$$M_{ib_{(Z^E)}} = \frac{S_{i_{(Z^E)}}}{Min\ S_{i_{(Z^E)}}} + \frac{P_{i_{(Z^E)}}}{Min\ P_{i_{(Z^E)}}} \tag{25}$$

$$M_{ic_{(Z^E)}} = \frac{\lambda\left(S_{i_{(Z^E)}}\right) + (1-\lambda)\left(P_{i_{(Z^E)}}\right)}{\lambda S_{i_{(Z^E)}} + (1-\lambda)\ max\ P_{i_{(Z^E)}}}; 0 \leq \lambda \leq 1 \tag{26}$$

where $M_{ia_{(Z^E)}}$ refers to the arithmetic mean of sums, while $M_{ib_{(Z^E)}}$ refers to the sum of relative scores compared to the best. Also, $M_{ic_{(Z^E)}}$ denotes the balanced compromise scores. In the $M_{ic_{(Z^E)}}$, λ usually equal to 0.5. For the CoCoSo flexibility, different values can be assigned to λ in [0,1] range.

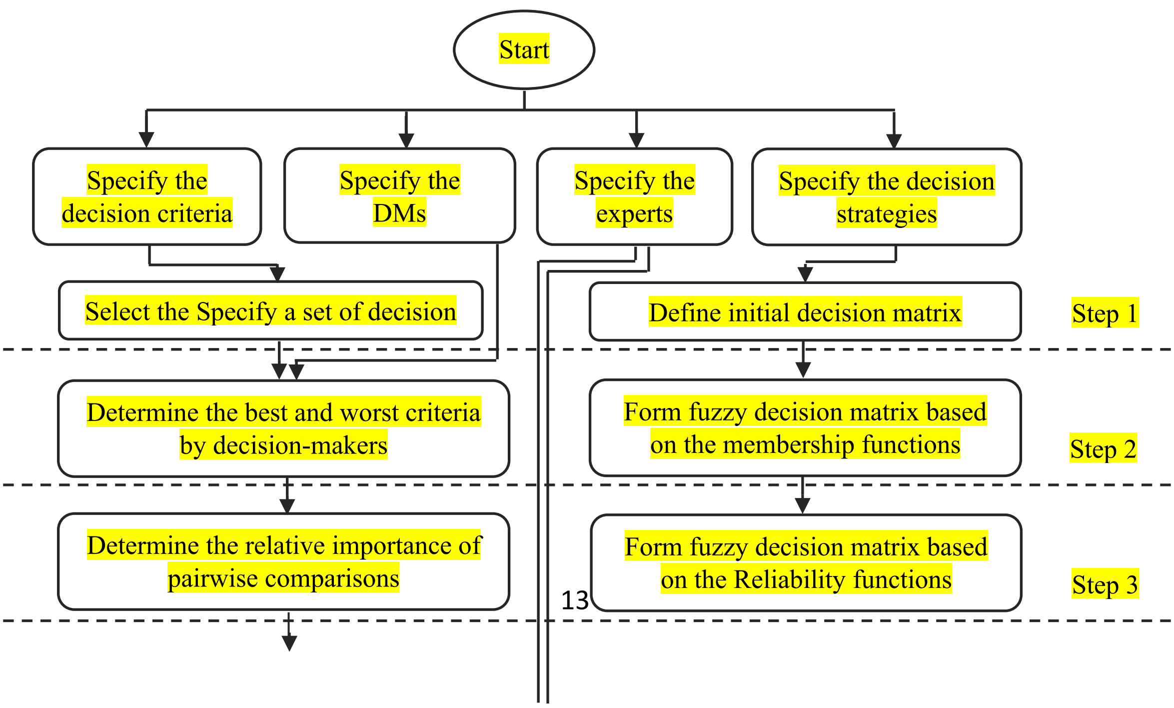
Step 8*:* Determine the final ranking order of alternatives using Eq. (27).

The final alternatives ranking is determined based on the $M_{i_{(Z^E)}}$ values. The $M_{i_{(Z^E)}}$ values are calculated based on the obtained results of the arithmetic mean of sums ($M_{ia_{(Z^E)}}$), the sum of relative scores compared to the best ($M_{ib_{(Z^E)}}$), and the balanced compromise scores ($M_{ic_{(Z^E)}}$) according to Eq. (27).

$$M_{i_{(Z^E)}} = \left(M_{ia_{(Z^E)}} \times M_{ib_{(Z^E)}} \times M_{ic_{(Z^E)}}\right)^{\frac{1}{3}} + \frac{1}{3}\left(M_{ia_{(Z^E)}} + M_{ib_{(Z^E)}} + M_{ic_{(Z^E)}}\right) \tag{27}$$

After calculating the final value of alternatives according to Eq. (27), each alternative that obtains a higher value for $M_{i_{(Z^E)}}$ is considered the more important and better alternative.

According to the described steps, the step-by-step algorithm of the proposed framework based on the Z^E-BWM and Z^E-CoCoSo is shown in Figure 2. As mentioned in sub-section 2.2, there are five steps for obtaining the weight coefficients based on the Z^E-BWM and eight steps to calculate the ranks of the alternative based on the Z^E-CoCoSo. In Figure 2, the steps on the left are related to Z^E-BWM, and the steps on the right are related to the Z^E-CoCoSo method.



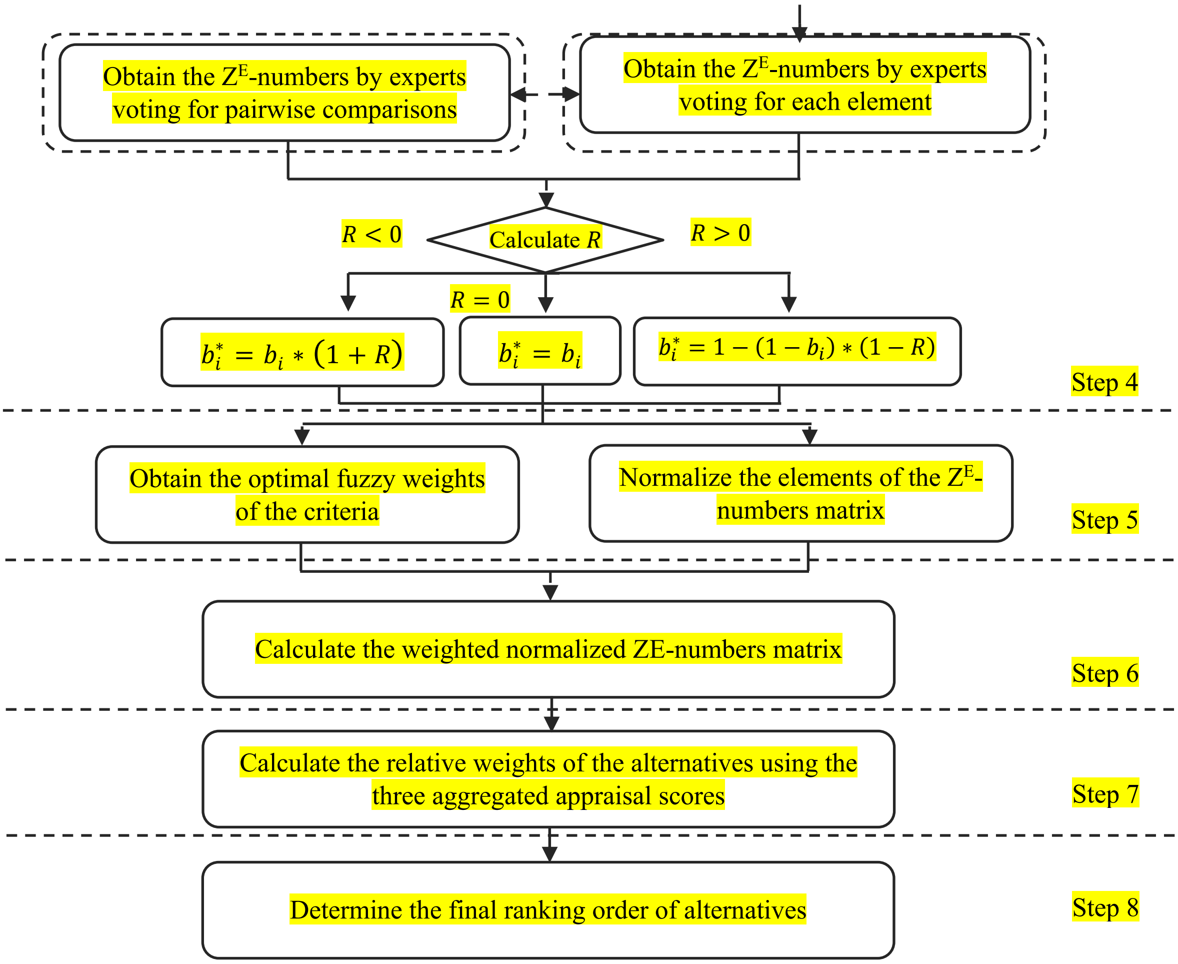


Figure 2. Flow diagram of the proposed approach.

3. Case Study

As part of this study, we apply the novel proposed decision-making approach to a real-life case study in the city of Tabriz, Iran, in order to demonstrate its feasibility, applicability, and efficiency in dealing with a significant environmental problem. As illustrated in Figure 2, a graphical summary of the proposed decision-making approach for RPS has been provided Figure 2. The purpose of this section is to provide information about the profile and background of decision-makers and experts, as well as to define the problem and context. We present the required criteria for the development of a sustainable, resilient RPS, a case study, and potential recycling partners (alternatives). The results are presented in two separate subsections for the determination of the weight and evaluation of the recycling partners.

3.1. Context Definition

As a result of the introduction of global standards and targets, such as the Sustainable Development Goals (SDG) and Kyoto Protocol, municipal waste management systems are receiving a great deal of attention from governments and private and public organizations. The main objective of these organizations is to promote sustainable and eco-friendly practices in order to minimize environmental concerns. One of the main reasons sustainable waste management is receiving great attention is its direct relationship with SDG 11, SDG 12, and indirectly SDG 13 which are sustainable cities and communities, responsible consumption and production, and climate action. As a result, waste recycling is one of the major pathways to transforming current traditional waste management systems into sustainable ones. In order to address the high and massive disposal of waste that is able to be reused and can provide economic and environmental benefits, recycling has become an increasingly important solution. Thus, although recycling is getting attention and more recycling companies are increasing worldwide, a major problem arises in the supply chain of waste management systems to organize and plan different operations and functions, such as determining the most suitable recycling partner. In light of the earlier discussion on sustainability, RPS is a complex multidimensional decision-making problem that is affected by a variety of decision criteria. An array of economic, environmental, and social decision criteria can be used to meet the Sustainable Development Goals (SDGs) as well as other relevant laws and regulations. Additionally, since municipal waste management systems are highly critical, any unplanned or sudden problem can have devastating consequences. Several recent events, such as the COVID-19 pandemic, have demonstrated the importance of maintaining system resilience in the event of disruptions and restrictions associated with pandemics. As a result, a robust evaluation of recycling partners would simultaneously take sustainability and resilience into account.

Table 3. The list of criteria for RPS.

Category	Criteria	Description	Type	Reference
Economic (C_1)	Operation cost (C_{11})	Per unit costs including transportation, labor, maintenance, dismantling, and recycling costs.	C	[[35], [68], [69]]
	Performance quality (C_{12})	The average rate of recycling products.	B	
	Financial stability (C_{13})	The average rate of profitability against costs.	B	
	Technological capability (C_{14})	Average capability and capacity in required techniques to handle recovery and recycling processes.	B	
	Net profit (C_{15})	Profit per unit of the recycling process.	B	
Environmental (C_2)	Resource use efficiency (C_{21})	Rate material consumption and labor for recycling operations.	B	[[35], [69], [70]]
	Green R & D (C_{22})	Rate of implementation of green practices through the recycling processes and operations.	B	
	Energy efficiency (C_{23})	Energy efficiency rate considering overall usage of electricity, water, and fuel.	B	
	Emission and waste generation (C_{24})	Rate of gas emissions and waste produced through recycling operations.	C	
	Environmental competencies (C_{25})	The capability of using environmentally friendly materials, implementing clean technologies, and reducing pollution effects.	B	
	Environment management systems (C_{26})	Level of implementation operations based on the ISO and other international environmental standards.	B	
Social (C_3)	Occupational health & safety systems (C_{31})	Degree of hygiene and cleanliness in the collection, transportation, and recycling operations.	B	[[26], [71], [72]]
	Information disclosure (C_{32})	Degree of professional data privacy and protection of customers and stakeholders.	B	
	Ethical issues and legal compliance (C_{33})	Degree of company's commitment to ethical and legal norms and rules.	B	
	Brand reputation (C_{34})	Reputation degree of each company.	B	
Resilience (C_4)	Robustness (C_{41})	The capability to withstand disruptions in the waste supply chain.	B	[[12], [73], [74]]
	Flexibility (C_{42})	The ability for quick and easy actions against disruptions in the waste supply chain.	B	
	Agility (C_{43})	The ability to tackle and address unforeseen and unexpected demand or supply.	B	
	Visibility (C_{44})	The ability of a recycling company to provide information on all steps and operations through the waste supply chain.	B	

In order to conduct a comprehensive evaluation of recycling partners, sustainability and resilience decision criteria are identified and defined in Table 3. There are four categories of criteria: economic, environmental, social, and resilience. Table 3 provides a brief description of each criterion and its type (C represents cost criterion, and B represents benefit criterion).

This study considers a practical case study to address sustainable resilient RPS by the proposed approach. In this regard, one of the major waste collection and treatment facilities is selected in Tabriz, Iran (located in East Azerbaijan province), which acts within the municipal waste management system of the city. In Tabriz, Iran, this central facility works directly with a large recycling company. As a result of the information and data privacy agreement with the company, we cannot disclose its name. As a result, we will refer to the case study company as ABC from now on. ABC performs a variety of business activities based on municipal waste types, such as paper, organic, and plastic.

An important focus of the ABC is on plastic waste, which is highly valuable for recycling processes due to its economic and environmental benefits. To handle plastic waste in an environmentally friendly manner, ABC collaborates with other smaller regional partners. Due to Tabriz's large population (approximately 1.6 million), and its high waste generation rate, the city has a high potential for plastic recycling. Following a meeting with ABC management, five major recycling partner alternatives were proposed for evaluation based on their current circumstances. These recycling partner alternatives are labeled as A_1, A_2, A_3, A_4, and A_5. All five recycling partner alternatives are located in East Azerbaijan province, and their major secondary market for recycled products is limited to Iran and Middle East counties.

Based on the defined decision criteria for sustainable resilient RPS, four decision-makers from the sales department of ABC are invited to participate in the decision-making process. Due to the structure of Z^E-numbers, ten experts were invited to participate in the decision-making process. These experts are not working in the ABC; however, they are actively working in the waste management and recycling operations of various waste management facilities and recycling companies in Tabriz, Iran. Experts are invited to vote whether they agree, disagree, or have a neutral opinion on DMs' evaluations. All decision-makers (DMs) and experts were involved in weight determination and evaluating recycling partners. Required input data for the proposed approach were collected through a detailed questionnaire. Questionnaires used for determining weight coefficients and ranking evaluations are provided in a supplementary file. A summary of the profile of DMs and experts is presented in Table 4.

Table 4. Profile of decision-makers and experts.

Title	Gender	Job	Experience (years)	Academic degree
DM_1	Male	Sales Executive.	8	M.Sc.
DM_2	Male	Sales Executive.	3	M.Sc.
DM_3	Female	Sales Executive.	15	B.Sc.
DM_4	Male	Sales Executive.	6	M.Sc.

E_1	Female	Brand loyalty expert in an environmental organization.	2	M.A.
E_2	Female	R&D engineer in a recycling company.	9	M.Sc.
E_3	Male	R&D engineer in a recycling company.	8	M.Sc.
E_4	Male	Head of the financial department in a recycling company.	13	B.Sc.
E_5	Male	Quality control manager in a recycling company.	10	M.Sc.
E_6	Female	Auditor in a company providing services for ISO and international standards.	10	B.Sc.
E_7	Male	Assistant Sales Executive in a recycling company.	5	M.A.
E_8	Male	Logistics manager in a recycling company.	14	B.Sc.
E_9	Male	Head manager of an environmental organization.	20	B.Sc.
E_{10}	Male	Logistics manager in a recycling company.	16	B.Sc.

DM shows decision-makers, E represents experts.

4. Implementation of the proposed methods and Results

This section presents the detailed implementation of the methodology and results of weight coefficients and the ranking of alternatives using the proposed framework. Results are presented in two separate subsections for weight coefficients according to the Z^E-BWM, and Z^E-CoCoSo. Two more subsections are also considered for sensitivity analysis and comparative analysis.

4.1. Weight Coefficients

The purpose of this part is to present results on weight coefficients using the five steps of the BWM under Z^E-numbers. To provide a straightforward view of how weight coefficients are calculated, important steps of the Z^E-BWM are elaborated in several tables. Due to the high number of decision criteria, Z^E-BWM is used to determine the local weight coefficients of the main criteria and later to obtain the local weight coefficients of sub-criteria. Finally, local weight coefficients are used to determine each criterion's optimal global weight coefficients.

According to the procedure of the Z^E-BWM, in step 1, the set of criteria and the sub-criteria are specified. In step 2, the DMs are asked to select the best and worst criteria and the best and worst sub-criteria of each criterion based on their opinions. As can be seen in Table 5, the DMs selected C_1 and C_4 as the best criteria and C_3 as the worst criterion. In step 3, DMs are asked to provide input pairwise comparison data for the vector of the best criterion to the other criteria and the vector of the other criteria to the worst criterion. Using the linguistic terms provided in Table 1 and Table 2, the best-to-other and other-to-worst pairwise comparison vectors are constructed by DMs. Table 5 shows the results of the input pairwise comparison data vectors based on the DMs' opinions. In Table 5, row “A” shows DMs' opinion on the pairwise comparison, while row “B” shows the reliability of their scores.

According to step 4, the aggregated experts' judgments and calculated R values are also shown in Table 5, where experts expressed their judgment on both vectors. As defined earlier, *R* denotes the consistency of DMs' opinions with experts' judgments. Of course, the value of 1 shows the full consistency, and as R gets values closer to -1, it indicates lower consistency between DMs and experts' judgments. In the same way, after converting linguistic terms into numerical values, the detailed numerical input is represented in Table A1 in Appendix A.

Table 5. Z^E-BWM inputs for main criteria.

DM	Best & Worst criteria		Z	Sub criteria				Experts' votes			R
				C_1	C_2	C_3	C_4	Yes	No	θ	
DM_1	Best	C_1	A	EI	FI	VI	WI	8	-	2	1
			B	VH	H	M	H				
	Worst	C_3	A	VI	FI	EI	I	9	-	1	1
			B	VH	M	VH	H				
DM_2	Best	C_1	A	EI	I	AI	FI	4	4	2	0
			B	VH	M	H	H				
	Worst	C_3	A	AI	I	EI	VI	7	1	2	0.750
			B	VH	L	H	M				
DM_3	Best	C_1	A	EI	WI	I	FI	7	1	2	0.750
			B	VH	L	M	L				
	Worst	C_3	A	I	FI	EI	FI	6	2	2	0.500
			B	H	L	L	L				
DM_4	Best	C_4	A	FI	I	AI	EI	3	5	2	-0.250
			B	M	H	VH	VH				
	Worst	C_3	A	VI	I	EI	AI	4	3	3	0.143
			B	VH	M	VH	H				

Next, sub-criteria in each category undergo a similar procedure. In such a way that the selecting of the best and worst sub-criteria, performed pairwise comparisons vectors, aggregated experts' judgments, and calculated R values for economic, environmental, social, and resilience sub-criteria are constructed by DMs according to Tables A2, A4, A6, and A8 in Appendix A, respectively (Steps 1-3 of the Z^E-BWM).

Also, based on step 4, in the same way, after converting linguistic terms into numerical values, detailed numerical inputs for economic, environmental, social, and resilience sub-criteria are represented in Tables A3, A5, A7, and A9 in Appendix A, respectively.

In step 5, the mathematical model Eq. (25) uses the collected input data to determine the local weight coefficients for the main criteria and the other four categories. Table 6 provides complete results of the Z^E-BWM for all main criteria and sub-criteria, the first column of Table 10 shows the main criteria and sub-criteria, and local fuzzy weight coefficients are reported in the second column. Crisp values of local weight coefficients are calculated using Eq. (9). A fuzzy global weights coefficient are calculated by multiplying a sub-criterion's fuzzy local weight coefficient by its main criteria. Fuzzy global weight coefficients are reported in the third column of Table 6. Crisp global values of sub-criteria are determined using Eq. (9) in the last column of Table 6.

Table 6. Final Z^E-BWM results.

Criteria	Fuzzy local weight	Crisp local weight	Fuzzy global weight	Crisp global weight
C_1	(0.36,0.40,0.42)	0.400		
C_{11}	(0.20,0.23,0.27)	0.230	(0.074,0.092,0.111)	0.092
C_{12}	(0.20,0.23,0.26)	0.226	(0.072,0.091,0.108)	0.091
C_{13}	(0.08,0.08,0.09)	0.084	(0.030,0.034,0.037)	0.034
C_{14}	(0.10,0.10,0.10)	0.096	(0.035,0.039,0.040)	0.038
C_{15}	(0.30,0.37,0.41)	0.364	(0.109,0.149,0.173)	0.146
C_2	(0.18,0.20,0.22)	0.202		
C_{21}	(0.16,0.20,0.21)	0.197	(0.029,0.041,0.048)	0.04
C_{22}	(0.13,0.14,0.16)	0.142	(0.023,0.029,0.035)	0.029
C_{23}	(0.11,0.11,0.23)	0.133	(0.021,0.023,0.051)	0.027
C_{24}	(0.25,0.29,0.29)	0.280	(0.044,0.058,0.064)	0.056
C_{25}	(0.13,0.17,0.19)	0.167	(0.024,0.034,0.043)	0.034
C_{26}	(0.07,0.08,0.08)	0.081	(0.013,0.017,0.019)	0.017
C_3	(0.11,0.11,0.13)	0.090		
C_{31}	(0.08,0.09,0.09)	0.248	(0.021,0.023,0.023)	0.023
C_{32}	(0.11,0.12,0.13)	0.119	(0.009,0.011,0.012)	0.011
C_{33}	(0.48,0.48,0.48)	0.482	(0.040,0.044,0.045)	0.044
C_{34}	(0.14,0.15,0.16)	0.152	(0.012,0.014,0.015)	0.014
C_4	(0.26,0.31,0.33)	0.307		
C_{41}	(0.45,0.45,0.50)	0.455	(0.118,0.140,0.164)	0.14
C_{42}	(0.20,0.22,0.27)	0.228	(0.053,0.070,0.090)	0.07
C_{43}	(0.20,0.20,0.21)	0.203	(0.053,0.063,0.068)	0.062
C_{44}	(0.11,0.11,0.13)	0.114	(0.029,0.035,0.042)	0.035

According to Table 6, economic main criteria obtained the highest weight coefficient with a value of 0.400. Resilience, environmental, and main social criteria with the value of 0.307, 0.202, and 0.096 are second, third, and fourth important main criteria, respectively. Considering all sub-criteria, net profit (C_{15}) and information disclosure (C_{32}) are the most important and least important criteria, respectively. Sub-criteria are ranked as $C_{15} > C_{41} > C_{11} > C_{12} > C_{42} > C_{43} > C_{24} > C_{33} > C_{21} > C_{14} > C_{44} > C_{25} > C_{13} > C_{22} > C_{23} > C_{31} > C_{26} > C_{34} > C_{32}$.

4.2. Ranking Recycling Partners

In this part, results of the ranking of recycling partner alternatives are presented based on the input data of the decision-makers and experts. According to the mentioned steps of the Z^E-CoCoSo for ranking recycling partner alternatives, as the first step, the initial decision matrix is defined based on the 19 sub-criteria and five recycling partner alternatives.

Table 7. The decision-makers' opinions.

DMs	DM₁										DM₂									
Criteria/ Alternatives	**A1**		**A2**		**A3**		**A4**		**A5**		**A1**		**A2**		**A3**		**A4**		**A5**	
	A	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
C_{11}	VI	VH	I	H	WI	H	AI	VH	FI	H	VI	H	FI	M	FI	L	VI	H	FI	M
C_{12}	FI	M	WI	L	AI	VH	I	L	VI	H	EI	VH	FI	H	AI	VH	VI	M	I	M
C_{13}	I	L	I	M	VI	VH	EI	H	WI	M	I	M	FI	M	AI	VH	EI	VH	FI	H
C_{14}	AI	VH	I	H	VI	VH	WI	VL	I	VL	AI	VH	FI	H	VI	H	EI	VH	VI	H
C_{15}	FI	H	FI	VL	VI	M	I	L	WI	L	FI	L	FI	M	VI	M	I	VL	WI	L
C_{21}	EI	M	FI	M	AI	L	FI	H	FI	VL	EI	VH	I	VL	AI	VH	I	H	FI	L
C_{22}	VI	M	I	M	VI	H	AI	VH	WI	H	I	VL	VI	L	VI	H	I	M	EI	VH
C_{23}	AI	VH	I	VL	AI	VH	FI	M	WI	M	VI	H	I	M	VI	M	EI	VH	FI	M
C_{24}	I	VL	VI	VH	FI	M	AI	M	FI	VH	I	M	AI	VH	I	M	VI	L	EI	VH
C_{25}	WI	M	FI	H	VI	VH	AI	VH	FI	VL	FI	H	FI	VL	AI	VH	I	VL	FI	H
C_{26}	AI	H	I	M	FI	H	WI	VL	EI	H	AI	VH	I	L	FI	L	WI	M	EI	VH
C_{31}	I	VH	EI	VH	VI	H	I	H	I	VH	FI	VL	FI	M	AI	VH	I	M	VI	VH
C_{32}	FI	H	FI	L	VI	M	WI	VH	FI	L	EI	VH	I	VL	AI	VH	FI	H	I	M
C_{33}	FI	M	EI	H	I	L	EI	VH	WI	H	FI	M	I	H	AI	H	VI	VH	FI	VL
C_{34}	I	H	VI	M	AI	VH	I	L	I	L	I	L	I	H	VI	H	FI	L	I	VL
C_{41}	FI	VL	I	VH	AI	VH	VI	H	I	L	FI	VL	I	H	VI	H	I	L	FI	L
C_{42}	VI	H	I	VH	VI	H	FI	L	WI	VH	VI	VH	VI	VH	VI	M	FI	M	I	VL
C_{43}	FI	L	WI	L	AI	VH	I	L	FI	H	FI	H	I	M	AI	VH	FI	M	EI	VH
C_{44}	EI	VH	FI	VL	VI	VL	FI	VL	FI	L	EI	VH	FI	M	VI	L	FI	H	FI	H

DMs	DM3										DM4									
Criteria/ Alternatives	A1		A2		A3		A4		A5		A1		A2		A3		A4		A5	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
C_{11}	I	L	I	H	FI	L	VI	VL	I	VL	I	L	AI	VH	FI	VH	AI	VH	VI	VH
C_{12}	FI	M	FI	M	AI	VH	VI	H	I	H	FI	L	FI	M	VI	M	I	M	I	M
C_{13}	I	H	FI	VL	I	H	WI	M	FI	L	I	H	VI	VL	VI	VH	EI	VH	WI	VL
C_{14}	FI	M	I	VL	AI	VH	VI	VH	FI	VL	AI	VH	I	H	VI	H	AI	VH	I	H
C_{15}	I	L	FI	M	AI	VH	I	H	I	M	FI	M	VI	L	VI	VL	I	H	FI	L
C_{21}	EI	VH	FI	L	AI	VH	EI	VH	I	H	EI	VH	FI	VL	I	M	FI	H	VI	M
C_{22}	I	H	FI	H	I	H	VI	VH	FI	M	VI	L	I	VL	VI	M	VI	VL	FI	H
C_{23}	I	VL	AI	VH	VI	H	EI	VH	FI	L	AI	VH	I	M	AI	VH	WI	H	WI	H
C_{24}	I	VL	VI	H	FI	L	I	L	EI	VH	VI	H	I	H	FI	H	I	H	I	M
C_{25}	WI	H	FI	M	AI	VH	I	M	I	H	FI	L	FI	H	AI	VH	I	M	WI	VH
C_{26}	FI	L	VI	VH	FI	M	I	H	EI	VH	FI	L	I	L	I	L	FI	M	FI	VL
C_{31}	AI	VH	FI	L	AI	VH	EI	VH	FI	VL	I	M	FI	VL	VI	M	AI	VH	I	L
C_{32}	FI	M	EI	VH	I	H	FI	VL	I	L	FI	M	I	H	AI	VH	FI	L	FI	H
C_{33}	I	H	EI	VH	VI	M	EI	VH	FI	M	FI	L	I	H	I	VH	EI	VH	FI	L
C_{34}	FI	H	I	M	AI	VH	VI	H	FI	L	FI	M	I	L	AI	VH	AI	VH	I	M
C_{41}	EI	VH	I	H	AI	VH	I	M	FI	M	EI	VH	VI	VH	FI	H	EI	VH	FI	M
C_{42}	FI	L	EI	VH	I	M	FI	H	FI	M	I	L	I	L	I	VL	FI	M	FI	L
C_{43}	I	VL	FI	L	AI	VH	I	H	EI	VH	FI	L	I	M	VI	M	I	VL	I	VL
C_{44}	EI	VH	I	M	AI	VH	EI	VH	FI	H	WI	H	I	M	AI	VH	FI	H	WI	VH

In step 2, the DMs formed a fuzzy decision matrix based on the linguistic membership functions provided in Table 1. Also, in step 3, the DMs formed a fuzzy decision matrix based on the linguistic reliability functions provided in Table 2. The result of the steps 3 and 4 express the complete initial decision matrix of all four DMs are presented in Table 7, where column "A" shows the membership function score, and column "B" denotes the reliability value.

In step 4, the experts' judgments on DMs' opinions are presented in Table B1 in Appendix B. In Table B1, experts' judgments are stated with "*" value, which denotes expert judgment on the performance evaluation of DM_1 for each alternative. For instance, a "*" under the "Yes" column for alternative A1 denotes that expert 1 agrees with the performance evaluation of DM_1 for alternative A1.

In the continuation of step 4, according to the provided preliminaries of Z^E-numbers in section 2 and Eqs. (2-9), new fuzzy reliabilities are calculated. Table 8 shows an example of calculated new reliability values for DM_1. Table B2 in Appendix B reports new reliability values for all DMs.

Table 8. New fuzzy reliabilities for decision matrix of DM_1.

Alternatives	**A1**	**A2**	**A3**	**A4**	**A5**
Criteria	New B	New B	New B	New B	New B
C_{11}	(0.83,1.00,1.00)	(0.43,0.60,0.77)	(1,1,1)	(0.87,0.96,0.96)	(0.5,0.7,0.9)
C_{12}	(0.60,0.71,0.83)	(0.09,0.26,0.43)	(1,1,1)	(0.60,0.69,0.78)	(0.5,0.7,0.9)
C_{13}	(0.49,0.60,0.71)	(0.26,0.43,0.60)	(1,1,1)	(0.78,0.87,0.96)	(0.3,0.5,0.7)
C_{14}	(0.83,1.00,1.00)	(0.43,0.60,0.77)	(1,1,1)	(0.55,0.55.78)	(0,0,0.3)
C_{15}	(0.71,0.83,0.94)	(0.00,0.00,0.26)	(1,1,1)	(0.60,0.69,0.78)	(0.1,0.3,0.5)
C_{21}	(0.60,0.71,0.83)	(0.26,0.43,0.60)	(1,1,1)	(0.78,0.87,0.96)	(0,0,0.3)
C_{22}	(0.60,0.71,0.83)	(0.26,0.43,0.60)	(1,1,1)	(0.87,0.96,0.96)	(0.5,0.7,0.9)
C_{23}	(0.83,1.00,1.00)	(0.00,0.00,0.26)	(1,1,1)	(0.69,0.78,0.87)	(0.3,0.5,0.7)
C_{24}	(0.43,0.43,0.60)	(0.60,0.86,0.86)	(1,1,1)	(0.69,0.78,0.87)	(0.7,1.0,1.0)
C_{25}	(0.60,0.71,0.83)	(0.43,0.60,0.77)	(1,1,1)	(0.87,0.96,0.96)	(0,0,0.3)
C_{26}	(0.71,0.83,0.94)	(0.26,0.43,0.60)	(1,1,1)	(0.55,0.55.78)	(0.5,0.7,0.9)
C_{31}	(0.83,1.00,1.00)	(0.60,0.86,0.86)	(1,1,1)	(0.78,0.87,0.96)	(0.7,1.0,1.0)
C_{32}	(0.71,0.83,0.94)	(0.09,0.26,0.43)	(1,1,1)	(0.87,0.96,0.96)	(0.1,0.3,0.5)
C_{33}	(0.60,0.71,0.83)	(0.43,0.60,0.77)	(1,1,1)	(0.87,0.96,0.96)	(0.5,0.7,0.9)
C_{34}	(0.71,0.83,0.94)	(0.26,0.43,0.60)	(1,1,1)	(0.60,0.69,0.78)	(0.1,0.3,0.5)
C_{41}	(0.43,0.43,0.60)	(0.60,0.86,0.86)	(1,1,1)	(0.78,0.87,0.96)	(0.1,0.3,0.5)
C_{42}	(0.71,0.83,0.94)	(0.60,0.86,0.86)	(1,1,1)	(0.60,0.69,0.78)	(0.7,1.0,1.0)
C_{43}	(0.49,0.60,0.71)	(0.09,0.26,0.43)	(1,1,1)	(0.60,0.69,0.78)	(0.5,0.7,0.9)
C_{44}	(0.83,1.00,1.00)	(0.00,0.00,0.26)	(1,1,1)	(0.55,0.55.78)	(0.1,0.3,0.5)

Based on the performance scores and reliability values, a consolidated decision matrix is developed. Decision matrices of other DMs are reported in Table B3 in Appendix B. To continue with a single decision matrix, all four decision matrices (by DMs) are aggregated in Table 9.

Table 9. Aggregated fuzzy decision matrix based on Z^E-numbers.

Alternatives/ Criteria	A1	A2	A3	A4	A5
C_{11}	(2.10,2.46,2.82)	(2.17,2.62,3.06)	(1.20,1.64,2.15)	(2.32,2.63,2.92)	(1.79,2.24,2.68)
C_{12}	(0.99,1.23,1.46)	(0.85,1.16,1.52)	(4.12,4.61,5.10)	(2.17,2.55,2.93)	(2.25,2.66,3.07)
C_{13}	(1.98,2.37,2.76)	(1.06,1.32,1.59)	(3.41,3.92,4.43)	(0.70,0.78,0.86)	(0.59,0.83,1.14)
C_{14}	(3.02,3.51,3.99)	(1.61,1.98,2.35)	(3.65,4.14,4.63)	(1.45,1.70,1.98)	(1.44,1.75,2.06)
C_{15}	(1.20,1.56,1.92)	(0.96,1.24,1.51)	(3.47,3.97,4.45)	(1.86,2.23,2.60)	(0.77,1.05,1.42)
C_{21}	(0.91,0.91,0.91)	(0.91,1.19,1.46)	(3.79,4.30,4.79)	(1.26,1.52,1.76)	(1.23,1.53,1.83)
C_{22}	(1.99,2.33,2.67)	(1.02,1.23,1.45)	(3.12,3.61,4.09)	(2.47,2.84,3.21)	(0.98,1.25,1.54)
C_{23}	(2.68,3.06,3.44)	(1.70,1.99,2.30)	(3.90,4.40,4.89)	(0.81,0.96,1.13)	(0.80,1.13,1.55)
C_{24}	(1.71,2.03,2.35)	(2.92,3.35,3.79)	(1.66,2.15,2.64)	(2.16,2.51,2.87)	(1.26,1.42,1.55)
C_{25}	(0.79,1.05,1.44)	(1.21,1.61,2.01)	(4.21,4.71,5.21)	(2.10,2.47,2.84)	(0.92,1.22,1.57)
C_{26}	(1.85,2.26,2.64)	(1.99,2.36,2.73)	(1.61,2.09,2.57)	(0.82,1.13,1.52)	(0.73,0.78,0.84)
C_{31}	(1.96,2.38,2.78)	(0.78,0.98,1.15)	(3.87,4.36,4.85)	(1.91,2.15,2.38)	(1.90,2.32,2.73)
C_{32}	(1.10,1.34,1.59)	(1.34,1.58,1.80)	(3.63,4.15,4.65)	(0.65,0.90,1.18)	(1.46,1.84,2.23)
C_{33}	(1.24,1.61,1.97)	(1.34,1.47,1.59)	(3.61,4.12,4.62)	(1.17,1.21,1.24)	(0.89,1.22,1.59)
C_{34}	(1.48,1.88,2.27)	(1.89,2.23,2.59)	(4.18,4.68,5.17)	(2.14,2.56,2.96)	(1.50,1.85,2.20)
C_{41}	(0.93,1.08,1.20)	(2.40,2.85,3.29)	(3.14,3.68,4.20)	(1.65,1.87,2.08)	(1.22,1.59,1.95)
C_{42}	(1.85,2.23,2.60)	(1.72,1.94,2.16)	(2.78,3.26,3.73)	(1.10,1.47,1.84)	(1.01,1.35,1.73)
C_{43}	(1.02,1.32,1.65)	(1.06,1.40,1.74)	(4.12,4.61,5.10)	(1.47,1.81,2.15)	(0.91,1.02,1.12)
C_{44}	(0.82,0.91,1.01)	(1.07,1.36,1.64)	(3.88,4.37,4.86)	(1.05,1.30,1.54)	(1.01,1.38,1.81)

In step 5, using Eq. (24), aggregated decision matrix is normalized based on the nature of the criteria. The normalized aggregated decision matrix under Z^E-numbers is shown in Table B4 in Appendix B.

In step 6, weighted sum $S_{i_{(Z^E)}}$ and weighted product $P_{i_{(Z^E)}}$ values are determined based on the multiplication of weight coefficients and normalized aggregated decision matrix as in Eqs. (22-23). Results of $S_{i_{(Z^E)}}$ and $P_{i_{(Z^E)}}$ are reported in Table B5 and B6 in Appendix B.

In step 7, using Eqs. (24-26) three appraisal scores of alternatives are calculated. λ is considered as 0.5 for the calculations. At the end and step 8, each alternative's final fuzzy compromise score is determined based on Eq. (27). The results of three appraisal and final compromise scores are reported in Table 10. Finally, alternatives are prioritized based on the crisp value of their compromise score. According to the results, alternative A3 is selected as the most suitable recycling partner, while A5 is selected as the least suitable recycling partner.

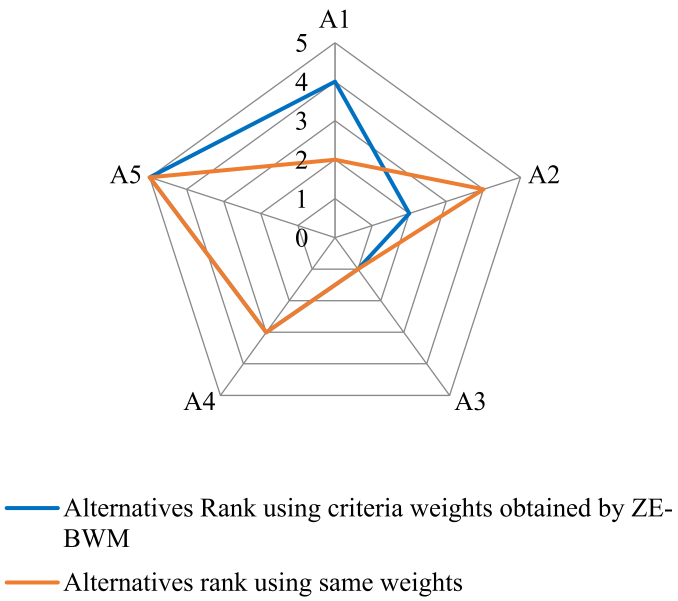
Table 10. Results of the ranking.

Alt.	$M_{ia(Z^E)}$	$M_{ib(Z^E)}$	$M_{ic(Z^E)}$	M_{ia}	Crisp	Rank
A1	(0.187,0.197,0.208)	(1.473,2.064,3.318)	(0.891,0.936,0.983)	(1.476,1.791,2.382)	1.837	4
A2	(0.188,0.198,0.209)	(1.587,2.313,3.782)	(0.893,0.940,0.989)	(1.532,1.905,2.581)	1.955	2
A3	(0.201,0.211,0.221)	(2.147,3.334,5.781)	(0.955,1.000,1.047)	(1.845,2.404,3.452)	2.485	1
A4	(0.188,0.198,0.208)	(1.496,2.053,3.394)	(0.897,0.940,0.986)	(1.492,1.790,2.415)	1.844	3
A5	(0.186,0.196,0.207)	(1.421,2.000,3.199)	(0.883,0.932,0.980)	(1.475,1.758,2.328	1.806	5

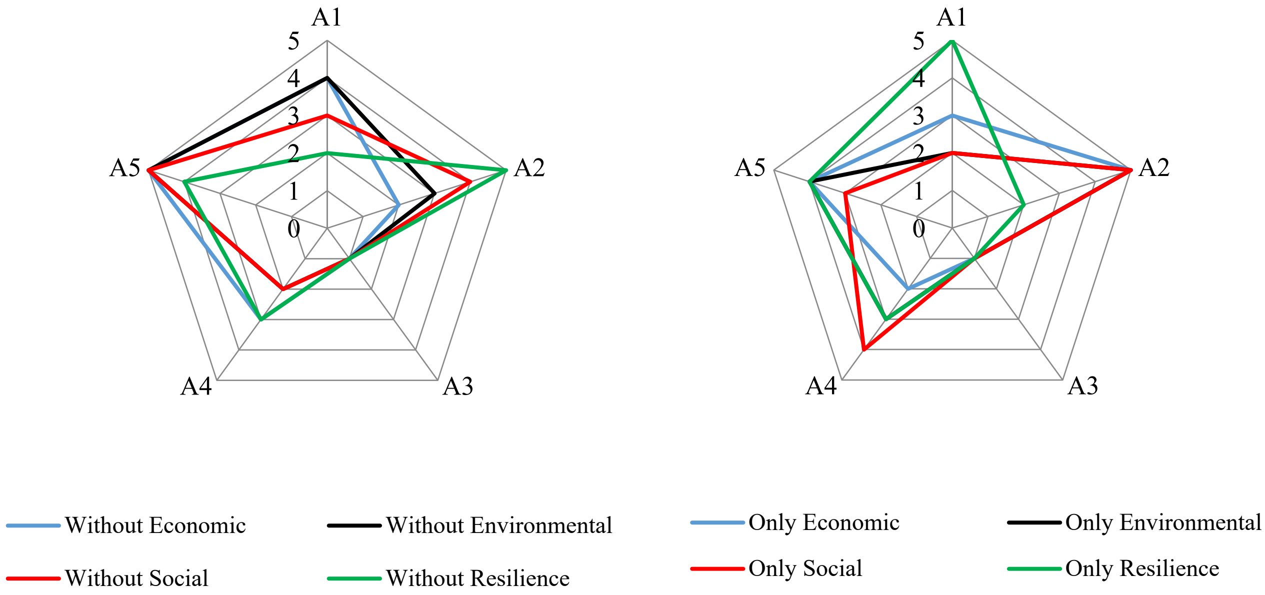
4.3. Sensitivity Analysis: Managerial and Methodological

One of the key contributions of this study is the development of a RPS framework based on sustainability and resilience decision criteria. Considering economic, social, environmental and resilience decision criteria empower decision-makers or managers to have a broad understanding of the performance of recycling partners. Thus, the final performance score of recycling partners is very sensitive and dependent on weight coefficient of the decision criteria.

For this purpose, a managerial sensitivity analysis is conducted to measure the effects of possible changes in the weight coefficient of decision criteria. The sensitivity analysis is focused on three main tests: a) analyzing how the performance of partners changes when all decision criteria are considered the same, b) analyzing how the performance of partners changes if a criteria category is excluded, and c) analyzing how the performance of partners changes if the evaluation framework is only focused on one specific criteria category.



(a) Overall effect of weight coefficients.



(b) Effects of excluding a criteria category.

(c) Effects of focusing only on a criteria category.

Figure 3. Managerial Sensitivity Analysis

Results of the sensitivity analysis tests are shown in Figure 3. First sensitivity analysis test on the overall effect of weight coefficients is depicted in Figure 3.a where results show that if all decision criteria have equal weight coefficients, there would be slight changes to the final ranking of recycling partners. Although A3 stays the best-performing partner, A2 as the 2nd best-performing partner is ranked in the 4th place. On the other hand, A1 ranked as 4th is now ranked as the second best-performing partner.

Results of the second sensitivity analysis are represented in Figure 3.b. For this test, the problem is solved under four different conditions, where one category is excluded in each case. The purpose of this test is to determine whether the absence of a particular criteria category affects the final performance of a partnership. An important finding is that A3 is selected as the best-performing partner in all exclusion cases. Moreover, results stay the same only when the economic category is excluded. In case of excluding other categories, we observe serious changes in the ranking order of partners. Compared to the initial results of the proposed approach, A1's position change from 4th to 3rd and 2nd excluding social category and resilience category, respectively. A2's position goes through a lot of changes from 2nd place to 3rd, 4th and 5th excluding the environmental, social, and resilience categories, respectively. Only changes in ranking order of A4 happened by, excluding the environmental and social categories. Finally, the only change in A5's position happens while excluding the resilience category. All in all, results indicate how each recycling partner is sensitive to changes based on its performance under different criteria categories.

The third test of the sensitivity analysis focuses on addressing the problem by only focusing on one specific category of the criteria to gain a better understanding of the performance of the partners under each category. According to Figure 3.c, A3 obtains 1st ranking in all cases, which shows A3 outperform all other partners in all criteria categories. However, results show that ranking order of other partners change a lot under each criteria category. Overall ranking order changes from A3>A2>A4>A1>A5 to A3>A4>A1>A5>A2 under economic category, to A3>A1>A4>A5>A2 under environmental category, to A3>A1>A5>A4>A2 under social category and to A3>A2>A4>A5>A1 under resilience category. An interesting finding is that A2 only performs well under the resilience category and has the worst performance in the rest of categories, but it is selected as the 2nd best-performing partner in initial results. This indicates how important it is to perform well under resilience criteria. A similar thing also happens for A1, ranked 5th in the resilience category, but 2nd and 3rd in other categories.

One of the major concerns of using CoCoSo is its dependency on λ which affects the final compromise solution. As mentioned earlier, λ is usually considered as 0.5; therefore, a sensitivity analysis is conducted to analyze the possible changes in the ranking of the alternatives based on the 11 different λ values. Figure 4 illustrates all ranking in each λ scenario. Results of the sensitivity analysis indicate that results obtained by Z^E-CoCoSo are robust. However, there exists one slight change in the ranking of alternatives when $\lambda = 0.5$ such that the ranking order of A5 and A1 changes.

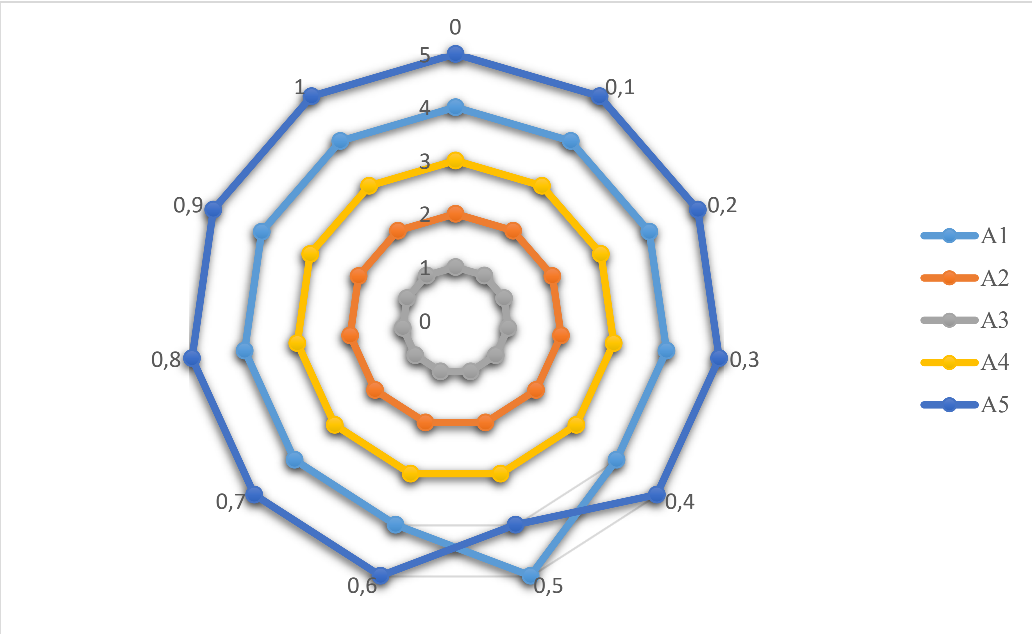


Figure 4. Sensitivity analysis on λ parameter.

4.4. Comparative Analysis

The present study contributes two important contributions by developing novel extensions of BWM and CoCoSo based on the Z^E-numbers. To demonstrate the efficiency and superiority of these extensions over previous extensions under Z-numbers and fuzzy numbers, two comparative analyses are conducted.

To compare the efficiency of novel Z^E-BWM, the results of Z^E-BWM are compared with results of Z-BWM [49] and F-BWM [48], which are considered two major fuzzy extensions of BWM in the literature. Fuzzy results and corresponding crisp weight coefficients are reported in Table 11.

Table 11. Comparative analysis of fuzzy weights determined by Z^E-BWM compared to Z-BWM and F-BWM.

Criteria	Z^E -BWM	Crisp	Z-BWM	Crisp	F-BWM	Crisp
C_{11}	(0.074,0.092,0.111)	0.092	(0.080,0.084,0.092)	0.085	(0.076,0.092,0.122)	0.094
C_{12}	(0.072,0.091,0.108)	0.091	(0.094,0.099,0.109)	0.100	(0.087,0.109,0.140)	0.111
C_{13}	(0.030,0.034,0.037)	0.034	(0.043,0.046,0.051)	0.046	(0.032,0.033,0.037)	0.034
C_{14}	(0.035,0.039,0.040)	0.038	(0.038,0.041,0.044)	0.041	(0.027,0.029,0.032)	0.029
C_{15}	(0.109,0.149,0.173)	0.146	(0.121,0.139,0.174)	0.142	(0.118,0.130,0.173)	0.135
C_{21}	(0.029,0.041,0.048)	0.040	(0.029,0.033,0.042)	0.034	(0.021,0.024,0.038)	0.026
C_{22}	(0.023,0.029,0.035)	0.029	(0.033,0.034,0.036)	0.034	(0.040,0.046,0.072)	0.049
C_{23}	(0.021,0.023,0.051)	0.027	(0.038,0.044,0.050)	0.044	(0.021,0.024,0.038)	0.026
C_{24}	(0.044,0.058,0.064)	0.056	(0.035,0.043,0.053)	0.043	(0.034,0.044,0.064)	0.046
C_{25}	(0.024,0.034,0.043)	0.034	(0.032,0.040,0.048)	0.040	(0.026,0.034,0.056)	0.036
C_{26}	(0.013,0.017,0.019)	0.017	(0.015,0.016,0.017)	0.016	(0.013,0.014,0.017)	0.014
C_{31}	(0.021,0.023,0.023)	0.023	(0.034,0.038,0.040)	0.038	(0.029,0.031,0.041)	0.032
C_{32}	(0.009,0.011,0.012)	0.011	(0.014,0.015,0.020)	0.016	(0.011,0.011,0.111)	0.028
C_{33}	(0.040,0.044,0.045)	0.044	(0.042,0.042,0.044)	0.042	(0.028,0.033,0.041)	0.034
C_{34}	(0.012,0.014,0.015)	0.014	(0.013,0.015,0.016)	0.015	(0.015,0.015,0.018)	0.016
C_{41}	(0.118,0.140,0.164)	0.140	(0.093,0.108,0.135)	0.110	(0.133,0.149,0.187)	0.153
C_{42}	(0.053,0.070,0.090)	0.070	(0.069,0.078,0.092)	0.079	(0.061,0.078,0.108)	0.080
C_{43}	(0.053,0.063,0.068)	0.062	(0.048,0.049,0.057)	0.050	(0.032,0.040,0.065)	0.043
C_{44}	(0.029,0.035,0.042)	0.035	(0.025,0.026,0.031)	0.027	(0.032,0.036,0.047)	0.037

According to Table 11, although Z^E-BWM and Z-BWM determine C_{15} as the most important criterion, F-BWM determines C41 as the most important criterion and puts C_{15} as the second most important one criterion. On the other hand, Z-BWM and F-BWM obtain different solutions on the least important criterion compared to Z^E-BWM. While Z^E-BWM determines C_{32} as the least important criterion, Z-BWM, and F-BWM select C_{34} and C_{26}, respectively. All sub-criteria are ranked based on Z^E-BWM, Z-BWM, and F-BWM as follows. Z^E-BWM: $C_{15} > C_{41} > C_{11} > C_{12} > C_{42} > C_{43} > C_{24} > C_{33} > C_{21} > C_{14} > C_{44} > C_{25} > C_{13} > C_{22} > C_{23} > C_{31} > C_{26} > C_{34} > C_{32}$, Z-BWM: $C_{15} > C_{41} > C_{12} > C_{11} > C_{42} > C_{43} > C_{13} > C_{23} > C_{24} > C_{33} > C_{14} > C_{25} > C_{31} > C_{22} > C_{21} > C_{44} > C_{26} > C_{32} > C_{34}$, and F-BWM: $C_{41} > C_{15} > C_{12} > C_{11} > C_{42} > C_{22} > C_{24} > C_{43} > C_{44} > C_{25} > C_{33} > C_{13} > C_{31} > C_{14} > C_{32} > C_{23} > C_{21} > C_{34} > C_{26}$. Apart from changes in the top and bottom criteria, several slight changes are also observed in the ranking of all three approaches. These observations show how important it is to use more advanced uncertain sets such as Z^E-numbers since traditional uncertain sets may lead to solutions which are not optimal. In other words, such differences in results of Z^E-BWM compared to previous versions show high importance of experts' judgements on decision-makers' opinions and final weight coefficients.

A comparative analysis is conducted to evaluate the performance of the novel Z^E-CoCoSo with Z-CoCoSo [75] and F-CoCoSo [59]. Comparative analysis of these methods is summarized in their final ranking order, illustrated in Figure 5. Observations indicate that all three methods identify alternative A3 as the most suitable recycling partner. On the other hand, Z^E-CoCoSo and Z-CoCoSo determine A5 as the least suitable recycling partner; however, F-CoCoSo chooses A1 as the least suitable alternative. There exist other slight changes in the ranking order of other alternatives. Results of the comparative analysis indicate how significantly CoCoSo based on Z^E-numbers can lead to more accurate and different results than its prior extensions. Therefore, results obtained by Z^E-CoCoSo will be considered for real-life implications with high reliability.

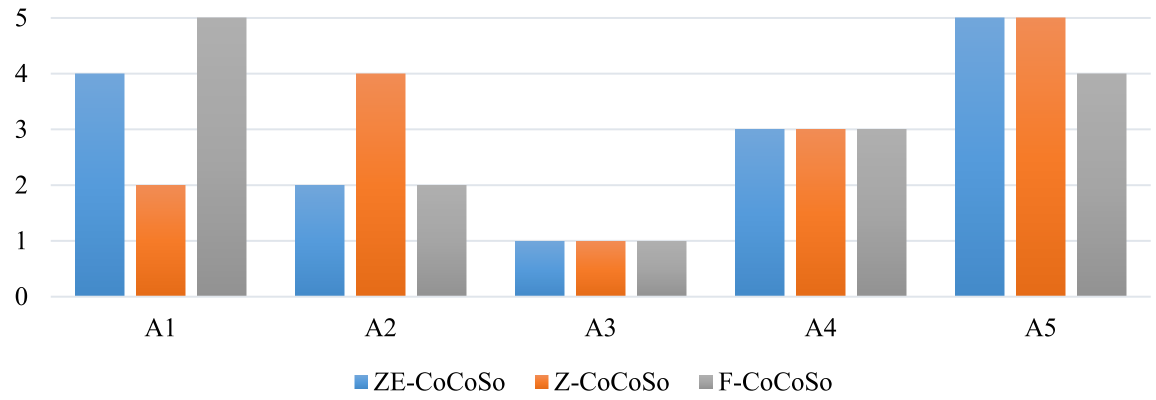


Figure 5. Comparative analysis on the ranking of alternatives of Z^E-CoCoSo with Z-CoCoSo and F-CoCoSo.

To understand why the superiority of Z^E-CoCoSo over Z-CoCoSo and fuzzy CoCoSo, it should be noted that considering the judgments of experts in addition to decision-makers' opinions increases the reliability of the results. Due to the progress of fuzzy CoCoSo to Z^E-CoCoSo, in fuzzy CoCoSo only the uncertainty of decision makers' opinions is considered, while in Z-CoCoSo in addition to uncertainty, the reliability of decision makers' opinions is also evaluated. Reliability assessment is a unique feature provided by Z-numbers. Reliability assessment at two different stages by two groups of decision-makers and experts using the Z^E-CoCoSo framework increases the impact of this unique feature on the results.

It is also important to mention that although the use of the Z^E-numbers framework for the CoCoSo method leads to more accurate and reliable results than Z-CoCoSo and fuzzy CoCoSo, the data collection and data analysis steps are more complicated and longer. This complexity in the analysis process using the Z^E-numbers framework is not so much problematic. Therefore, due to the importance of obtaining accurate and reliable results, the increase in complexity and the slight lengthening of the calculation process are ignored to achieve more reliable and accurate results.

To provide a more comprehensive analysis, the results obtained by Z^E-CoCoSo were compared with alternative ranking results by the VIKOR [76], MABAC [77], and TOPSIS [78] methods under the Z^E-numbers. The provided results for comparing alternative ranks in Table 12 show that the first and last priority ranks are the same based on all methods. In other words, alternative A3 is selected as the first rank and alternative A5 as the last rank using all methods. The difference between the results of the proposed methods is in the second to fourth ranks. The main reason for this difference is the closeness of the scores obtained for alternatives A1, A2, and A4. Considering that the CoCoSo method determines the evaluation score of alternatives based on 3 different strategies, this advantage makes the results obtained using the CoCoSo method more accurate than other previously introduced methods.

Table 12. Comparative analysis on the ranking of alternatives of CoCoSo, VIKOR, MABAC, and TOPSIS.

Alt.	ZE-CoCoSo		ZE-VIKOR		ZE-MABAC		ZE-TOPSIS	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
A1	1.837	4	0.4891	4	-0.0835	3	0.340	2
A2	1.955	2	0.4861	3	-0.1041	4	0.227	3
A3	2.485	1	0.0000	1	0.5054	1	1.014	1
A4	1.844	3	0.3835	2	-0.0664	2	0.174	4
A5	1.806	5	0.5084	5	-0.1133	5	0.059	5

5. Discussion: Managerial & Methodological Insights

In a city such as Tabriz, which has a population of approximately 1.6 million, urban waste management is one of the top priorities of the municipality and environmental organizations. Considering the high importance and significant role of sustainability and circular economy in current urban waste management systems, serious efforts and decisions are being taken to transform traditional urban waste management systems. Transforming to sustainable urban waste management systems and promoting a circular economy to maximize recycling rate and mitigate environmental issues have become important targets for all corresponding urban and municipal organizations to achieve a sustainable city and society. In sustainable waste management systems, recycling is an essential component and requires appropriate tools for its planning and implementation. When appropriate and potential recycling partners are involved in the recycling process of different types of materials, RPS is an important part of the recycling process in sustainable waste management systems. By taking into account sustainability measures and factors, RPS aims to address the problem on a range of economic, environmental, social, and resilience levels. In spite of the fact that such a framework would improve RPS, it still lacks a number of serious aspects that need to be taken into consideration in order to develop a solid and robust framework. Waste management systems, including urban systems, have a limited ability to withstand unexpected changes, risks, and disruptions. The recent COVID-19 pandemic is an example of such a disruption. The COVID-19 pandemic had devastating effects on all sectors and supply chains, including the waste supply chain, resulting in serious operational problems. In this regard, a crucial step rises in treating urban waste due to the pandemic's negative operational, environmental, environmental, and social impacts. Thus, developing an RPS framework to handle such big changes and disruptions is very important in a sustainable waste management system. In this regard, resilience measures can play critical roles in RPS problems along with sustainability factors.

As a result, this study developed a sustainable, resilient framework for RPS based on 19 decision criteria, 15 of which pertain to sustainability, and four of which pertain to resilience. To thoroughly analyze different aspects of the waste supply chain network and evaluate recycling partners, the framework was developed with a variety of decision criteria. This framework increases the reliability of the alignment of recycling partners with those of the central company and the entire municipal waste management system.

While various MCDM methods have been used to address multi-dimensional and complicated decision-making problems, including RPS, no study focused on how important input data from participants can affect the results in uncertain conditions. One of the common ways to handle uncertainty in MCDM problems is to use various uncertainty sets such as different versions of fuzzy logic, by obtaining decision-makers' opinions through linguistic terms. Therefore, all studies focus on decision-makers as the core source of data providers in group decision-making problems. However, decision-makers usually come from a variety of professions, ages, and backgrounds. These characteristics may have serious effects on their expressed opinions on a MCDM problem which would increase the biasedness of their provided data. In the process of regional and urban decision-making for urban planning issues, bias and subjectivity can have very costly consequences. Thus, the purpose of this study is to address this issue by using ZE-numbers to weight and rank parts of a MCDM problem.

The Z^E-numbers empower the decision-making environment to consider experts' judgments over decision-makers' opinions to generate more meaningful and reliable solutions. This is a unique capability in decision science provided by the Z^E-numbers framework for decision methods. Evaluating criteria and alternatives by the Z^E-numbers framework to make an optimal decision using two different stages with two different approaches by two groups of decision-makers and experts increases the reliability of the decision. Also, the framework proposed by Z^E-Numbers makes it possible to reach a reliable decision using the expert's judgment when there are conflicts in the DMs' opinions. In other words, for the first time, the problem of conflicting opinions is solved with the Z^E-Numbers framework proposed for the MCDM methods.

For urban planning problems such as RPS, decision-makers may have very different characteristics; thus, their views also may be different when evaluating criteria and alternatives. The main advantage of the Z^E-numbers framework shows its importance in such decision problems. In this research, using the experts' judgment on the results of evaluations of DMs, conflicting opinions were resolved to reach a reliable decision.

6. Conclusions

With the global promotion of sustainable and green activities, environmental experts are seeking to transform the operating framework of waste supply chain functions and processes. Despite the fact that sustainability concepts provide numerous advantages for waste supply chains, they also increase the complexity of operations and processes. In order to mitigate environmental costs, RPS is one of the most important problems in the waste supply chain. As a result of sustainability measurements, RPS becomes a multidimensional and complex decision-making problem. The COVID-19 pandemic and its devastating impact on global supply chains demonstrated, however, that sustainability alone could not provide a robust solution to supply chain problems. As such, the waste supply chain's ability to resist and recover from sudden changes and disruptions is of great importance. During the COVID-19 pandemic, waste supply chains faced different sudden and unexpected challenges such as high increase in waste generation rate, transportation limitations, limited capacity of waste management facilities, and treatment of hazardous waste. As a result, resilience in the waste supply chain is an important measure to ensure its efficiency and performance during periods of disruption and change. A consideration of resilience and sustainability measures can provide better solutions to such problems under a variety of circumstances.

Using BWM and CoCoSo under Z^E-numbers, the present study develops a novel group decision-making approach to address sustainable, resilient RPS. An important contribution of this study is the development of a sustainable resilient framework for evaluating recycling partners. To increase the reliability of final solutions under uncertain conditions, this study applies Z^E-numbers to incorporate experts' judgments and decision-makers' opinions. Involvement of experts would empower top managers and authorities to consider judgments of middle-level managers, first-level managers, and any professional specialists over decision-makers' opinions which may be potentially biased. In this regard, this study, for the first time, develops novel extensions of BWM and CoCoSo based Z^E-numbers, called Z^E-BWM and Z^E-CoCoSo. In both methods, decision-makers' opinions and experts' judgments are used to determine recycling partners' weight coefficients and ranking order. Using the city of Tabriz, Iran as a case study, the proposed approach is demonstrated to be relevant and effective for complex and multidimensional environmental issues. According to the results of Z^E-BWM, net profit, waste supply chain robustness, and operation cost are the three most important criteria for RPS. Z^E-CoCoSo also indicate that A3 is the best performing and most appropriate recycling partner for the recycling company.

Despite the fact that this study presents several novelties and contributions, future studies can address some of its limitations. One major future direction is the application of the developed approach to other MCDM problems in fields such as supply chain management, facility location selection, transportation, energy planning, agriculture planning, and technology development. Z^E-numbers are only used for BWM and CoCoSo so far. Under Z^E-numbers, other well-known weighting and ranking MCDM methods may also be developed. While BWM is a well-known MCDM method, its weight coefficients are determined by pairwise comparisons of the DMs. In order to determine the weight coefficient with a lower bias and a higher degree of accuracy, an objective method such as Shannon's Entropy may be incorporated into BWM.

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Appendix A

Table A1. Calculations of BWM for main criteria.

DM	Best & Worst criteria		Z	Sub criteria C$_1$	C$_2$	C$_3$	C$_4$	R
DM$_1$	Best	C$_1$	A	(1,1,1)	(3/2,2,5/2)	(7/2,4,9/2)	(2/3,1, 3/2)	1
			B	(1,1,1)	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(0.5,0.7,0.9)	
			New B	(1,1,1)	(1.00,1.00,1.00)	(1.00,1.00,1.00)	(1.00,1.00,1.00)	
			$Z^E_{(Bj)}$	(1,1,1)	(3/2,2,5/2)	(7/2,4,9/2)	(2/3,1, 3/2)	
	Worst	C$_3$	A	(7/2,4,9/2)	(3/2,2,5/2)	(1,1,1)	(5/2,3,7/2)	1
			B	(0.7,1.0,1.0)	(0.3,0.5,0.7)	(1,1,1)	(0.5,0.7,0.9)	
			New B	(1.00,1.00,1.00)	(1.00,1.00,1.00)	(1,1,1)	(1.00,1.00,1.00)	
			$Z^E_{(jW)}$	(7/2,4,9/2)	(3/2,2,5/2)	(1,1,1)	(5/2,3,7/2)	
DM$_2$	Best	C$_1$	A	(1,1,1)	(5/2,3,7/2)	(9/2,5,11/2)	(3/2,2,5/2)	0
			B	(1,1,1)	(0.3,0.5,0.7)	(0.7,1.0,1.0)	(0.5,0.7,0.9)	
			New B	(1,1,1)	(0.3,0.5,0.7)	(0.7,1.0,1.0)	(0.5,0.7,0.9)	
			$Z^E_{(Bj)}$	(1,1,1)	(1.77,2.12,2.47)	(4.39,4.88,5.37)	(1.25,1.67,2.09)	
	Worst	C$_3$	A	(9/2,5,11/2)	(5/2,3,7/2)	(1,1,1)	(7/2,4,9/2)	0.750
			B	(0.7,1.0,1.0)	(0.1,0.3,0.5)	(1,1,1)	(0.3,0.5,0.7)	
			New B	(0.92,1.00,1.00)	(0.77,0.82,0.87)	(1,1,1)	(0.82,0.87,0.92)	
			$Z^E_{(jW)}$	(4.47,4.97,5.46)	(2.26,2.72,3.17)	(1,1,1)	(3.26,3.73,4.20)	
DM$_3$	Best	C$_1$	A	(1,1,1)	(2/3,1, 3/2)	(5/2,3,7/2)	(3/2,2,5/2)	0.750
			B	(1,1,1)	(0.1,0.3,0.5)	(0.5,0.7,0.9)	(0.1,0.3,0.5)	
			New B	(1,1,1)	(0.77,0.82,0.87)	(0.87,0.92,0.97)	(0.77,0.82,0.87)	
			$Z^E_{(Bj)}$	(1,1,1)	(0.60,0.91,1.36)	(2.40,2.88,3.36)	(0.60,0.91,1.36)	
	Worst	C$_3$	A	(5/2,3,7/2)	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)	0.500
			B	(0.5,0.7,0.9)	(0.1,0.3,0.5)	(1,1,1)	(0.1,0.3,0.5)	
			New B	(0.75,0.85,0.95)	(0.55,0.65,0.75)	(1,1,1)	(0.55,0.65,0.75)	
			$Z^E_{(jW)}$	(2.30,2.77,3.23)	(1.21,1.61,2.02)	(1,1,1)	(1.21,1.61,2.02)	
DM$_4$	Best	C$_4$	A	(3/2,2,5/2)	(5/2,3,7/2)	(9/2,5,11/2)	(1,1,1)	-0.250
			B	(0.3,0.5,0.7)	(0.5,0.7,0.9)	(0.7,1.0,1.0)	(1,1,1)	

			New B	(0.22,0.37,0.52)	(0.37,0.52,0.67)	(0.52,0.75,0.75)	(1,1,1)	
			$Z^E_{(Bj)}$	(0.91,1.22,1.52)	(1.80,2.16,2.52)	(3.80,4.22,4.64)	(1,1,1)	
	Worst	C_3	A	(7/2,4,9/2)	(5/2,3,7/2)	(1,1,1)	(9/2,5,11/2)	0.143
			B	(0.7,1.0,1.0)	(0.3,0.5,0.7)	(1,1,1)	(0.7,1.0,1.0)	
			New B	(0.74,1.00,1.00)	(0.40,0.57,0.74)	(1,1,1)	(0.74,1.00,1.00)	
			$Z^E_{(jW)}$	(3.42,3.91,4.40)	(1.89,2.26,2.64)	(1,1,1)	(4.40,4.89,5.40)	

Table A2. Z^E-BWM inputs for economic criteria.

DM	Best & Worst criteria		Z	Sub criteria					Experts' votes			R
				C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	Yes	No	θ	
DM_1	Best	C_{11}	A	EI	WI	VI	FI	WI	4	3	3	0.143
			B	M	H	L	H	H				
	Worst	C_{13}	A	VI	FI	EI	WI	VI	6	1	3	0.714
			B	VH	H	M	VL	VH				
DM_2	Best	C_{15}	A	FI	VI	AI	FI	EI	7	2	1	0.555
			B	VL	H	VH	M	VH				
	Worst	C_{13}	A	VI	VI	EI	FI	AI	7	1	2	0.750
			B	L	L	H	M	L				
DM_3	Best	C_{15}	A	FI	WI	I	VI	EI	4	4	2	0
			B	VH	VH	H	H	H				
	Worst	C_{14}	A	I	VI	FI	EI	VI	2	3	5	-0.200
			B	VH	H	VH	H	VH				
DM_4	Best	C_{12}	A	I	EI	AI	VI	WI	2	4	4	-0.333
			B	H	VH	M	H	VH				
	Worst	C_{13}	A	FI	AI	EI	WI	VI	8	1	1	0.777
			B	H	VH	M	L	H				

Table A3. Calculations of BWM for economic criteria.

DM	Best & Worst criteria		Z	Sub criteria					R
				C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	
DM_1	Best	C_{11}	A	(1,1,1)	(2/3,1, 3/2)	(7/2,4,9/2)	(3/2,2,5/2)	(2/3,1, 3/2)	0.143

			B	(1,1,1)	(0.5,0.7,0.9)	(0.1,0.3,0.5)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	
			New B	(1,1,1)	(0.57,0.74,0.91)	(0.23,0.40,0.57)	(0.57,0.74,0.91)	(0.57,0.74,0.91)	
			$Z_{(Bj)}^{E}$	(1,1,1)	(0.57,0.86,1.29)	(2.21,2.53,2.85)	(1.29,1.72,2.15)	(0.57,0.86,1.29)	
	Worst	C_{13}	A	(7/2,4,9/2)	(3/2,2,5/2)	(1,1,1)	(2/3,1, 3/2)	(7/2,4,9/2)	0.714
			B	(0.1,0.3,0.5)	(0.5,0.7,0.9)	(1,1,1)	(0,0,0.3)	(0.7,1.0,1.0)	
			New B	(0.74,0.80,0.86)	(0.86,0.91,0.97)	(1,1,1)	(0.71,0.71,0.80)	(0.91,1.00,1.00)	
			$Z_{(jW)}^{E}$	(3.13,3.58,4.02)	(1.43,1.91,2.39)	(1,1,1)	(0.57,0.85,1.28)	(3.47,3.97,4.47)	
DM₂	Best	C_{15}	A	(3/2,2,5/2)	(7/2,4,9/2)	(9/2,5,11/2)	(3/2,2,5/2)	(1,1,1)	0.555
			B	(0,0,0.3)	(0.5,0.7,0.9)	(0.7,1.0,1.0)	(0.3,0.5,0.7)	(1,1,1)	
			New B	(0.55,0.55,0.69)	(0.78,0.87,0.96)	(0.87,1.00,1.00)	(0.69,0.78,0.87)	(1,1,1)	
			$Z_{(Bj)}^{E}$	(1.14,1.51,1.89)	(3.26,3.73,4.20)	(4.45,4.95,5.44)	(1.32,1.77,2.21)	(1,1,1)	
	Worst	C_{13}	A	(7/2,4,9/2)	(7/2,4,9/2)	(1,1,1)	(3/2,2,5/2)	(9/2,5,11/2)	0.750
			B	(0.1,0.3,0.5)	(0.1,0.3,0.5)	(1,1,1)	(0.3,0.5,0.7)	(0.7,1.0,1.0)	
			New B	(0.77,0.82,0.87)	(0.77,0.82,0.87)	(1,1,1)	(0.82,0.87,0.92)	(0.92,1.00,1.00)	
			$Z_{(jW)}^{E}$	(3.17,3.62,4.07)	(3.17,3.62,4.07)	(1,1,1)	(1.40,1.87,2.33)	(4.47,4.97,5.46)	
DM₃	Best	C_{15}	A	(3/2,2,5/2)	(2/3,1, 3/2)	(5/2,3,7/2)	(7/2,4,9/2)	(1,1,1)	0.000
			B	(0.7,1.0,1.0)	(0.7,1.0,1.0)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(1,1,1)	
			New B	(0.7,1.0,1.0)	(0.7,1.0,1.0)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(1,1,1)	
			$Z_{(Bj)}^{E}$	(1.46,1.95,2.44)	(0.65,0.97,1.46)	(2.09,2.51,2.93)	(2.93,3.35,3.76)	(1,1,1)	
	Worst	C_{14}	A	(5/2,3,7/2)	(7/2,4,9/2)	(3/2,2,5/2)	(1,1,1)	(7/2,4,9/2)	-0.200
			B	(0.7,1.0,1.0)	(0.5,0.7,0.9)	(0.7,1.0,1.0)	(1,1,1)	(0.7,1.0,1.0)	
			New B	(0.56,0.80,0.80)	(0.40,0.56,0.72)	(0.56,0.80,0.80)	(1,1,1)	(0.56,0.80,0.80)	
			$Z_{(jW)}^{E}$	(2.18,2.62,3.05)	(2.62,2.99,3.37)	(1.31,1.74,2.18)	(1,1,1)	(3.05,3.49,3.92)	
DM₄	Best	C_{12}	A	(5/2,3,7/2)	(1,1,1)	(9/2,5,11/2)	(7/2,4,9/2)	(2/3,1, 3/2)	-0.333
			B	(0.5,0.7,0.9)	(1,1,1)	(0.3,0.5,0.7)	(0.5,0.7,0.9)	(0.7,1.0,1.0)	
			New B	(0.33,0.47,0.60)	(1,1,1)	(0.20,0.33,0.47)	(0.33,0.47,0.60)	(0.47,0.67,0.67)	
			$Z_{(Bj)}^{E}$	(1.54,1.85,2.15)	(1,1,1)	(2.59,2.88,3.17)	(2.15,2.46,2.77)	(0.53,0.78,1.20)	
	Worst	C_{13}	A	(3/2,2,5/2)	(9/2,5,11/2)	(1,1,1)	(2/3,1, 3/2)	(7/2,4,9/2)	0.777
			B	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(1,1,1)	(0.1,0.3,0.5)	(0.5,0.7,0.9)	
			New B	(0.89,0.93,0.98)	(0.84,0.89,0.93)	(1,1,1)	(0.80,0.84,0.89)	(0.89,0.93,0.98)	
			$Z_{(jW)}^{E}$	(1.45,1.93,2.41)	(4.24,4.71,5.18)	(1,1,1)	(0.61,0.92,1.38)	(3.38,3.86,4.34)	

Table A4. Z^E-BWM inputs for environmental criteria.

DM	Best & Worst criteria		Z	Sub criteria						Experts' votes			R
				C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	Yes	No	θ	
DM₁	Best	C_{21}	A	EI	WI	FI	WI	I	AI	4	3	3	0.143
			B	VH	H	M	H	L	VH				
	Worst	C_{26}	A	AI	FI	I	I	VI	EI	7	2	1	0.555
			B	VH	H	H	H	M	H				
DM₂	Best	C_{24}	A	WI	FI	FI	EI	I	VI	5	3	2	0.250
			B	L	VL	M	VH	H	H				
	Worst	C_{26}	A	I	FI	FI	VI	I	EI	7	2	1	0.555
			B	L	M	M	VH	VH	H				
DM₃	Best	C_{25}	A	I	WI	I	FI	EI	VI	5	2	3	0.429
			B	L	M	L	M	H	M				
	Worst	C_{26}	A	FI	I	I	FI	VI	EI	5	3	2	0.250
			B	M	H	M	VH	H	VH				
DM₄	Best	C_{22}	A	WI	EI	FI	FI	FI	VI	5	2	3	0.429
			B	L	H	H	M	M	H				
	Worst	C_{26}	A	EI	VI	FI	FI	FI	EI	6	3	1	0.333
			B	H	H	M	M	L	M				

Table A5. Calculations of BWM for environmental criteria.

DM	Best & Worst criteria		Z	Sub criteria						R
				C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	
DM_1	Best	C_{21}	A	(1,1,1)	(2/3,1, 3/2)	(3/2,2,5/2)	(2/3,1, 3/2)	(5/2,3,7/2)	(9/2,5,11/2)	0.143
			B	(1,1,1)	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(0.5,0.7,0.9)	(0.1,0.3,0.5)	(0.7,1.0,1.0)	
			New B	(1,1,1)	(0.57,0.74,0.91)	(0.40,0.57,0.74)	(0.57,0.74,0.91)	(0.23,0.40,0.57)	(0.74,1.00,1.00)	
			$Z^E_{(Bj)}$	(1,1,1)	(0.57,0.86,1.29)	(1.13,1.51,1.89)	(0.57,0.86,1.29)	(1.58,1.90,2.21)	(4.40,4.90,5.38)	
	Worst	C_{26}	A	(9/2,5,11/2)	(3/2,2,5/2)	(5/2,3,7/2)	(5/2,3,7/2)	(7/2,4,9/2)	(1,1,1)	0.555
			B	(0.7,1.0,1.0)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(1,1,1)	
			New B	(0.87,1.00,1.00)	(0.78,0.87,0.96)	(0.78,0.87,0.96)	(0.78,0.87,0.96)	(0.69,0.78,0.87)	(1,1,1)	
			$Z^E_{(jW)}$	(4.45,4.95,5.44)	(1.40,1.87,2.33)	(2.33,2.80,3.26)	(2.33,2.80,3.26)	(3.10,3.53,3.97)	(1,1,1)	
DM_2	Best	C_{24}	A	(2/3,1, 3/2)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	(5/2,3,7/2)	(7/2,4,9/2)	0.250
			B	(0.1,0.3,0.5)	(0,0,0.3)	(0.3,0.5,0.7)	(1,1,1)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	
			New B	(0.32,0.47,0.62)	(0.25,0.25,0.47)	(0.47,0.62,0.77)	(1,1,1)	(0.65,0.77,0.92)	(0.65,0.77,0.92)	
			$Z^E_{(Bj)}$	(0.46,0.69,1.03)	(0.80,1.07,1.34)	(1.18,1.57,1.97)	(1,1,1)	(2.20,2.64,3.08)	(3.08,3.52,3.96)	
	Worst	C_{26}	A	(5/2,3,7/2)	(3/2,2,5/2)	(3/2,2,5/2)	(7/2,4,9/2)	(5/2,3,7/2)	(1,1,1)	0.555
			B	(0.1,0.3,0.5)	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.5,0.7,0.9)	(0.7,1.0,1.0)	(1,1,1)	
			New B	(0.60,0.69,0.78)	(0.69,0.78,0.87)	(0.69,0.78,0.87)	(0.78,0.87,0.96)	(0.87,1.00,1.00)	(1,1,1)	
			$Z^E_{(jW)}$	(2.08,2.49,2.91)	(1.32,1.77,2.21)	(1.32,1.77,2.21)	(3.26,3.73,4.20)	(2.47,2.97,3.46)	(1,1,1)	
DM_3	Best	C_{25}	A	(5/2,3,7/2)	(2/3,1, 3/2)	(5/2,3,7/2)	(3/2,2,5/2)	(1,1,1)	(7/2,4,9/2)	0.429
			B	(0.1,0.3,0.5)	(0.3,0.5,0.7)	(0.1,0.3,0.5)	(0.3,0.5,0.7)	(1,1,1)	(0.3,0.5,0.7)	
			New B	(0.47,0.60,0.71)	(0.60,0.71,0.83)	(0.47,0.60,0.71)	(0.60,0.71,0.83)	(1,1,1)	(0.60,0.71,0.83)	
			$Z^E_{(Bj)}$	(1.93,2.32,2.70)	(0.56,0.84,1.27)	(1.93,2.32,2.70)	(1.27,1.69,2.11)	(1,1,1)	(2.95,3.37,3.80)	
	Worst	C_{26}	A	(3/2,2,5/2)	(5/2,3,7/2)	(5/2,3,7/2)	(3/2,2,5/2)	(7/2,4,9/2)	(1,1,1)	0.250
			B	(0.3,0.5,0.7)	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(0.7,1.0,1.0)	(0.5,0.7,0.9)	(1,1,1)	
			New B	(0.47,0.62,0.77)	(0.65,0.77,0.92)	(0.47,0.62,0.77)	(0.77,1.00,1.00)	(0.65,0.77,0.92)	(1,1,1)	
			$Z^E_{(jW)}$	(1.18,1.57,1.97)	(2.20,2.64,3.08)	(1.97,2.36,2.76)	(1.47,1.96,2.45)	(3.08,3.52,3.96)	(1,1,1)	
DM_4	Best	C_{22}	A	(2/3,1, 3/2)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	(7/2,4,9/2)	0.429
			B	(0.1,0.3,0.5)	(1,1,1)	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.5,0.7,0.9)	
			New B	(0.47,0.60,0.71)	(1,1,1)	(0.71,0.83,0.94)	(0.60,0.71,0.83)	(0.60,0.71,0.83)	(0.71,0.83,0.94)	
			$Z^E_{(Bj)}$	(0.51,0.77,1.16)	(1,1,1)	(1.37,1.82,2.28)	(1.27,1.69,2.11)	(1.27,1.69,2.11)	(3.19,3.64,4.10)	
	Worst	C_{26}	A	(1,1,1)	(7/2,4,9/2)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	0.333
			B	(1,1,1)	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.1,0.3,0.5)	(1,1,1)	
			New B	(1,1,1)	(0.67,0.80,0.93)	(0.53,0.67,0.80)	(0.53,0.67,0.80)	(0.40,0.53,0.67)	(1,1,1)	
			$Z^E_{(jW)}$	(1,1,1)	(3.13,3.58,4.02)	(1.22,1.64,2.04)	(1.22,1.64,2.04)	(1.09,1.46,1.82)	(1,1,1)	

Table A6. Z^E-BWM inputs for social criteria.

DM	Best & Worst criteria		Z	Sub criteria				Experts' votes			R
				C_{31}	C_{32}	C_{33}	C_{34}	Yes	No	θ	
DM_1	Best	C_{34}	A	FI	I	WI	EI	8	0	2	1
			B	M	M	H	VH				
	Worst	C_{32}	A	FI	EI	WI	I	9	0	1	1
			B	VL	H	I	L				
DM_2	Best	C_{31}	A	EI	VI	FI	WI	2	4	4	-0.333
			B	VH	M	H	H				
	Worst	C_{32}	A	VI	EI	FI	FI	4	4	2	0
			B	VH	H	L	M				
DM_3	Best	C_{33}	A	EI	AI	EI	VI	8	0	2	1
			B	M	VH	VH	VL				
	Worst	C_{32}	A	FI	EI	AI	FI	8	0	2	1
			B	H	VH	VH	L				
DM_4	Best	C_{33}	A	FI	AI	EI	VI	6	1	3	0.714
			B	M	H	VH	L				
	Worst	C_{32}	A	FI	EI	AI	FI	7	0	3	1
			B	M	VH	VH	M				

Table A7. Calculations of BWM for social criteria.

DM	Best & Worst criteria		Z	Sub criteria				R
				C_{31}	C_{32}	C_{33}	C_{34}	
DM_1	Best	C_{34}	A	(3/2,2,5/2)	(5/2,3,7/2)	(2/3,1, 3/2)	(1,1,1)	1
			B	(0.7,1.0,1.0)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(1,1,1)	
			New B	(1.00,1.00,1.00)	(1.00,1.00,1.00)	(1.00,1.00,1.00)	(1,1,1)	
			$Z^E_{(Bj)}$	(3/2,2,5/2)	(5/2,3,7/2)	(2/3,1, 3/2)	(1,1,1)	
	Worst	C_{32}	A	(3/2,2,5/2)	(1,1,1)	(2/3,1, 3/2)	(5/2,3,7/2)	1
			B	(0,0,0.3)	(1,1,1)	(0.1,0.3,0.5)	(0.5,0.7,0.9)	
			New B	(1.00,1.00,1.00)	(1,1,1)	(1.00,1.00,1.00)	(1.00,1.00,1.00)	
			$Z^E_{(jW)}$	(3/2,2,5/2)	(1,1,1)	(2/3,1, 3/2)	(5/2,3,7/2)	
DM_2	Best	C_{31}	A	(1,1,1)	(7/2,4,9/2)	(3/2,2,5/2)	(2/3,1, 3/2)	-0.333
			B	(1,1,1)	(0.7,1.0,1.0)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	

			New B	(1,1,1)	(0.47,0.67,0.67)	(0.33,0.47,0.60)	(0.33,0.47,0.60)	
			$Z^E_{(Bj)}$	(1,1,1)	(2.79,3.19,3.59)	(1.03,1.37,1.71)	(0.46,0.68,1.03)	
	Worst	C_{32}	A	(7/2,4,9/2)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	0
			B	(0.7,1.0,1.0)	(1,1,1)	(0.1,0.3,0.5)	(0.3,0.5,0.7)	
			New B	(0.7,1.0,1.0)	(1,1,1)	(0.1,0.3,0.5)	(0.3,0.5,0.7)	
			$Z^E_{(jW)}$	(3.41,3.90,4.39)	(1,1,1)	(0.82,1.10,1.37)	(1.06,1.41,1.77)	
DM₃	Best	C_{33}	A	(1,1,1)	(9/2,5,11/2)	(1,1,1)	(7/2,4,9/2)	1
			B	(0.3,0.5,0.7)	(0.7,1.0,1.0)	(1,1,1)	(0,0,0.3)	
			New B	(1.00,1.00,1.00)	(1.00,1.00,1.00)	(1,1,1)	(1.00,1.00,1.00)	
			$Z^E_{(Bj)}$	(1,1,1)	(9/2,5,11/2)	(1,1,1)	(7/2,4,9/2)	
	Worst	C_{32}	A	(3/2,2,5/2)	(1,1,1)	(9/2,5,11/2)	(3/2,2,5/2)	1
			B	(0.5,0.7,0.9)	(1,1,1)	(0.7,1.0,1.0)	(0.1,0.3,0.5)	
			New B	(1.00,1.00,1.00)	(1,1,1)	(1.00,1.00,1.00)	(1.00,1.00,1.00)	
			$Z^E_{(jW)}$	(3/2,2,5/2)	(1,1,1)	(9/2,5,11/2)	(3/2,2,5/2)	
DM₄	Best	C_{33}	A	(3/2,2,5/2)	(9/2,5,11/2)	(1,1,1)	(7/2,4,9/2)	0.714
			B	(0.3,0.5,0.7)	(0.5,0.7,0.9)	(1,1,1)	(0.1,0.3,0.5)	
			New B	(0.80,0.86,0.91)	(0.86,0.91,0.97)	(1,1,1)	(0.74,0.80,0.86)	
			$Z^E_{(Bj)}$	(1.39,1.85,2.32)	(4.30,4.77,5.25)	(1,1,1)	(3.13,3.58,4.02)	
	Worst	C_{32}	A	(3/2,2,5/2)	(1,1,1)	(9/2,5,11/2)	(3/2,2,5/2)	1
			B	(0.3,0.5,0.7)	(1,1,1)	(0.5,0.7,0.9)	(0.3,0.5,0.7)	
			New B	(1.00,1.00,1.00)	(1,1,1)	(1.00,1.00,1.00)	(1.00,1.00,1.00)	
			$Z^E_{(jW)}$	(3/2,2,5/2)	(1,1,1)	(9/2,5,11/2)	(3/2,2,5/2)	

Table A8. Z^E-BWM inputs for resilience criteria.

DM	**Best & Worst criteria**		**Z**	**Sub criteria**				**Experts' votes**			**R**
				C_{41}	C_{42}	C_{43}	C_{44}	Yes	No	θ	
DM₁	Best	C_{41}	A	EI	FI	VI	FI	6	0	4	1
			B	VH	L	H	M				
	Worst	C_{43}	A	VI	I	EI	FI	4	2	4	0.333
			B	VH	H	M	M				
DM₂	Best	C_{41}	A	EI	WI	VI	AI	6	1	3	0.714
			B	VH	L	M	VH				
	Worst	C_{44}	A	AI	I	FI	EI	3	3	4	0

			B	VH	H	H	H				
DM_3	Best	C_{41}	A	EI	I	VI	AI	6	1	3	0.714
			B	VH	M	M	M				
	Worst	C_{44}	A	AI	VI	FI	EI	6	2	2	0.500
			B	VH	H	M	H				
DM_4	Best	C_{41}	A	EI	VI	FI	FI	8	0	2	1
			B	VH	M	L	M				
	Worst	C_{42}	A	VI	EI	WI	FI	2	4	4	-0.333
			B	VH	H	L	M				

Table A9. Calculations of BWM for resilience criteria.

DM	**Best & Worst criteria**		**Z**	**Sub criteria**				**R**
				C_{41}	C_{42}	C_{43}	C_{44}	
DM_1	Best	C_{41}	A	(1,1,1)	(3/2,2,5/2)	(7/2,4,9/2)	(3/2,2,5/2)	1
			B	(1,1,1)	(0.1,0.3,0.5)	(0.7,1.0,1.0)	(0.3,0.5,0.7)	
			New B	(1,1,1)	(1.00,1.00,1.00)	(1.00,1.00,1.00)	(1.00,1.00,1.00)	
			$Z^E_{(Bj)}$	(1,1,1)	(3/2,2,5/2)	(7/2,4,9/2)	(3/2,2,5/2)	
	Worst	C_{43}	A	(7/2,4,9/2)	(5/2,3,7/2)	(1,1,1)	(3/2,2,5/2)	0.333
			B	(0.7,1.0,1.0)	(0.5,0.7,0.9)	(1,1,1)	(0.3,0.5,0.7)	
			New B	(0.80,1.00,1.00)	(0.67,0.80,0.93)	(1,1,1)	(0.53,0.67,0.80)	
			$Z^E_{(jW)}$	(3.44,3.93,4.42)	(2.24,2.68,3.13)	(1,1,1)	(1.23,1.64,2.04)	
DM_2	Best	C_{41}	A	(1,1,1)	(2/3,1,3/2)	(7/2,4,9/2)	(9/2,5,11/2)	0.714
			B	(0.7,1.0,1.0)	(0.1,0.3,0.5)	(0.3,0.5,0.7)	(0.7,1.0,1.0)	
			New B	(0.91,1.00,1.00)	(0.74,0.80,0.86)	(0.80,0.86,0.91)	(0.91,1.00,1.00)	
			$Z^E_{(Bj)}$	(1,1,1)	(0.60,0.90,1.34)	(3.24,3.71,4.17)	(4.47,4.96,5.46)	
	Worst	C_{44}	A	(9/2,5,11/2)	(5/2,3,7/2)	(3/2,2,5/2)	(1,1,1)	0
			B	(0.7,1.0,1.0)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(1,1,1)	
			New B	(0.7,1.0,1.0)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(1,1,1)	
			$Z^E_{(jW)}$	(4.39,4.87,5.36)	(2.09,2.51,2.93)	(1.25,1.67,2.09)	(1,1,1)	
DM_3	Best	C_{41}	A	(1,1,1)	(5/2,3,7/2)	(7/2,4,9/2)	(9/2,5,11/2)	0.714
			B	(1,1,1)	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.7,1.0,1.0)	
			New B	(1,1,1)	(0.80,0.86,0.91)	(0.80,0.86,0.91)	(0.91,1.00,1.00)	

			$Z^{E}_{(Bj)}$	(1,1,1)	(2.32,2.78,3.24)	(3.24,3.71,4.17)	(4.47,4.96,5.46)	
	Worst	C_{44}	A	(9/2,5,11/2)	(7/2,4,9/2)	(3/2,2,5/2)	(1,1,1)	0.500
			B	(0.7,1.0,1.0)	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(1,1,1)	
			New B	(0.75,1.00,1.00)	(0.75,0.85,0.95)	(0.65,0.75,0.85)	(1,1,1)	
			$Z^{E}_{(jW)}$	(4.41,4.89,5.38)	(3.23,3.69,4.15)	(1.30,1.73,2.17)	(1,1,1)	
DM_4	Best	C_{41}	A	(1,1,1)	(7/2,4,9/2)	(3/2,2,5/2)	(3/2,2,5/2)	1
			B	(1,1,1)	(0.7,1.0,1.0)	(0.1,0.3,0.5)	(0.3,0.5,0.7)	
			New B	(1,1,1)	(1.00,1.00,1.00)	(1.00,1.00,1.00)	(1.00,1.00,1.00)	
			$Z^{E}_{(Bj)}$	(1,1,1)	(7/2,4,9/2)	(3/2,2,5/2)	(3/2,2,5/2)	
	Worst	C_{42}	A	(7/2,4,9/2)	(1,1,1)	(2/3,1,3/2)	(3/2,2,5/2)	-0.333
			B	(0.7,1.0,1.0)	(1,1,1)	(0.1,0.3,0.5)	(0.3,0.5,0.7)	
			New B	(0.47,0.67,0.67)	(1,1,1)	(0.07,0.20,0.33)	(0.20,0.33,0.47)	
			$Z^{E}_{(jW)}$	(2.80,3.19,3.59)	(1,1,1)	(0.30,0.45,0.67)	(0.86,1.15,1.44)	

Appendix B

Table B1 – Experts' judgments on opinions of decision-makers for ranking.

DMs	**DM$_1$**															**DM$_2$**														
Alternatives	**A1**			**A2**			**A3**			**A4**			**A5**			**A1**			**A2**			**A3**			**A4**			**A5**		
Experts	**Yes**	**No**	θ	**Yes**	**No**	θ	**Yes**	**No**	θ	**Yes**	**No**	θ	**Yes**	**No**	θ	**Yes**	**No**	θ	**Yes**	**No**	θ	**Yes**	**No**	θ	**Yes**	**No**	θ	**Yes**	**No**	θ
E_1	*					*	*			*				*				*			*	*			*				*	
E_2	*			*			*			*				*		*			*			*			*					*
E_3		*			*		*			*			*				*		*				*		*			*		
E_4			*		*		*			*			*			*					*	*			*			*		
E_5			*		*		*			*					*	*			*					*	*				*	
E_6	*			*					*		*			*			*		*			*					*	*		
E_7		*		*			*					*	*			*			*			*			*			*		
E_8	*					*	*				*			*		*			*			*				*				*
E_9	*					*	*			*					*	*					*	*			*			*		
E_{10}			*		*				*	*			*				*		*			*					*			*

DMs	**DM$_3$**															**DM$_4$**														
Alternatives	**A1**			**A2**			**A3**			**A4**			**A5**			**A1**			**A2**			**A3**			**A4**			**A5**		
Experts	**Yes**	**No**	θ	**Yes**	**No**	θ	**Yes**	**No**	θ	**Yes**	**No**	θ	**Yes**	**No**	θ	**Yes**	**No**	θ	**Yes**	**No**	θ	**Yes**	**No**	θ	**Yes**	**No**	θ	**Yes**	**No**	θ
E_1	*				*		*					*	*				*			*				*			*	*		
E_2	*				*		*				*		*				*			*				*		*				*
E_3		*		*			*					*	*					*		*		*			*				*	
E_4			*			*	*				*			*				*			*	*			*			*		
E_5		*			*				*		*		*			*			*			*				*				*
E_6		*		*			*					*	*				*				*		*		*					*
E_7	*			*			*			*			*			*					*			*	*				*	
E_8	*					*			*		*		*			*			*			*					*			*
E_9		*		*			*					*			*		*				*	*			*			*		
E_{10}	*			*			*				*			*			*			*				*		*			*	

Table B2 – New fuzzy reliabilities.

DMs			DM₁					DM₂		
Alternatives	A1	A2	A3	A4	A5	A1	A2	A3	A4	A5
Criteria	New B	New B	New B	New B	New B	New B	New B	New B	New B	New B
C_{11}	(0.83,1.00,1.00)	(0.43,0.60,0.77)	(1,1,1)	(0.87,0.96,0.96)	(0.5,0.7,0.9)	(0.67,0.80,0.93)	(1,1,1)	(0.80,0.84,0.89)	(0.87,0.92,0.97)	(0.60,0.71,0.83)
C_{12}	(0.60,0.71,0.83)	(0.09,0.26,0.43)	(1,1,1)	(0.60,0.69,0.78)	(0.5,0.7,0.9)	(0.80,1.00,1.00)	(1,1,1)	(0.93,1.00,1.00)	(0.82,0.87,0.92)	(0.60,0.71,0.83)
C_{13}	(0.49,0.60,0.71)	(0.26,0.43,0.60)	(1,1,1)	(0.78,0.87,0.96)	(0.3,0.5,0.7)	(0.53,0.67,0.80)	(1,1,1)	(0.93,1.00,1.00)	(0.92,1.00,1.00)	(0.71,0.83,0.94)
C_{14}	(0.83,1.00,1.00)	(0.43,0.60,0.77)	(1,1,1)	(0.55,0.55.78)	(0,0,0.3)	(0.80,1.00,1.00)	(1,1,1)	(0.89,0.93,0.98)	(0.92,1.00,1.00)	(0.71,0.83,0.94)
C_{15}	(0.71,0.83,0.94)	(0.00,0.00,0.26)	(1,1,1)	(0.60,0.69,0.78)	(0.1,0.3,0.5)	(0.40,0.53,0.67)	(1,1,1)	(0.84,0.89,0.93)	(0.75,0.75,0.82)	(0.49,0.60,0.71)
C_{21}	(0.60,0.71,0.83)	(0.26,0.43,0.60)	(1,1,1)	(0.78,0.87,0.96)	(0,0,0.3)	(0.80,1.00,1.00)	(1,1,1)	(0.93,1.00,1.00)	(0.87,0.92,0.97)	(0.49,0.60,0.71)
C_{22}	(0.60,0.71,0.83)	(0.26,0.43,0.60)	(1,1,1)	(0.87,0.96,0.96)	(0.5,0.7,0.9)	(0.33,0.33,0.53)	(1,1,1)	(0.89,0.93,0.98)	(0.82,0.87,0.92)	(0.80,1.00,1.00)
C_{23}	(0.83,1.00,1.00)	(0.00,0.00,0.26)	(1,1,1)	(0.69,0.78,0.87)	(0.3,0.5,0.7)	(0.67,0.80,0.93)	(1,1,1)	(0.84,0.89,0.93)	(0.92,1.00,1.00)	(0.60,0.71,0.83)
C_{24}	(0.43,0.43,0.60)	(0.60,0.86,0.86)	(1,1,1)	(0.69,0.78,0.87)	(0.7,1.0,1.0)	(0.53,0.67,0.80)	(1,1,1)	(0.84,0.89,0.93)	(0.77,0.82,0.87)	(0.80,1.00,1.00)
C_{25}	(0.60,0.71,0.83)	(0.43,0.60,0.77)	(1,1,1)	(0.87,0.96,0.96)	(0,0,0.3)	(0.67,0.80,0.93)	(1,1,1)	(0.93,1.00,1.00)	(0.75,0.75,0.82)	(0.71,0.83,0.94)
C_{26}	(0.71,0.83,0.94)	(0.26,0.43,0.60)	(1,1,1)	(0.55,0.55.78)	(0.5,0.7,0.9)	(0.80,1.00,1.00)	(1,1,1)	(0.80,0.84,0.89)	(0.82,0.87,0.92)	(0.80,1.00,1.00)
C_{31}	(0.83,1.00,1.00)	(0.60,0.86,0.86)	(1,1,1)	(0.78,0.87,0.96)	(0.7,1.0,1.0)	(0.33,0.33,0.53)	(1,1,1)	(0.93,1.00,1.00)	(0.82,0.87,0.92)	(0.80,1.00,1.00)
C_{32}	(0.71,0.83,0.94)	(0.09,0.26,0.43)	(1,1,1)	(0.87,0.96,0.96)	(0.1,0.3,0.5)	(0.80,1.00,1.00)	(1,1,1)	(0.93,1.00,1.00)	(0.87,0.92,0.97)	(0.60,0.71,0.83)
C_{33}	(0.60,0.71,0.83)	(0.43,0.60,0.77)	(1,1,1)	(0.87,0.96,0.96)	(0.5,0.7,0.9)	(0.53,0.67,0.80)	(1,1,1)	(0.89,0.93,0.98)	(0.92,1.00,1.00)	(0.43,0.43,0.60)
C_{34}	(0.71,0.83,0.94)	(0.26,0.43,0.60)	(1,1,1)	(0.60,0.69,0.78)	(0.1,0.3,0.5)	(0.40,0.53,0.67)	(1,1,1)	(0.89,0.93,0.98)	(0.77,0.82,0.87)	(0.43,0.43,0.60)
C_{41}	(0.43,0.43,0.60)	(0.60,0.86,0.86)	(1,1,1)	(0.78,0.87,0.96)	(0.1,0.3,0.5)	(0.33,0.33,0.53)	(1,1,1)	(0.89,0.93,0.98)	(0.77,0.82,0.87)	(0.49,0.60,0.71)
C_{42}	(0.71,0.83,0.94)	(0.60,0.86,0.86)	(1,1,1)	(0.60,0.69,0.78)	(0.7,1.0,1.0)	(0.80,1.00,1.00)	(1,1,1)	(0.84,0.89,0.93)	(0.82,0.87,0.92)	(0.43,0.43,0.60)
C_{43}	(0.49,0.60,0.71)	(0.09,0.26,0.43)	(1,1,1)	(0.60,0.69,0.78)	(0.5,0.7,0.9)	(0.67,0.80,0.93)	(1,1,1)	(0.93,1.00,1.00)	(0.82,0.87,0.92)	(0.80,1.00,1.00)
C_{44}	(0.83,1.00,1.00)	(0.00,0.00,0.26)	(1,1,1)	(0.55,0.55.78)	(0.1,0.3,0.5)	(0.80,1.00,1.00)	(1,1,1)	(0.80,0.84,0.89)	(0.87,0.92,0.97)	(0.71,0.83,0.94)
DMs			**DM₃**					**DM₄**		
Alternatives	A1	A2	A3	A4	A5	A1	A2	A3	A4	A5
Criteria	New B	New B	New B	New B	New B	New B	New B	New B	New B	New B
C_{11}	(0.20,0.38,0.56)	(0.62,0.77,0.92)	(1,1,1)	(0.00,0.00,0.10)	(0.56,0.56,0.69)	(0.07,0.22,0.37)	(0.47,0.67,0.67)	(0.90,1.00,1.00)	(0.77,1.00,1.00)	(0.7,1.0,1.0)
C_{12}	(0.38,0.56,0.73)	(0.47,62,0.77)	(1,1,1)	(0.17,0.23,0.30)	(0.78,0.87,0.96)	(0.07,0.22,0.37)	(0.20,0.33,0.47)	(0.77,0.83,0.90)	(0.47,0.62,0.77)	(0.3,0.5,0.7)

C_{13}	(0.56,0.73,0.91)	(0.25,0.25,0.47)	(1,1,1)	(0.10,0.17,0.23)	(0.60,0.69,0.78)	(0.37,0.52,0.67)	(0.00,0.00,0.20)	(0.90,1.00,1.00)	(0.77,1.00,1.00)	(0,0,0.3)
C_{14}	(0.38,0.56,0.73)	(0.25,0.25,0.47)	(1,1,1)	(0.23,0.33,0.33)	(0.56,0.56,0.69)	(0.52,0.75,0.75)	(0.33,0.47,0.60)	(0.83,0.90,0.97)	(0.77,1.00,1.00)	(0.5,0.7,0.9)
C_{15}	(0.20,0.38,0.56)	(0.47,62,0.77)	(1,1,1)	(0.17,0.23,0.30)	(0.69,0.78,0.87)	(0.22,0.37,0.52)	(0.07,0.20,0.33)	(0.67,0.67,0.77)	(0.62,0.77,0.92)	(0.1,0.3,0.5)
C_{21}	(0.73,1.00,1.00)	(0.32,.047,0.62)	(1,1,1)	(0.23,0.33,0.33)	(0.78,0.87,0.96)	(0.52,0.75,0.75)	(0.00,0.00,0.20)	(0.77,0.83,0.90)	(0.62,0.77,0.92)	(0.3,0.5,0.7)
C_{22}	(0.56,0.73,0.91)	(0.62,0.77,0.92)	(1,1,1)	(0.23,0.33,0.33)	(0.69,0.78,0.87)	(0.07,0.22,0.37)	(0.00,0.00,0.20)	(0.77,0.83,0.90)	(0.25,0.25,0.47)	(0.5,0.7,0.9)
C_{23}	(0.11,0.110.38)	(0.77,1.00,1.00)	(1,1,1)	(0.23,0.33,0.33)	(0.60,0.69,0.78)	(0.52,0.75,0.75)	(0.20,0.33,0.47)	(0.90,1.00,1.00)	(0.62,0.77,0.92)	(0.5,0.7,0.9)
C_{24}	(0.11,0.110.38)	(0.62,0.77,0.92)	(1,1,1)	(0.03,0.10,0.17)	(0.87,1.00,1.00)	(0.37,0.52,0.67)	(0.33,0.47,0.60)	(0.83,0.90,0.97)	(0.62,0.77,0.92)	(0.3,0.5,0.7)
C_{25}	(0.56,0.73,0.91)	(0.47,62,0.77)	(1,1,1)	(0.10,0.17,0.23)	(0.78,0.87,0.96)	(0.07,0.22,0.37)	(0.33,0.47,0.60)	(0.90,1.00,1.00)	(0.47,0.62,0.77)	(0.7,1.0,1.0)
C_{26}	(0.20,0.38,0.56)	(0.77,1.00,1.00)	(1,1,1)	(0.17,0.23,0.30)	(0.87,1.00,1.00)	(0.07,0.22,0.37)	(0.07,0.20,0.33)	(0.70,0.77,0.83)	(0.47,0.62,0.77)	(0,0,0.3)
C_{31}	(0.73,1.00,1.00)	(0.32,.047,0.62)	(1,1,1)	(0.23,0.33,0.33)	(0.56,0.56,0.69)	(0.22,0.37,0.52)	(0.00,0.00,0.20)	(0.77,0.83,0.90)	(0.77,1.00,1.00)	(0.1,0.3,0.5)
C_{32}	(0.38,0.56,0.73)	(0.77,1.00,1.00)	(1,1,1)	(0.00,0.00,0.10)	(0.60,0.69,0.78)	(0.22,0.37,0.52)	(0.33,0.47,0.60)	(0.90,1.00,1.00)	(0.32,0.47,0.62)	(0.5,0.7,0.9)
C_{33}	(0.56,0.73,0.91)	(0.77,1.00,1.00)	(1,1,1)	(0.23,0.33,0.33)	(0.69,0.78,0.87)	(0.07,0.22,0.37)	(0.33,0.47,0.60)	(0.90,1.00,1.00)	(0.77,1.00,1.00)	(0.1,0.3,0.5)
C_{34}	(0.56,0.73,0.91)	(0.47,62,0.77)	(1,1,1)	(0.17,0.23,0.30)	(0.60,0.69,0.78)	(0.22,0.37,0.52)	(0.07,0.20,0.33)	(0.90,1.00,1.00)	(0.77,1.00,1.00)	(0.3,0.5,0.7)
C_{41}	(0.73,1.00,1.00)	(0.62,0.77,0.92)	(1,1,1)	(0.10,0.17,0.23)	(0.69,0.78,0.87)	(0.52,0.75,0.75)	(0.47,0.67,0.67)	(0.83,0.90,0.97)	(0.77,1.00,1.00)	(0.3,0.5,0.7)
C_{42}	(0.20,0.38,0.56)	(0.77,1.00,1.00)	(1,1,1)	(0.17,0.23,0.30)	(0.69,0.78,0.87)	(0.07,0.22,0.37)	(0.07,0.20,0.33)	(0.67,0.67,0.77)	(0.47,0.62,0.77)	(0.1,0.3,0.5)
C_{43}	(0.11,0.110.38)	(0.32,.047,0.62)	(1,1,1)	(0.17,0.23,0.30)	(0.87,1.00,1.00)	(0.07,0.22,0.37)	(0.20,0.33,0.47)	(0.77,0.83,0.90)	(0.25,0.25,0.47)	(0,0,0.3)
C_{44}	(0.73,1.00,1.00)	(0.47,62,0.77)	(1,1,1)	(0.23,0.33,0.33)	(0.78,0.87,0.96)	(0.37,0.52,0.67)	(0.20,0.33,0.47)	(0.90,1.00,1.00)	(0.62,0.77,0.92)	(0.7,1.0,1.0)

Table B3 –Fuzzy decision matrices based on Z^E-numbers.

DMs	**DM_1**					**DM_2**				
Alternatives	A1	A2	A3	A4	A5	A1	A2	A3	A4	A5
C_{11}	(3.45,3.94,4.44)	(1.94,2.32,2.71)	(2/3,1, 3/2)	(4.37,4.86,5.35)	(1.25,1.67,2.09)	(3.13,3.58,4.02)	(1.50,2.00,2.50)	(1.38,1.83,2.29)	(3.36,3.84,4.32)	(1.27,1.69,2.11)
C_{12}	(1.27,1.69,2.11)	(0.34,0.51,0.76)	(9/2,5,11/2)	(2.08,2.49,2.91)	(2.93,3.35,3.76)	(0.98,0.98,0.98)	(1.50,2.00,2.50)	(4.47,4.97,5.47)	(3.26,3.73,4.20)	(2.11,2.53,2.95)
C_{13}	(1.94,2.32, 2.71)	(1.64,1.97,2.30)	(7/2,4,9/2)	(0.93,0.93,0.93)	(0.47,0.71,1.06)	(2.04,2.45,2.86)	(1.50,2.00,2.50)	(4.47,4.97,5.47)	(0.99,0.99,0.99)	(1.37,1.82,2.28)
C_{14}	(4.44,4.93,5.42)	(1.94,2.32,2.71)	(7/2,4,9/2)	(0.51,0.77,1.15)	(0.56,0.67,0.78)	(4.42,4.92,5.41)	(1.50,2.00,2.50)	(3.38,3.86,4.34)	(0.99,0.99,0.99)	(3.19,3.64,4.10)
C_{15}	(1.37,1.82,2.28)	(0.31,0.42,0.52)	(7/2,4,9/2)	(2.08,2.49,2.91)	(0.37,0.55,0.82)	(1.09,1.46,1.82)	(1.50,2.00,2.50)	(3.30,3.77,4.24)	(2.18,2.62,3.05)	(0.52,0.77,1.16)
C_{21}	(0.84, 0.84, 0.84)	(0.98,1.31,1.64)	(9/2,5,11/2)	(1.40,1.87,2.33)	(0.34,0.45,0.56)	(0.98,0.98,0.98)	(2.50,3.00,3.50)	(4.47,4.97,5.47)	(2.40,2.88,3.36)	(1.16,1.55,1.94)
C_{22}	(2.95,3.37,3.80)	(0.52,0.62,0.73)	(7/2,4,9/2)	(4.37,4.86,5.35)	(0.56,0.84,1.25)	(1.51,1.81,2.11)	(3.50,4.00,4.50)	(3.38,3.86,4.34)	(2.33,2.80,3.26)	(0.98,0.98,0.98)
C_{23}	(4.44,4.93,5.42)	(0.52,0.62,0.73)	(9/2,5,11/2)	(1.32,1.77,2.21)	(0.47,0.71,1.06)	(3.13,3.58,4.02)	(2.50,3.00,3.50)	(3.30,3.77,4.24)	(0.99,0.99,0.99)	(1.27,1.69,2.11)

C_{24}	(1.69,2.03,2.37)	(3.16,3.61,4.07)	(3/2,2,5/2)	(3.97,4.42,4.86)	(1.46,1.95,2.43)	(2.04,2.45,2.86)	(4.50,5.00,5.50)	(2.36,2.83,3.30)	(3.17,3.62,4.07)	(0.98,0.98,0.98)
C_{25}	(0.72,0.84,1.27)	(1.16,1.55,1.94)	(7/2,4,9/2)	(4.37,4.86,5.35)	(0.34,0.45,0.56)	(1.34,1.79,2.24)	(1.50,2.00,2.50)	(4.47,4.97,5.47)	(2.18,2.62,3.05)	(1.37,1.82,2.28)
C_{26}	(4.10,4.55,5.01)	(1.64,1.97,2.30)	(3/2,2,5/2)	(0.51,0.77,1.15)	(0.84,0.84,0.84)	(4.42,4.92,5.41)	(2.50,3.00,3.50)	(1.38,1.83,2.29)	(0.62,0.93,1.40)	(0.98,0.98,0.98)
C_{31}	(2.46,2.96,3.45)	(0.90,0.90,0.90)	(7/2,4,9/2)	(2.33,2.80,3.26)	(2.44,2.92,3.41)	(0.90,1.21,1.51)	(1.50,2.00,2.50)	(4.47,4.97,5.47)	(2.33,2.80,3.26)	(3.44,3.94,4.43)
C_{32}	(1.37,1.82,2.28)	(0.76,1.02,1.27)	(7/2,4,9/2)	(0.65,0.97,1.46)	(0.82,1.10,1.37)	(0.98,0.98,0.98)	(2.50,3.00,3.50)	(4.47,4.97,5.47)	(1.44,1.92,2.40)	(2.11,2.53,2.95)
C_{33}	(1.27,1.69,2.11)	(0.77,0.77,0.77)	(5/2,3,7/2)	(0.97,0.97,0.97)	(0.56,0.84,1.25)	(1.23,1.64,2.04)	(2.50,3.00,3.50)	(4.34,4.83,5.31)	(3.48,3.97,4.47)	(1.02,1.35,1.69)
C_{34}	(2.28,2.73,3.19)	(2.30,2.62,2.95)	(9/2,5,11/2)	(2.08,2.49,2.91)	(1.37,1.64,1.92)	(1.82,2.19,2.55)	(2.50,3.00,3.50)	(3.38,3.86,4.34)	(1.36,1.81,2.26)	(1.69,2.03,2.37)
C_{41}	(1.02,1.35,1.69)	(2.26,2.71,3.16)	(9/2,5,11/2)	(3.26,3.73,4.20)	(1.37,1.64,1.92)	(0.90,1.21,1.51)	(2.50,3.00,3.50)	(3.38,3.86,4.34)	(2.26,2.72,3.17)	(1.16,1.55,1.94)
C_{42}	(3.19,3.64,4.10)	(2.26,2.71,3.16)	(7/2,4,9/2)	(1.25,1.66,2.08)	(0.56,0.84,1.25)	(3.44,3.93,4.42)	(3.50,4.00,4.50)	(3.30,3.77,4.24)	(1.40,1.87,2.33)	(1.69,2.03,2.37)
C_{43}	(1.16,1.55,1.94)	(0.34,0.51,0.76)	(9/2,5,11/2)	(2.08,2.49,2.91)	(1.25,1.67,2.09)	(1.34,1.79,2.34)	(2.50,3.00,3.50)	(4.47,4.97,5.47)	(1.40,1.87,2.33)	(0.98,0.98,0.98)
C_{44}	(1,1,1)	(0.31,0.42,0.52)	(7/2,4,9/2)	(1.15,1.53,1.92)	(0.82,1.10,1.37)	(0.98,0.98,0.98)	(1.50,2.00,2.50)	(3.21,3.67,4.13)	(1.44,1.92,2.40)	(1.37,1.82,2.28)
R	0.429	-0.143	1	0.556	0	0.333	1	0.778	0.75	0.429
DMs			**DM_3**					**DM_4**		
Alternatives	A1	A2	A3	A4	A5	A1	A2	A3	A4	A5
C_{11}	(1.54,1.85,2.16)	(2.12,2.54,2.96)	(1.50,2.00,2.50)	(0.45,0.52,0.58)	(1.91,2.29,2.67)	(1.17,1.41,1.64)	(3.59,3.99,4.39)	(1.49,1.98,2.48)	(4.41,4.90,5.39)	(3.41,3.90,4.39)
C_{12}	(1.12,1.49,1.87)	(1.18,1.57,1.97)	(4.50,5.00,5.50)	(1.68,1.93,2.17)	(2.33,2.80,3.26)	(0.70,0.94,1.17)	(0.86,1.15,1.44)	(3.19,3.65,4.10)	(1.97,2.36,2.76)	(1.77,2.12,2.47)
C_{13}	(2.14,2.57,2.99)	(0.80,1.07,1.34)	(2.50,3.00,3.50)	(0.27,0.41,0.62)	(1.25,1.66,2.08)	(1.80,2.16,2.52)	(0.64,0.73,0.82)	(3.47,3.97,4.46)	(0.98,0.98,0.98)	(0.15,0.22,0.34)
C_{14}	(1.12,1.49,1.87)	(1.34,1.61,1.87)	(4.50,5.00,5.50)	(1.96,2.24,2.52)	(1.14,1.53,1.91)	(3.80,4.22,4.64)	(1.72,2.07,2.41)	(3.32,3.79,4.27)	(4.41,4.90,5.39)	(2.09,2.51,2.93)
C_{15}	(1.54,1.85,2.16)	(1.18,1.57,1.97)	(4.50,5.00,5.50)	(1.20,1.44,1.68)	(2.21,2.65,3.09)	(0.91,1.22,1.52)	(1.57,1.79,2.01)	(3.90,3.31,3.73)	(2.19,2.63,3.07)	(0.82,1.10,1.37)
C_{21}	(0.98,0.98,0.98)	(1.03,1.37,1.71)	(4.50,5.00,5.50)	(0.56,0.56,0.56)	(2.33,2.80,3.26)	(0.84,0.84,0.84)	(0.27,0.37,0.46)	(2.28,2.74,3.19)	(1.32,1.75,2.19)	(2.47,2.83,3.18)
C_{22}	(2.14,2.57,2.99)	(1.27,1.69,2.12)	(2.50,3.00,3.50)	(1.96,2.24,2.52)	(1.32,1.77,2.21)	(1.64,1.88,2.11)	(0.46,0.55,0.64)	(3.19,3.65,4.10)	(1.87,2.14,2.41)	(1.25,1.67,2.09)
C_{23}	(0.98,1.18,1.38)	(4.41,4.90,5.39)	(3.50,4.00,4.50)	(0.56,0.56,0.56)	(1.25,1.66,2.08)	(3.80,4.22,4.64)	(1.44,1.73,2.02)	(4.46,4.96,5.45)	(0.58,0.88,1.32)	(0.56,0.83,1.25)
C_{24}	(0.98,1.18,1.38)	(2.96,3.39,3.81)	(1.50,2.00,2.50)	(0.79,0.95,1.11)	(0.99,0.99,0.99)	(2.52,2.88,3.24)	(1.72,2.07,2.41)	(1.42,1.90,2.37)	(2.19,2.63,3.07)	(1.77,2.12,2.47)
C_{25}	(0.57,0.86,1.28)	(1.18,1.57,1.97)	(4.50,5.00,5.50)	(1.03,1.23,1.44)	(2.33,2.80,3.26)	(0.70,0.94,1.17)	(1.04,1.38,1.72)	(4.46,4.96,5.45)	(1.97,2.36,2.76)	(0.65,0.97,1.46)
C_{26}	(0.92,1.23,1.54)	(3.43,3.92,4.41)	(1.50,2.00,2.50)	(1.20,1.44,1.68)	(0.99,0.99,0.99)	(0.70,0.94,1.17)	(1.12,1.34,1.57)	(2.19,2.63,3.07)	(1.18,1.57,1.97)	(0.34,0.45,0.60)
C_{31}	(4.40,4.89,5.37)	(1.03,1.37,1.71)	(4.50,5.00,5.50)	(0.56,0.56,0.56)	(1.14,1.53,1.91)	(1.52,1.82,2.13)	(0.27,0.37,0.46)	(3.19,3.65,4.10)	(4.41,4.90,5.39)	(1.37,1.64,1.92)
C_{32}	(1.12,1.49,1.87)	(0.98,0.98,0.98)	(2.50,3.00,3.50)	(0.19,0.26,0.32)	(2.08,2.49,2.91)	(0.91,1.22,1.52)	(1.72,2.07,2.41)	(4.46,4.96,5.45)	(1.03,1.37,1.71)	(1.25,1.67,2.09)
C_{33}	(2.14,2.57,2.99)	(0.98,0.98,0.98)	(3.50,4.00,4.50)	(0.56,0.56,0.56)	(1.32,1.77,2.21)	(0.70,0.94,1.17)	(1.72,2.07,2.41)	(4.46,4.96,5.45)	(0.98,0.98,0.98)	(0.82,1.10,1.37)
C_{34}	(1.28,1.71,2.14)	(1.97,2.36,2.76)	(4.50,5.00,5.50)	(1.68,1.93,2.17)	(1.25,1.66,2.08)	(0.91,1.22,1.52)	(1.12,1.34,1.57)	(4.46,4.96,5.45)	(4.41,4.90,5.39)	(1.77,2.12,2.47)
C_{41}	(0.98,0.98,0.98)	(2.12,2.54,2.96)	(4.50,5.00,5.50)	(1.03,1.23,1.44)	(1.32,1.77,2.21)	(0.84,0.84,0.84)	(2.79,3.19,3.59)	(1.42,1.90,2.37)	(0.98,0.98,0.98)	(1.06,1.41,1.77)

C_{42}	(0.92,1.23,1.54)	(0.98,0.98,0.98)	(2.50,3.00,3.50)	(0.72,0.96,1.20)	(1.32,1.77,2.21)	(1.17,1.41,1.64)	(1.12,1.34,1.57)	(2.07,2.49,2.90)	(1.18,1.57,1.97)	(0.82,1.10,1.37)
C_{43}	(0.98,1.18,1.38)	(1.03,1.37,1.71)	(4.50,5.00,5.50)	(1.20,1.44,1.68)	(0.99,0.99,0.99)	(0.70,0.94,1.17)	(1.44,1.73,2.02)	(3.19,3.65,4.10)	(1.34,1.61,1.87)	(0.56,0.67,0.78)
C_{44}	(0.98,0.98,0.98)	(1.97,2.36,2.76)	(4.50,5.00,5.50)	(0.56,0.56,0.56)	(1.40,1.87,2.33)	(0.48,0.72,1.08)	(1.44,1.73,2.02)	(4.46,4.96,5.45)	(1.32,1.75,2.19)	(0.65,0.97,1.46)
R	0.111	0.25	1	-0.667	0.556	-0.25	-0.333	0.667	0.25	0

Table B4 – Normalized aggregated Z^E-numbers decision matrix.

Criteria\ Alternatives	A1	A2	A3	A4	A5
C_{11}	(0.43,0.49,0.57)	(0.39,0.46,0.55)	(0.56,0.73,1.00)	(0.41,0.46,0.52)	(0.45,0.54,0.67)
C_{12}	(0.19,0.24,0.29)	(0.17,0.23,0.30)	(0.81,0.90,1.00)	(0.43,0.50,0.57)	(0.44,0.52,0.60)
C_{13}	(0.45,0.53,0.62)	(0.24,0.30,0.36)	(0.77,0.88,1.00)	(0.16,0.18,0.19)	(0.13,0.19,0.26)
C_{14}	(0.65,0.76,0.86)	(0.35,0.43,0.51)	(0.79,0.89,1.00)	(0.31,0.37,0.43)	(0.31,0.38,0.44)
C_{15}	(0.27,0.35,0.43)	(0.22,0.28,0.34)	(0.78,0.89,1.00)	(0.42,0.50,0.58)	(0.17,0.24,0.32)
C_{21}	(0.19,0.19,0.19)	(0.19,0.25,0.30)	(0.79,0.90,1.00)	(0.26,0.32,0.37)	(0.26,0.32,0.38)
C_{22}	(0.49,0.57,0.65)	(0.25,0.30,0.35)	(0.76,0.88,1.00)	(0.60,0.69,0.78)	(0.24,0.31,0.38)
C_{23}	(0.55,0.63,0.70)	(0.35,0.41,0.47)	(0.80,0.90,1.00)	(0.17,0.20,0.23)	(0.16,0.23,0.32)
C_{24}	(0.54,0.62,0.74)	(0.33,0.38,0.43)	(0.48,0.59,0.76)	(0.44,0.50,0.59)	(0.81,0.89,1.00)
C_{25}	(0.15,0.28,0.38)	(0.32,0.42,0.53)	(0.81,0.90,1.00)	(0.40,0.47,0.55)	(0.18,0.23,0.30)
C_{26}	(0.68,0.83,0.97)	(0.73,0.86,1.00)	(0.59,.077,0.94)	(0.30,0.41,0.56)	(0.27,0.29,0.31)
C_{31}	(0.40,0.49,0.57)	(0.16,0.20,0.24)	(0.80,0.90,1.00)	(0.39,0.44,0.49)	(0.39,0.48,0.56)
C_{32}	(0.24,0.29,0.34)	(0.29,0.34,0.39)	(0.78,0.89,1.00)	(0.14,0.19,0.25)	(0.31,0.40,0.48)
C_{33}	(027,0.35,0.43)	(0.29,0.32,0.34)	(0.78,0.89,1.00)	(0.25,0.26,0.27)	(0.19,0.26,0.34)
C_{34}	(0.29,0.36,0.44)	(0.37,0.43,0.50)	(0.81,0.91,1.00)	(0.41,0.50,0.57)	(0.29,0.36,0.43)
C_{41}	(0.22,0.26,0.29)	(0.57,0.68,0.78)	(0.75,0.88,1.00)	(0.39,0.45,0.50)	(0.29,0.38,0.46)
C_{42}	(0.50,0.60,0.70)	(0.46,0.52,0.58)	(0.75,0.87,1.00)	(0.29,0.39,0.49)	(0.27,0.36,0.46)
C_{43}	(0.20,0.26,0.32)	(0.21,0.27,0.34)	(0.81,0.90,1.00)	(0.29,.035,0.42)	(0.18,0.20,0.22)
C_{44}	(0.17,0.19,0.21)	(0.22,0.28,0.34)	(0.80,0.90,1.00)	(0.22,0.27,0.32)	(0.21,0.28,0.37)

Table B5 – $S_{i_{(Z^E)}}$ values.

Criteria\ Alternatives	A1	A2	A3	A4	A5
C_{11}	(0.032,0.045,0.063)	(0.029,0.042,0.061)	(0.041,0.067,0.111)	(0.030,0.042,0.058)	(0.033,0.050,0.074)
C_{12}	(0.014,0.022,0.031)	(0.012,0.021,0.032)	(0.058,0.082,0.108)	(0.031,0.045,0.062)	(0.032,0.047,0.065)
C_{13}	(0.013,0.018,0.023)	(0.072,0.102,0.130)	(0.023,0.030,0.037)	(0.005,0.006,0.007)	(0.004,0.006,0.010)
C_{14}	(0.023,0.030,0.034)	(0.012,0.017,0.020)	(0.028,0.035,0.040)	(0.011,0.014,0.017)	(0.011,0.015,0.018)
C_{15}	(0.029,0.052,0.074)	(0.024,0.042,0.059)	(0.085,0.133,0.173)	(0.046,0.074,0.100)	(0.019,0.036,0.055)
C_{21}	(0.006,0.008,0.009)	(0.006,0.010,0.014)	(0.023,0.037,0.048)	(0.008,0.013,0.018)	(0.008,0.013,0.018)
C_{22}	(0.011,0.017,0.023)	(0.006,0.009,0.012)	(0.017,0.026,0.035)	(0.014,0.020,0.027)	(0.006,0.009,0.013)
C_{23}	(0.012,0.014,0.036)	(0.007,0.009,0.024)	(0.017,0.021,0.051)	(0.004,0.005,0.012)	(0.003,0.005,0.016)
C_{24}	(0.024,0.036,0.047)	(0.015,0.022,0.028)	(0.021,0.034,0.049)	(0.019,0.029,0.038)	(0.036,0.052,0.064)
C_{25}	(0.004,0.010,0.016)	(0.008,0.014,0.023)	(0.019,0.031,0.043)	(0.001,0.016,0.024)	(0.004,0.008,0.013)
C_{26}	(0.009,0.014,0.018)	(0.009,0.015,0.019)	(0.008,0.013,0.002)	(0.004,0.007,0.011)	(0.004,0.005,0.006)
C_{31}	(0.008,0.011,0.013)	(0.003,0.005,0.006)	(0.017,0.021,0.023)	(0.008,0.010,0.011)	(0.008,0.011,0.013)
C_{32}	(0.002,0.003,0.004)	(0.003,0.004,0.005)	(0.007,0.010,0.012)	(0.001,0.002,0.003)	(0.003,0.004,0.006)
C_{33}	(0.011,0.015,0.019)	(0.012,0.014,0.015)	(0.031,0.039,0.045)	(0.010,0.011,0.012)	(0.008,0.011,0.015)
C_{34}	(0.003,0.005,0.007)	(0.004,0.006,0.008)	(0.010,0.013,0.015)	(0.005,0.007,0.009)	(0.003,0.005,0.006)
C_{41}	(0.026,0.036,0.048)	(0.067,0.100,0.128)	(0.088,0.123,0.164)	(0.046,0.063,0.082)	(0.034,0.053,0.075)
C_{42}	(0.027,0.042,0.063)	(0.024,0.036,0.052)	(0.040,0.061,0.090)	(0.015,0.027,0.044)	(0.014,0.025,0.041)
C_{43}	(0.011,0.016,0.022)	(0.011,0.017,0.023)	(0.043,0.057,0.068)	(0.015,0.022,0.029)	(0.010,0.013,0.015)
C_{44}	(0.005,0.007,0.009)	(0.006,0.010,0.014)	(0.023,0.031,0.042)	(0.006,0.009,0.013)	(0.006,0.010,0.016)
$S_{i_{(Z^E)}}$	**(0.270,0.401,0.559)**	**(0.330,0.495,0.673)**	**(0.599,0.864,1.156)**	**(0.279,0.395,0.577)**	**(0.246,0.378,0.530)**

Table B6 - $P_{i_{(Z^E)}}$ values.

Criteria\ Alternatives	A1	A2	A3	A4	A5
C_{11}	(0.911,0.936,0.959)	(0.901,0.931,0.957)	(0.938,0.971,1.000)	(0.906,0.931,0.953)	(0.915,0.945,0.971)
C_{12}	(0.836,0.878,0.915)	(0.826,0.875,0.917)	(0.977,0.990,1.000)	(0.913,0.939,0.960	(0.915,0.942,0.964)
C_{13}	(0.971,0.979,0.986)	(0.949,0.960,0.970)	(0.990,0.996,1.000)	(0.934,0.943,0.951)	(0.927,0.945,0.960)
C_{14}	(0.983,0.989,0.995)	(0.959,0.968,0.977)	(0.991,0.995,1.000)	(0.954,0.962,0.971)	(0.954,0.963,0.972)
C_{15}	(0.797,0.855,0.912)	(0.770,0.827,0.889)	(0.958,0.983,1.000)	(0.861,0.902,0.942)	(0.736,0.808,0.883)
C_{21}	(0.923,0.934,0.953)	(0.923,0.945,0.966)	(0.989,0.996,1.000)	(0.937,0.954,0.972)	(0.937,0.954,0.972)
C_{22}	(0.975,0.984,0.990)	(0.953,0.966,0.976)	(0.990,0.996,1.000)	(0.982,0.989,0.994)	(0.951,0.967,0.978)
C_{23}	(0.970,0.989,0.993)	(0.948,0.980,0.984)	(0.989,0.998,1.000)	(0.914,0.964,0.970)	(0.911,0.967,0.976)
C_{24}	(0.961,0.973,0.987)	(0.932,0.945,0.964)	(0.954,0.970,0.988)	(0.949,0.961,0.977)	(0.987,0.993,1.000)
C_{25}	(0.922,0.958,0.977)	(0.952,0.971,0.985)	(0.991,0.996,1.000)	(0.961,0.975,0.986)	(0.929,0.951,0.972)
C_{26}	(0.993,0.997,1.000)	(0.994,0.997,1.000)	(0.990,0.996,0.999)	(0.977,0.985,0.992)	(0.975,0.979,0.985)
C_{31}	(0.979,0.984,0.988)	(0.959,0.964,0.970)	(0.995,0.998,1.000)	(0.979,0.981,0.985)	(0.979,0.983,0.988)
C_{32}	(0.983,0.986,0.990)	(0.985,0.988,0.992)	(0.997,0.999,1.000)	(0.977,0.982,0.988)	(0.986,0.990,0.993)
C_{33}	(0.943,0.955,0.967)	(0.946,0.951,0.958)	(0.989,0.995,1.000)	(0.940,0.942,0.949)	(0.928,0.942,0.958)
C_{34}	(0.982,0.986,0.990)	(0.985,0.988,0.992)	(0.997,0.999,1.000)	(0.987,0.990,0.993)	(0.982,0.986,0.990)
C_{41}	(0.780,0.828,0.864)	(0.912,0.947,0.971)	(0.954,0.982,1.000)	(0.857,0.894,0.921)	(0.816,0.873,0.912)
C_{42}	(0.940,0.965,0.981)	(0.932,0.955,0.972)	(0.974,0.990,1.000)	(0.895,0.936,0.963)	(0.889,0.931,0.960)
C_{43}	(0.896,0.919,0.941)	(0.899,0.921,0.944)	(0.986,0.993,1.000)	(0.919,0.936,0.955)	(0.890,0.904,0.923)
C_{44}	(0.928,0.944,0.956)	(0.938,0.956,0.969)	(0.991,0.996,1.000)	(0.938,0.955,0.967)	(0.937,0.956,0.972)
$P_{i_{(Z^E)}}$	**(17.673,18.039,18.344)**	**(17.663,18.035,18.353)**	**(18.640,18.839,18.987)**	**(17.78,18.121,18.389)**	**(17.544,17.979,18.329)**