https://doi.org/10.1016/j.jclepro.2017.10.184

Waste-to-Energy, Municipal Solid Waste Treatment, and Best Available Technology: Comprehensive Evaluation by An Interval-valued Fuzzy Multi-Criteria Decision Making Method

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Abstract: The treatment of municipal solid waste (MSW) has become an urgently important task of many countries. This objective of this study is to present a novel group multi-attribute decision analysis method for prioritizing the MSW treatment alternatives based on the interval-valued fuzzy set theory. This study allows multiple stakeholders to participate in the process of decision-making and they are also allowed to use linguistic variables to rate the alternatives and determine the weights of the evaluation criteria. The interval-valued fuzzy group decision making trail and evaluation laboratory (DEMATEL) method was developed to determine the weights of the evaluation criteria by considering the independent relationships among these criteria. The multi-actor interval-valued fuzzy grey relational analysis was developed to rank the waste-to-energy scenarios. Four alternative processes for MSW treatment including landfill, anaerobic digestion, incineration, and gasification were studied by the developed model, and the results reveal that the developed model can successfully help the stakeholders to determine the priority sequence of the alternative MSW treatment scenarios.

Keywords: municipal solid waste; multi-criteria decision making; interval-valued fuzzy set; interval-valued fuzzy decision making trail and evaluation laboratory; interval-valued fuzzy grey relational analysis

1. Introduction

The treatment of municipal solid waste (MSW) has become an urgent social problem in China with its rapid urbanization, economy prosperity, and sharply increase of population, because the untreated MSW accounts to 7 billion tons over the years and one-third of China's cities have face various challenges of MSW treatment (Zhao *et al.*, 2016). The treatment of MSW is complicated due to its variable composition which is determined by the local demographic and the life habits of the local residents (Nixon *et al.*, 2013). Solid waste management usually involved various technologies for waste reduction, reuse, recycling and recovery. Waste-to-energy has attracted more and more attentions recently. For instance, anaerobic digestion process can produce biogas through this treatment technology; incineration can recover electricity and heat; gasification can generate syngas from MSW combustion (Xiong *et al.*, 2016). There are also some other MSW treatment solutions, i.e. land fill, composting, pyrolysis, and fertilization, etc. (Singh *et al.*, 2011). These alternative solutions for MSW treatment perform different in economic, environmental and social aspects, thus, the stakeholders are usually puzzled when selecting the scenario for MSW treatment. Moreover, there are usually involving various different stakeholders, i.e. local residents, administrator, engineers, scholars, and environmentalists, etc. Therefore, the selection of the best or the most sustainable scenario for MSW treatment is a multi-criteria decision making (MCDM) problem and requires the participation of multiple stakeholders for a trade-off solution.

The selection of MSW treatment scenario is a complex, multi-dimensional, and multi-stakeholder problem. There are usually various MCDM methods about the selection of MSW treatment process. Soltani *et al.* (2016) employed the life cycle sustainability assessment method for comparing the economic, environmental and social impacts of different solutions for MSW treatment, a weighted approach was developed to aggregate the impacts based on the willingness/preferences of the stakeholders, and game theory method was used to achieve an agreement on a mutually sustainable and pragmatic solution. Woon (2015) used life cycle environmental assessment (LCA) and life cycle cost analysis (LCC) to investigate the MSW management options in Hong Kong. Yap and Nixon (2015) used the AHP (Analytic Hierarchy Process) as the decision-making model to assess the trade-offs between the benefits, opportunities, costs and risks of the alternative technologies for energy recovery from MSW. Liu *et al*. (2015) developed a novel hybrid multi-criteria decision making (MCDM) model by integrating the 2-tuple DEMATEL technique and fuzzy multi-objective optimization by ratio analysis (MOORA) method for selection of health-care waste (HCW) treatment alternatives. Mir *et al*. (2016) extended the TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method for selecting the best MSW treatment scenario through comparisons, and Viekriterijumsko Kompromisno Rangiranje (VIKOR) method which can determine the compromise solution for the decision-makers was employed to validate the results determined by TOPSIS. Lu *et al.* (2016) developed a hybrid decision making approach combining interval 2-tuple induced distance operators with the technique for order preference by similarity to an ideal solution (TOPSIS) for tackling HCW treatment technology selection problems with linguistic information. Menikpura *et al*. (2016) used net greenhouse gas emissions, net fossil resource consumption and net life cycle cost to compare the performances of landfill gas to energy and incineration. Rahman *et al*. (2017) used the AHP model to select the most appropriate waste-to-energy conversion technology for Dhaka city of Bangladesh, and three alternative scenarios including anaerobic digestion, pyrolysis, and plasma gasification were prioritized by considering technological, environmental and financial aspects. Shi et al. (2017) develop an integrated decision making framework based on cloud model and multi-attribute border approximation area comparison (MABAC) method for evaluating and selecting the best HCW treatment technology from a multiple stakeholder perspective, and the opinions of different stakeholders were incorporate in the decision-making process. These methods compared different MSW treatment technologies by considering multiple evaluation criteria for helping the users to select the most suitable or the best scenario among multiple MSW treatment solutions. However, there are still some research and practice gaps to be filled:

(1) The lack of the considerations of the independent relationships among the evaluation criteria: all these most neglect the independent relationships among the evaluation criteria; however, the hypothesis that all these evaluation criteria are independent does not match the actual conditions;
(2) The serious uncertainties in the determination of the decision-making matrix: the data of the alternatives with respect to some evaluation criteria cannot be determined directly due to the lack of information/knowledge. In addition, there are also various types of uncertainty or imprecise information existing in the decision-making process;
(3) The lack of trade-off evaluation: the evaluation of alternative MSW treatment scenarios usually involves multiple groups of stakeholders and considerations of different opinions for a trade-off decision-making is of vital importance.

In order to fill the above-mentioned three gaps, there are also some studies which developed some multi-criteria decision making methods by incorporating the interdependences and interactions among the evaluation as well as the uncertainties. For instance, Ozcan and Tuysuz (2016) used the DEMATEL method in which the interacted complex relationships among the evaluation criteria can be considered to determine the weights of the evaluation criteria, and the modified grey relational analysis (GRA) method was employed to rank the alternatives. Chen and Chen (2012), and Tzeng and Huang (2012) combined DEMATEL and Analytic Network Process (ANP) to determine the relative of the evaluation used in multi-criteria decision-making, and the problem of feedback and dependences among the evaluation criteria can also be incorporated. All these methods are beneficial for multi-criteria decision making with the considerations of all the dependences and interactions among the evaluation criteria. However, to the best of our knowledge, there are not any studies which can successfully address the above-mentioned three gaps simultaneously. For instance, although these previous studies can consider the dependences and interactions among the evaluation criteria, the uncertainties in the determination of the decision-making matrix and the involvement of multiple groups of decision-makers/stakeholders cannot be addressed.

In order to address the above-mentioned three gaps simultaneously, this study aims at developing an interval-valued fuzzy group multi-criteria decision-making method (IVFNCDM) method for ranking the alternative MSW treatment scenarios, and the developed method has the following four innovations:

(1) The complex independent relationships among the evaluation criteria have been incorporated when determining the weights of these criteria by employing the developed interval-valued fuzzy DEMATEL (decision making trail and evaluation laboratory) method, and the weights of the evaluation were determined with the considerations of the interdependences and interactions among these evaluation criteria;
(2) The interval-valued fuzzy set (IVFS) theory which can handle uncertainties in the decision-making process has been combined with the grey relational analysis method for ranking the alternative MSW treatment scenarios, and the IVFS theory has better performance than the traditional fuzzy set theory for addressing uncertainties and imprecise information due to the ambiguity and vagueness existing in human judgments;
(3) The evaluation and ranking of the MSW scenarios based on the proposed multi-criteria decision making method does not need the exact data of the alternative MSW scenarios with respect to the evaluation criteria, and the stakeholders/decision-makers are allowed to use

the linguistic variables which correspond to the interval-valued fuzzy numbers to rate the alternative MSW scenarios with respect to each of the evaluation criteria;

(4) The opinions and preferences of different groups of stakeholders/decision-makers can be incorporated in the process of decision-making, and the weights of the evaluation determined based on the opinions/preferences of different stakeholders/decision-makers were used simultaneously in the decision-making.'

An illustrative case including four scenarios for MSW treatment has been studied by the developed interval-valued fuzzy group multi-criteria decision-making method, anaerobic digestion was recognized as the best scenario for MSW treatment among these four alternative MSW treatment scenarios, followed by gasification, incineration, and landfill in the descending order.

Besides the introduction, the remainder of this study has been organized as follows: the methods developed in this study were presented in section 2; an illustrative case was studied by the developed interval-valued fuzzy group multi-criteria decision-making method in section 3; the results of this study were discussed in section 4; finally, this study has been concluded in section 5.

2. Methods

The traditional fuzzy set theory cannot enable the decision-makers to accurately describe their opinions by merely using a single number in interval [0 1], while it is more accurate to use an interval number rather than a crisp value to represent the uncertainty (Ashtiani *et al*., 2009). The representation of linguistic terms in the format of IVFS is more suitable than the form of the traditional fuzzy numbers (Cornelis *et al*., 2006). Therefore, the multi-criteria decision making methods based on the IVFS theory can effectively handle the uncertainties in decision-making process.

In this part, the IVFS theory was firstly introduced; then, the multi-actor interval-valued fuzzy DEMATEL was developed for determining the relative importance (weights) of the evaluation metrics/criteria with the considerations of the independent relationships among these criteria; finally, the multi-actor interval-valued fuzzy grey relational analysis was proposed for ranking the alternative MSW treatment scenarios.

2.1 IVFS

The IVFS defined on $(-\infty,+\infty)$ are given by (Gorzałczany, 1987):

$$\begin{aligned}
&A=\left\{\left(x,\left[\mu_A^L(x),\mu_A^U(x)\right]\right)\right\}\\
&\mu_A^L(x),\mu_A^U(x):X\rightarrow[0,1] \qquad \forall x\in X \quad \mu_A^L(x)\le\mu_A^U(x)\\
&\bar{\mu}_A(x)=\left[\mu_A^L(x),\mu_A^U(x)\right]\\
&A=\left\{\left(x,\bar{\mu}_A(x)\right)\right\},x\in(-\infty,+\infty)
\end{aligned} \tag{1}$$

where $\mu_A^L(x)$ and $\mu_A^U(x)$ are the lower limit and upper limit of the membership degrees.

Suppose $\tilde{a}=\left[(a_1,a_1');a_2;(a_3',a_3)\right]$ (as illustrated in Figure 1) and $\tilde{b}=\left[(b_1,b_1');b_2;(b_3',b_3)\right]$ are two IVFNs, and ν is a positive crisp number,

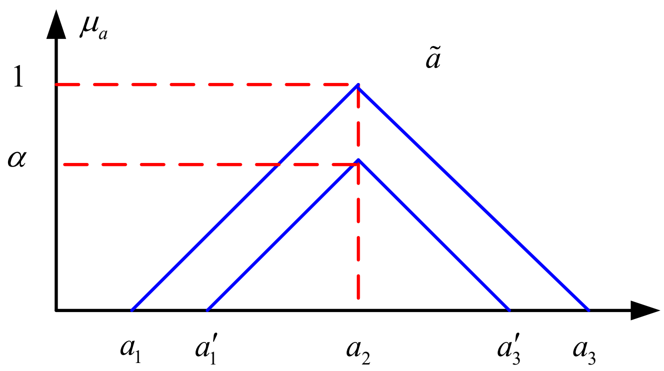

Figure 1: Interval-valued fuzzy set

The arithmetic operations are:

(1) Multiplication between a positive non-fuzzy number and an interval-valued fuzzy number (IVFN) (Kuo, 2011)

$$\nu \cdot \tilde{a} = \left[\left(\nu a_1, \nu a_1'\right); \nu a_2; \left(\nu a_3', \nu a_3\right)\right] \quad (2)$$

(2) Addition between two IVFNs (Kuo, 2011)

$$\tilde{a} + \tilde{b} = \left[\left(a_1, a_1'\right); a_2; \left(a_3', a_3\right)\right] + \left[\left(b_1, b_1'\right); b_2; \left(b_3', b_3\right)\right] = \left[\left(a_1 + b_1, a_1' + b_1'\right); a_2 + b_2; \left(a_3' + b_3', a_3 + b_3\right)\right] \quad (3)$$

(3) Subtraction between two IVFNs (Kuo, 2011)

$$\tilde{a} - \tilde{b} = \left[\left(a_1, a_1'\right); a_2; \left(a_3', a_3\right)\right] - \left[\left(b_1, b_1'\right); b_2; \left(b_3', b_3\right)\right] = \left[\left(a_1 - b_3, a_1' - b_3'\right); a_2 - b_2; \left(a_3' - b_1', a_3 - b_1\right)\right] \quad (4)$$

(4) Multiplication between two IVFNs (Kuo, 2011)

$$\tilde{a} \times \tilde{b} = \left[\left(a_1, a_1'\right); a_2; \left(a_3', a_3\right)\right] \times \left[\left(b_1, b_1'\right); b_2; \left(b_3', b_3\right)\right] = \left[\left(a_1 b_1, a_1' b_1'\right); a_2 b_2; \left(a_3' b_3', a_3 b_3\right)\right] \quad (5)$$

(5) Division between two IVFNs (Kuo, 2011)

$$\tilde{a} \div \tilde{b} = \left[\left(a_1, a_1'\right); a_2; \left(a_3', a_3\right)\right] \div \left[\left(b_1, b_1'\right); b_2; \left(b_3', b_3\right)\right] = \left[\left(a_1 / b_3, a_1' / b_3'\right); a_2 / b_2; \left(a_3' / b_1', a_3 / b_1\right)\right] \quad (6)$$

(6) Reciprocal of the IVFN

$$\tilde{a}^{-1} = \left[\left(\frac{1}{a_3}, \frac{1}{a_3'}\right); \frac{1}{a_2}; \left(\frac{1}{a_1'}, \frac{1}{a_1}\right)\right] \quad (7)$$

(7) Exponentiation

$$\left(\tilde{a}\right)^n = \left[\left(\left(a_1\right)^n, \left(a_1'\right)^n\right); \left(a_2\right)^n; \left(\left(a_3'\right)^n, \left(a_3\right)^n\right)\right] \quad (8)$$

(8) Defuzzification (Vahdani *et al.*, 2013)

The defuzzied numbers of $\tilde{a} = \left[\left(a_1, a_1' \right); a_2; \left(a_3', a_3 \right) \right]$ and $\tilde{b} = \left[\left(b_1, b_1' \right); b_2; \left(b_3', b_3 \right) \right]$ are:

$$h\left(\tilde{a}\right) = \frac{a_1 + a' + 2a_2 + a_3' + a_3}{6} \tag{9}$$

and

$$h\left(\tilde{b}\right) = \frac{b_1 + b + 2b_2 + b_3 + b_3}{6} \tag{10}$$

$\tilde{a}$ is greater than $\tilde{b}$, $\tilde{a} \succ \tilde{b}$ if $h\left(\tilde{a}\right) \succ h\left(\tilde{b}\right)$.

2.2 Interval-valued fuzzy DEMATEL

The interval-valued fuzzy DEMATEL was developed to determine the weights of the criteria for the evaluation of waste-to-energy scenarios, and it is derived from the traditional DEMATEL method which can incorporate the interdependences and interactions among the criteria (Song *et al.*, 2017). The proposed interval-valued fuzzy DEMATEL was specified as follows based on the previous works (Gabus and Fontela, 1973; Fontela and Gabus, 1976; Si *et al.*, 2017):

(1) Establishing the direct-influenced matrices (DIM) using linguistic variables.

(2) Weighted direct-influenced matrix determination.

(3) Normalization.

(4) Calculating the total relation matrix (TRM).

(5) Determining the relative importance of these factors.

Step 1: Establishing the direct-influenced matrices using linguistic variables. The objective of this step is to determine the relative degree of one factor affecting another by using the linguistic variables as presented in Table 1, and the linguistic terms can also be transformed into interval-based fuzzy numbers. The participants are asked to evaluate the effect of a factor on another factor using an interval-based fuzzy number which corresponds to a linguistic term. For instance, if the participants think that the relative effect of one factor on another factor is “very low influence (VL)”, denoted by [(0,1);1;(3,4)].

Table 1: The linguistic variables and corresponding IVFNs

Linguistic terms	Abbreviation	Interval-based fuzzy numbers
No influence	N	[(0,0);0;(0,0)]
Very low influence	VL	[(1.0,1.5);2.0;(2.5,3.0)]
Low influence	L	[(2.0,2.5);3.0;(3.5,4.0)]
Medium influence	M	[(3.0,3.5);4.0;(4.5,5.0)]
High influence	H	[(4.0,4.5);5.0;(5.5,6.0)]
Very high influence	VH	[(5.0,5.5);6.0;(6.5,7.0)]

Assuming there are a total of H participants and n factors to be considered in this complex system. Denotes the influence of the *i*-th factor on the *j*-th factor determined by the *k*-th participant by $\tilde{x}_{ij}^{k}$, and it is an interval-based fuzzy number. The results provided by the *k*-th participant can form a n×n matrix, as presented in Eq.11-12.

$$\tilde{X}^{k}=\begin{bmatrix} (0,0);0;(0,0) & \tilde{x}_{12}^{k} & \cdots & \tilde{x}_{1n}^{k} \\ \tilde{x}_{21}^{k} & (0,0);0;(0,0) & \cdots & \tilde{x}_{2n}^{k} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{n1}^{k} & \tilde{x}_{n2}^{k} & & (0,0);0;(0,0) \end{bmatrix}, k=1,2,\cdots,H \tag{11}$$

$$\tilde{x}_{ij}^{k}=\left[\left(x_{ij,k}^{1},x_{ij,k}^{\prime 1}\right);x_{ij,k}^{2};\left(x_{ij,k}^{\prime 3},x_{ij,k}^{3}\right)\right] \tag{12}$$

where $\tilde{X}^{k}$ represents the DIM determined by the k-th expert.

Step 2: Determining the weighted DIM. The weighted DIM, so-called "initial direct-relation matrix", could be calculated by Eq.13.

$$\tilde{A}=\left[\tilde{a}_{ij}\right]_{n\times n}=\begin{bmatrix}(0,0);0;(0,0) & \tilde{a}_{12} & \cdots & \tilde{a}_{1n}\\ \tilde{a}_{21} & (0,0);0;(0,0) & \cdots & \tilde{a}_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ \tilde{a}_{n1} & \tilde{a}_{n2} & & (0,0);0;(0,0)\end{bmatrix} \tag{13}$$

However, it is worth pointing out that there are H participants who represent different stakeholders, and the relative importance of their roles is different. Therefore, the weighted direct-influenced matrix should be determined by incorporating the relative importance of the roles of the stakeholders. According to the multiplication law between a positive non-fuzzy number and an IVFN, all the elements in the matrix $\tilde{A}$ can be calculated. Note that, if the relative importance of their roles is equal, and Eq.14 can be transformed into Eq.15 which is the arithmetic mean of the 2-tuples provided by the H experts in Step 1.

$$\tilde{a}_{ij}=\sum_{k=1}^{H}\tilde{\omega}_k\tilde{x}_{ij}^{k}=\sum_{k=1}^{H}\tilde{\omega}_k\left[\left(x_{ij,k}^{1},x_{ij,k}^{\prime 1}\right);x_{ij,k}^{2};\left(x_{ij,k}^{\prime 3},x_{ij,k}^{3}\right)\right]=\sum_{k=1}^{H}\left[\left(\lambda_k^{1}x_{ij,k}^{1},\lambda_k^{\prime 1}x_{ij,k}^{\prime 1}\right);\lambda_k^{2}x_{ij,k}^{2};\left(\lambda_k^{\prime 3}x_{ij,k}^{\prime 3},\lambda_k^{3}x_{ij,k}^{3}\right)\right] \tag{14}$$

$$\tilde{a}_{ij}=\sum_{k=1}^{H}\frac{1}{H}\tilde{x}_{ij}^{k}=\sum_{k=1}^{H}\frac{1}{H}\left[\left(x_{ij,k}^{1},x_{ij,k}^{\prime 1}\right);x_{ij,k}^{2};\left(x_{ij,k}^{\prime 3},x_{ij,k}^{3}\right)\right]=\sum_{k=1}^{H}\left[\left(\frac{1}{H}x_{ij,k}^{1},\frac{1}{H}x_{ij,k}^{\prime 1}\right);\frac{1}{H}x_{ij,k}^{2};\left(\frac{1}{H}x_{ij,k}^{\prime 3},\frac{1}{H}x_{ij,k}^{3}\right)\right] \tag{15}$$

where $\tilde{A}$ is the average matrix, $\tilde{a}_{ij}=\left[\left(a_{ij}^{1},a_{ij}^{\prime 1}\right);a_{ij}^{2};\left(a_{ij}^{\prime 3},a_{ij}^{3}\right)\right]$ is an interval-based fuzzy number, and $\tilde{\lambda}_k=\left[\left(\lambda_k^{1},\lambda_k^{\prime 1}\right);\lambda_k^{2};\left(\lambda_k^{\prime 3},\lambda_k^{3}\right)\right]$ is the weight of the *k*-th participant.

In this step, the relative importance of these participants can be determined by the interval-based fuzzy AHP method, and this method consists of three steps based on the interval-valued fuzzy number (Hsieh et al., 2004; Chou et al., 2012):

Sub-Step 1: Comparison matrix determination by using linguistic variables. The decision-makers determine the pair-wise comparison matrix by using the linguistic variables presented in Table 2.

Table 2: Linguistic variables and corresponding IVFNs

Linguistic variables	Abbreviation	IVFNs
Equal Importance (E)	$\tilde{1}$	[(1.0,1.0);1.0;(1.0,1.0)]
Weak importance (W)	$\tilde{2}$	[(1.0,1.5);2.0;(2.5,3.0)]
Low importance (L)	$\tilde{3}$	[(2.0,2.5);3.0;(3.5,4.0)]
Moderate importance (M)	$\tilde{4}$	[(3.0,3.5);4.0;(4.5,5.0)]
High importance (H)	$\tilde{5}$	[(4.0,4.5);5.0;(5.5,6.0)]
Significant importance (S)	$\tilde{6}$	[(5.0,5.5);6.0;(6.5,7.0)]
Reciprocals of above-mentioned variables (RE,RW,RL,RM,RH, and RS)		

Sub-Step 2: Obtaining the pair-wise comparison matrix by using the IVFNs. All the linguistic variables in the pair-wise comparison matrix can be substituted by using IVFNs according to Table 2. Then, the pair-wise comparison matrix composed by the IVFNs could be obtained, as presented Eq. 16.

$$\tilde{A} = \begin{vmatrix} \tilde{1} & \tilde{m}_{12} & \cdots & \tilde{m}_{1n} \\ \tilde{m}_{21} & \tilde{1} & \cdots & \tilde{m}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{m}_{n1} & \tilde{m}_{n2} & \cdots & \tilde{1} \end{vmatrix} = \begin{vmatrix} \tilde{1} & \tilde{m}_{12} & \cdots & \tilde{m}_{1n} \\ 1/\tilde{m}_{12} & \tilde{1} & \cdots & \tilde{m}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{m}_{n1} & 1/\tilde{m}_{2n} & \cdots & \tilde{1} \end{vmatrix} \tag{16}$$

where $\tilde{m}_{ij} = \left[\left(m_{ij}^{1}, m_{ij}^{\prime 1}\right); m_{ij}^{2}; \left(m_{ij}^{\prime 3}, m_{ij}^{3}\right)\right]$ represents the relative importance of the *i*-th stakeholder over the *j*-th stakeholder

Sub-Step 3: Fuzzy weights calculation. The interval-valued fuzzy geometric mean and interval-valued fuzzy weight of each stakeholder can be determined by extending the geometric mean technique developed by Buckley (1985) , as presented inEq.17 and Eq.18.

$$\tilde{r}_j = \left(\tilde{m}_{j1} \times \tilde{m}_{j2} \cdots \times \tilde{m}_{jn}\right)^{1/n}$$
$$= \left[\left(\left(\prod_{k=1}^{n} m_{jk}^{1}\right)^{\frac{1}{n}}, \left(\prod_{k=1}^{n} m_{jk}'^{1}\right)^{\frac{1}{n}}\right); \left(\prod_{k=1}^{n} m_{jk}^{2}\right)^{\frac{1}{n}}; \left(\left(\prod_{k=1}^{n} m_{jk}'^{3}\right)^{\frac{1}{n}}, \left(\prod_{k=1}^{n} m_{jk}^{3}\right)^{\frac{1}{n}}\right)\right] \tag{17}$$

$$\tilde{\lambda}_k = \tilde{r}_k \times \left(\tilde{r}_1 + \tilde{r}_2 + \cdots + \tilde{r}_n\right)^{-1}$$
$$= \left[\left(\frac{r_k^1}{\sum_{j=1}^{n} r_j^3}, \frac{r_k'^1}{\sum_{j=1}^{n} r_j'^3}\right); \frac{r_k^2}{\sum_{j=1}^{n} r_j^2}; \left(\frac{r_k'^3}{\sum_{j=1}^{n} r_j'^1}, \frac{r_k^3}{\sum_{j=1}^{n} r_j^1}\right)\right] \tag{18}$$

where $\tilde{r}_j = \left[\left(r_j^1, r_j'^1\right); r_j^2; \left(r_j'^3, r_j^3\right)\right]$ represents the geometric mean with respect tothe *j*-th stakeholder, and $\tilde{\lambda}_k = \left[\left(\lambda_k^1, \lambda_k'^1\right); \lambda_k^2; \left(\lambda_k'^3, \lambda_k^3\right)\right]$ represents the relative importance(weight) of the *k*-th stakeholder.

Step 3: Normalization. The normalized initial direct-relation matrix (NIDRM) $\tilde{D}$ could be obtained by Eqs.19 -21.

$$s = \max\left(\max_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}^3\right) \tag{19}$$

$$\tilde{D} = \left[\tilde{d}_{ij}\right]_{n \times n} = \left[\left(d_{ij}^1, d_{ij}^1\right); d_{ij}^2; \left(d_{ij}^3, d_{ij}^3\right)\right]_{n \times n} \tag{20}$$

$$\tilde{d}_{ij} = \frac{1}{s} \times \tilde{a}_{ij} = \frac{\tilde{a}_{ij}}{s} = \frac{\left[\left(a_{ij}^1, a_{ij}'^1\right); a_{ij}^2; \left(a_{ij}'^3, a_{ij}^3\right)\right]}{s} = \left[\left(\frac{a_{ij}^1}{s}, \frac{a_{ij}'^1}{s}\right); \frac{a_{ij}^2}{s}; \left(\frac{a_{ij}'^3}{s}, \frac{a_{ij}^3}{s}\right)\right] \tag{21}$$

where $\tilde{D}$ is the NIDRM, s represents the biggest value among the sums of each row and that of each column, and $\tilde{d}_{ij}$ is the element in cell (i, j) in the matrix $\tilde{D}$.

Step 4: Calculating the total relation matrix (TRM). The TRM can be determined by summing the direct effects which is expressed in $\tilde{D}$ and all the indirect effects which can be determined by raising $\tilde{D}$ to different powers. The indirect effects of factors will continuously decrease with the increase of the powers of matrix, and $\tilde{D}^{\infty}$ approaches to zero which guarantees convergent solutions to the matrix inversion. Then, the TRM could be calculated by Eqs.22-23.

$$\tilde{T} = \left[\tilde{t}_{ij}\right]_{n\times n} = \tilde{D}^1 + \tilde{D}^2 + \cdots + \tilde{D}^h, h \to \infty, \tilde{D}^h = \{0\}_{n\times n} \tag{22}$$

$$\tilde{t}_{ij} = \left[\left(t_{ij}^1, t_{ij}'^1\right); t_{ij}^2; \left(t_{ij}'^3, t_{ij}^3\right)\right] \tag{23}$$

The five elements of $\tilde{t}_{ij}$ can be determined by Eqs.24-33 based on the normalized initial direct-relation matrix.

$$D_1 = \left\{d_{ij}^1\right\}_{n\times n} \tag{24}$$

$$D_1' = \left\{d_{ij}'^1\right\}_{n\times n} \tag{25}$$

$$D_2 = \left\{d_{ij}^2\right\}_{n\times n} \tag{26}$$

$$D_3' = \left\{d_{ij}'^3\right\}_{n\times n} \tag{27}$$

$$D_3 = \left\{d_{ij}^3\right\}_{n\times n} \tag{28}$$

$$T^1 = \left\{t_{ij}^1\right\}_{n\times n} = D^1(\mathrm{I} - \mathrm{D}^1)^{-1} \tag{29}$$

$$T'^1 = \left\{ t'^1_{ij} \right\}_{n\times n} = D'_1(\mathrm{I} - D'_1)^{-1} \tag{30}$$

$$T^2 = \left\{ t^2_{ij} \right\}_{n\times n} = D_2(\mathrm{I} - \mathrm{D}_2)^{-1} \tag{31}$$

$$T'^3 = \left\{ t'^3_{ij} \right\}_{n\times n} = D'_3(\mathrm{I} - D'_3)^{-1} \tag{32}$$

$$T^3 = \left\{ t^3_{ij} \right\}_{n\times n} = D^3(\mathrm{I} - \mathrm{D}^3)^{-1} \tag{33}$$

where $T = \left\{ \tilde{t}_{ij} \right\}_{n\times n}$, $D = \left\{ \tilde{d}_{ij} \right\}_{n\times n}$, and T represents the TRM, and I represents the identity matrix.

The total effects including both the direct effects and the indirect effects caused by the *i*-th factor, denotes by r_i, can be calculated by Eq.34.

$$\tilde{r}_i = \sum_{j=1}^{n} \tilde{t}_{ij} = \left[\left(r_i^1, r_i'^1 \right); r_i^2; \left(r_i'^3, r_i^3 \right) \right] \tag{34}$$

The total effect which is the sum of the direct effects and the indirect effects received by the *j*-th factor, denotes by c_j, can be determined by Eq.35.

$$\tilde{c}_j = \sum_{i=1}^{n} \tilde{t}_{ij} = \left[\left(c_i^1, c_i'^1 \right); c_i^2; \left(c_i'^3, c_i^3 \right) \right] \tag{35}$$

Thus, the sum ($\tilde{r}_i + \tilde{c}_i$) represents the total effects with respect to the *i*-th factor, and it represents the relative importance of the *i*-th factor in the complex system; the difference $\left(\tilde{r}_i - \tilde{c}_i \right)$, so-called "relation" represents the net effect of the *i*-th factor to the complex system. The values of $\tilde{r}_i + \tilde{c}_i$ and $\left(\tilde{r}_i - \tilde{c}_i \right)$ can be determined by Eqs.36-37, and The defuzzied values of $\tilde{r}_i + \tilde{c}_i$ and $\left(\tilde{r}_i - \tilde{c}_i \right)$ can be determined by Eqs.38-39..

$$\tilde{r}_i + \tilde{c}_j = \left[\left(r_i^1 + c_i^1, r_i'^1 + c_i'^1\right); r_i^2 + c_i^2; \left(r_i'^3 + c_i'^3, r_i^3 + c_i^3\right)\right] \tag{36}$$

$$\tilde{r}_i - \tilde{c}_j = \left[\left(r_i^1 - c_i^3, r_i'^1 - c_i'^3\right); r_i^2 - c_i^2; \left(r_i'^3 - c_i'^1, r_i^3 - c_i^1\right)\right] \tag{37}$$

$$r_i + c_j = \frac{\left(r_i^1 + c_i^1 + r_i'^1 + c_i'^1\right) + 2\left(r_i^2 + c_i^2\right) + \left(r_i'^3 + c_i'^3 + r_i^3 + c_i^3\right)}{6} \tag{38}$$

$$r_i - c_j = \frac{\left(r_i^1 - c_i^3 + r_i'^1 - c_i'^3\right) + 2\left(r_i^2 - c_i^2\right) + \left(r_i'^3 - c_i'^1 + r_i^3 - c_i^1\right)}{6} \tag{39}$$

Step 5: Determining the relative importance of these factors.

After determining the coordinate values ($r_i + c_i$, $r_i - c_i$) with respect to all the factors, and they could be drawn out in the cause-effect relationship diagram.

As to the relative importance of these factors, there are usually two ways: one is to determine the relative weights of the factors according to the value of ($r_i + c_i$), another is to determine the relative weights of the factors by Eq.40 (Liu *et al.*, 2015). The second method by using the causal diagram to set the weights of the factors (Dalalah *et al.*, 2011; Baykasoğlu *et al.*, 2013) was applied in this study, and the normalized weights which represent the relative importance of these factors can be determined by Eq.41.

$$\bar{\omega}_j = \sqrt{\left(r_j + c_j\right)^2 + \left(r_j - c_j\right)^2} \tag{40}$$

$$\omega_j = \frac{\bar{\omega}_j}{\sum_{j=1}^{n} \bar{\omega}_j} \tag{41}$$

2.3 Interval-valued fuzzy group grey relational analysis

Assuming that there are a total of m (i=1,2,…,m) alternatives to be evaluated by n metrics (j=1,2,..,n). There are five steps in the developed multi-actor interval-valued fuzzy grey relational analysis:

Step 1: Determining the interval-valued fuzzy decision-making matrix by each of the decision-makers. Each of the K decision-makers will employ the linguistic variables to rate the alternatives with respect to the evaluation criteria (as presented in Table 3). Then, the performances of the alternatives with respect to each of the evaluation metrics can be determined.

Table 3: Linguistic variables and their corresponding interval-valued triangular fuzzy numbers for rating the alternatives

Linguistic variables	Abbreviation	Interval-valued triangular fuzzy numbers
Very poor	VP	[(0,0);0;(1.0,1.5)]
Poor	P	[(0,0.5);1;(2.5,3.5)]
Moderately poor	MP	[(0,1.5);3;(4.5,5.5)]
Fair	F	[(2.5,3.5);5;(6.5,7.5)]
Moderately good	MG	[(4.5,5.5);7;(8,9.5)]
Good	G	[(5.5,7.5);9;(9.5,10)]
Very Good	VG	[(8.5,9.5);10;(10,10)]

Reference: Kuo (2011)

The results determined by the *k*-th decision-maker can be denoted by Eqs.42-43.

$$\tilde{D}^k = \begin{bmatrix} \tilde{v}_{11}^k & \tilde{v}_{12}^k & \cdots & \tilde{v}_{1n}^k \\ \tilde{v}_{21}^k & \tilde{v}_{22}^k & \cdots & \tilde{v}_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{v}_{m1}^k & \tilde{v}_{m2}^k & & \tilde{v}_{mn}^k \end{bmatrix}, k = 1, 2, \cdots, H \tag{42}$$

$$\tilde{v}_{ij}^k = \left[\left(v_{ij,k}^1, v_{ij,k}'^1 \right); v_{ij,k}^2; \left(v_{ij,k}'^3, v_{ij,k}^3 \right) \right] \tag{43}$$

where $\tilde{D}^k$ represents the decision-making matrix determined by the *k*-th decision-maker, and $\tilde{v}_{11}^k$ is the IVFN to describe the relative performance of the *i*-th alternative with respect to the *j*-th criterion determined by the *k*-th decision-maker.

Step 2: Determining the aggregated interval-valued fuzzy decision-making matrix. The aggregated interval-valued fuzzy decision-making matrix can be determined by Eqs.44-45.

$$\tilde{D} = \begin{bmatrix} \tilde{v}_{11} & \tilde{v}_{12} & \cdots & \tilde{v}_{1n} \\ \tilde{v}_{21} & \tilde{v}_{22} & \cdots & \tilde{v}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{v}_{m1} & \tilde{v}_{m2} & & \tilde{v}_{mn} \end{bmatrix} \tag{44}$$

$$\tilde{v}_{ij} = \sum_{k=1}^{K} \tilde{\lambda}_k \tilde{v}_{ij}^k = \left[\sum_{k=1}^{H} \left(v_{ij,k}^1 \lambda_k^1, v_{ij,k}'^1 \lambda_k'^1 \right); v_{ij,k}^2 \lambda_k^2; \left(v_{ij,k}'^3 \lambda_k'^3, v_{ij,k}^3 \lambda_k^3 \right) \right] \tag{45}$$

where $\tilde{D}$ is the aggregated interval-valued fuzzy decision-making matrix, $\tilde{v}_{ij} = \left[\left(v_{ij}^1, v_{ij}'^1 \right); v_{ij}^2; \left(v_{ij}'^3, v_{ij}^3 \right) \right]$ is the IVFN to describe the relative performance of the *i*-th alternative with respect to the *j*-th criterion in the aggregated interval-valued fuzzy decision-making matrix, and $\tilde{\lambda}_k$ represents the role weight of the *k*-th decision-maker in the process of decision-making.

Step 3: Normalizing the aggregated interval-valued fuzzy decision-making matrix. As all the data in the aggregated interval-valued fuzzy decision-making matrix are used to rate the alternatives, all the evaluation metrics have been transformed into benefit-type and the aggregated interval-valued fuzzy decision-making matrix can be normalized by Eqs.46-47.

$$\tilde{R} = \begin{bmatrix} \tilde{r}_{11} & \tilde{r}_{12} & \cdots & \tilde{r}_{1n} \\ \tilde{r}_{21} & \tilde{r}_{22} & \cdots & \tilde{r}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{r}_{m1} & \tilde{r}_{m2} & & \tilde{r}_{mn} \end{bmatrix} \tag{46}$$

$$\tilde{r}_{ij} = \left[\left(\frac{v_{ij}^1}{\max_i \left\{ v_{ij}^3 \right\}}, \frac{v_{ij}'^1}{\max_i \left\{ v_{ij}^3 \right\}} \right); \frac{v_{ij}^2}{\max_i \left\{ v_{ij}^3 \right\}}; \left(\frac{v_{ij}'^3}{\max_i \left\{ v_{ij}^3 \right\}}, \frac{v_{ij}^3}{\max_i \left\{ v_{ij}^3 \right\}} \right) \right] \tag{47}$$

where $\tilde{R}$ represents the normalized aggregated interval-valued fuzzy decision-making matrix, and $\tilde{r}_{ij} = \left[\left(r_{ij}^1, r_{ij}'^1 \right); r_{ij}^2; \left(r_{ij}'^3, r_{ij}^3 \right) \right] (i = 1, 2, \cdots, m; j = 1, 2, \cdots, n)$ is the element in cell (i,j) of the normalized aggregated interval-valued fuzzy decision-making matrix.

Step 4: Determining the reference series. The reference series can be determined by Eqs.48.

$$\tilde{r}_j^0 = \left[\left(r_{0j}^1, r_{0j}'^1 \right); r_{0j}^2; \left(r_{0j}'^3, r_{0j}^3 \right) \right] = \left[(1,1); 1; (1,1) \right] (j = 1, 2, \cdots, n) \tag{48}$$

Step 5: Determining the distance between each of the alternatives and the reference series. The distance between each of the alternatives and the reference series with respect to each evaluation metric can be determined by Eqs.49-51.

$$\delta_{ij}^L = \sqrt{\frac{1}{3} \left[\left(r_{ij}'^1 - 1 \right)^2 + \left(r_{ij}^2 - 1 \right)^2 + \left(r_{ij}^3 - 1 \right)^2 \right]} (i = 1, 2, \cdots, m; j = 1, 2, \cdots, n) \tag{49}$$

$$\delta_{ij}^U = \sqrt{\frac{1}{3} \left[\left(r_{ij}^1 - 1 \right)^2 + \left(r_{ij}^2 - 1 \right)^2 + \left(r_{ij}'^3 - 1 \right)^2 \right]} (i = 1, 2, \cdots, m; j = 1, 2, \cdots, n) \tag{50}$$

$$\delta_{ij} = \left[\delta_{ij}^L \quad \delta_{ij}^U \right] \tag{51}$$

where $\delta_{ij} = \left[\delta_{ij}^{L} \quad \delta_{ij}^{U} \right]$ represents the distance between each of the alternatives and the reference series

Step 6: Calculating the grey relational coefficients. The grey relational coefficients can be determined by Eqs.52-54.

$$\xi_{ij}^{L} = \frac{\delta_{ij}^{L} + \zeta \max_{i} \max_{j} \delta_{ij}^{U}}{\min_{i} \min_{j} \delta_{ij}^{L} + \zeta \max_{i} \max_{j} \delta_{ij}^{U}} \tag{52}$$

$$\xi_{ij}^{U} = \frac{\delta_{ij}^{U} + \zeta \max_{i} \max_{j} \delta_{ij}^{U}}{\min_{i} \min_{j} \delta_{ij}^{U} + \zeta \max_{i} \max_{j} \delta_{ij}^{U}} \tag{53}$$

$$\xi_{ij} = \left[\xi_{ij}^{L} \quad \xi_{ij}^{U} \right] \tag{54}$$

where $\xi_{ij} = \left[\xi_{ij}^{L} \quad \xi_{ij}^{U} \right]$ represents the grey relational coefficients, and ζ usually takes the value of 0.5.

It is apparent that the larger the value of the grey relational coefficients, the further the distance between the alternative and the reference series.

Step 7: Determining the grey relational degrees of the alternatives. The grey relational degrees of the alternatives can be determined by Eq.55.

$$d_{i} = \sum_{j=1}^{n} \omega_{j} \xi_{ij} = \left[\sum_{j=1}^{n} \omega_{j} \xi_{ij}^{L} \quad \sum_{j=1}^{n} \omega_{j} \xi_{ij}^{U} \right] = \left[d_{i}^{L} \quad d_{i}^{U} \right] \tag{55}$$

where d_i represents the grey relational degree of the i-th alternative, and d_i^L and d_i^U are the lower and upper boundary of d_i.

The greater the value of the grey relational degree, the more inferior the alternative will be. In other words, the smaller the value of the grey relational degree, the more superior the alternative will be.

As for $d_i = \left[d_i^L \quad d_i^U\right]$ and $d_t = \left[d_t^L \quad d_t^U\right]$, the possibility of $d_i \geq d_t$ (Wang et al., 2005a; Wang et al., 2005b).

$$P(d_i \geq d_t) = \frac{\max\left\{0, d_i^U - d_t^L\right\} - \max\left\{0, d_i^L - d_t^U\right\}}{d_i^U - d_i^L + d_t^U - d_t^L} \tag{56}$$

The grey relational degree can be ranked according to the following rules:

I. $P(d_i \geq d_t) > 0.5$, the *i*-th alternative is more inferior to the *t*-th alternative;

II. $P(d_i \geq d_t) = 0.5$, the *i*-th alternative is indifferent to the *t*-th alternative;

III. $P(d_i \geq d_t) < 0.5$, the *i*-th alternative is superior to the *t*-th alternative.

3. Case study

In order to illustrate the developed model for multi-actor multi-criteria decision making on selecting the best scenario for MSW treatment among multiple alternatives, an illustrative case for selecting the best process for MSW treatment in Chongqing, China has been studied. Four representative alternative scenarios for MSW treatment were investigated, and they are landfill, anaerobic digestion, incineration, and gasification. Landfill is the traditional MSW treatment method, and the other three scenarios including anaerobic digestion, incineration, and gasification are the representative waste-to-energy scenarios for MSW treatment

Landfill (A_1): this is main disposal option and the most commonly used scenario for national household garbage treatment in China, and more than 85% of the cities in China adopted this scenario for the treatment of the household garbage, and there are a total of 366 landfill sites in China (Zhang *et al*., 2010);

Anaerobic digestion (A_2): the anaerobic digestion of organic fraction of municipal solid waste cannot only mitigate negative impacts on environment, but also produce biogas for household cooking and some other applications (Liu *et al.*, 2008);

Incineration (A_3): the incineration scenario can provide substantial reduction (around 90%) in total volume of waste, the bottom ash from incineration is clean and stable, and the heat from combustion can be used for the generation of steam and electricity (Cheng and Hu, 2010); and

Gasification (A_4): this option has been recognized as a promising energy efficient and environmental friendly scenario for MSW treatment, and the syngas generated by MSW gasification can be used directly or stored as an energy carrier (Chen *et al.,* 2013).

The selection of these four MSW treatment options was based on the consideration of incorporating both the universal solution such as landfill and some emerging technologies (i.e. incineration and gasification), but all these four options have both their own advantages and weak pints. For instance, the landfill scenario has the advantages of relatively lower cost and easiness for implementation, but it has also several serious weak points, i.e. high risk for water and soil pollution, requiring large area of occupied land, and low public acceptance (Cheng and Hu, 2010). Therefore, it is difficult for the decision-makers to select the best MSW treatment scenario among these four MSW treatment options.

Five metrics including comprehensive economic performances (M_1), total environmental impacts (M_2), integrated social acceptability (M_3), technological superiority (M_4), and compliance to policy

(M_5) have been employed to measure the priorities of these four alternatives for MSW treatment. The interval-valued fuzzy DEMATEL was firstly used to investigate the cause and effect relationships among these evaluation metrics and determine their relative weights which represent the relative importance of these metrics for the evaluation of these alternative wastewater treatment processes. There are three groups of decision-makers/stakeholders participating the analysis process of multi-actor interval-valued fuzzy DEMATEL, and they are administrators and managers group (DM#1), engineers and scholars group (DM#2), and local residents and environmentalists group (DM#3). There are 2 administrators from the Environmental Protection Agency of a local government in China and three senior managers from a national company for MSW in DM#1; DM#2 has 3 engineers working on MSW treatment, 2 professors focusing on environmental engineering, and 3 PhDs skilled in MSW treatment; DM#3 consists of 4 local residents who pat close attentions to MSW treatment and 2 environmentalists. Each of three groups of stakeholders held a workshop during November 2016 to February 2017 in Chongqing, and these workshops were coordinated by the authors to achieve a consensus when there are some arguments among these stakeholders. Each group of stakeholders firstly used the linguistic variable shown in Table 1 to establish the direct-influenced matrices (Step 1), and the results were presented in Table 4.

Then, the linguistic variables presented in Table 4 can be transformed into IVFNs (the results were presented in the Table A1 of the Appendix).

Table 4: The direct-influenced matrices determined by the three groups by decision-makers/stakeholders using linguistic variables

DM#1	M_1	M_2	M_3	M_4	M_5
comprehensive economic performances (M_1)	N	N	H	N	VL
total environmental impacts (M_2)	VL	N	VH	N	M
integrated social acceptability (M_3)	N	N	N	N	VH
technological superiority (M_4)	VH	VH	VH	N	H
compliance to policy (M_5)	N	N	VH	N	N
DM#2	M_1	M_2	M_3	M_4	M_5
comprehensive economic performances (M_1)	N	N	M	N	N
total environmental impacts (M_2)	VL	N	H	N	VL
integrated social acceptability (M_3)	N	N	N	N	M
technological superiority (M_4)	H	VH	M	N	M
compliance to policy (M_5)	N	N	M	N	N
DM#3	M_1	M_2	M_3	M_4	M_5
comprehensive economic performances (M_1)	N	N	M	N	VL
total environmental impacts (M_2)	N	N	VH	N	H
integrated social acceptability (M_3)	N	N	N	N	M
technological superiority (M_4)	VH	H	M	N	L
compliance to policy (M_5)	L	N	VH	N	N

Table 5: Comparison matrix for determining the role weights of the three groups of decision-makers

	DM#1	DM#2	DM#3
DM#1	E	W	M
DM#2	RW	E	L
DM#3	RM	RL	E
	DM#1	DM#2	DM#3
DM#1	[(1.0,1.0);1.0;(1.0,1.0)]	[(1.0,1.5);2.0;(2.5,3.0)]	[(3.0,3.5);4.0;(4.5,5.0)]
DM#2	[(0.33,0.40);0.5;(0.67,1)]	[(1.0,1.0);1.0;(1.0,1.0)]	[(2.0,2.5);3.0;(3.5,4.0)]
DM#3	[(0.20,0.22);0.25;(0.29,0.33)]	[(0.25,0.29);0.33;(0.40,0.50)]	[(1.0,1.0);1.0;(1.0,1.0)]

In order to determine the weighted direct-influenced matrix, the role weights of the three groups of decision-makers/stakeholders were firstly determined. The comparison matrix for determining the role weights of the three groups of decision-makers were presented in Table 5. According to Eq.3, the fuzzy geometric mean of each group of decision-makers can be determined, and they are [(1.4422,1.7380);2.0;(2.2407,2.4662)], [(0.8707,1.0000);1.1447;(1.3286,1.5874)], and [(0.3684,0.3996);0.4353;(0.4877,0.5485)], respectively. Then, the relative weights of three groups of decision-makers can be determined by Eq.4, and they are [(0.3134,0.4284);0.5587;(0.7141,0.9198)], [(0.1892,0.2465);0.3197;(0.4234,0.5920)], and [(0.0801,0.0985);0.1216;(0.1554,0.2046)], respectively.

According to Eq.10, the weighted direct-influenced matrix can be obtained, and the results were presented in Table A2 of the Appendix (**Step 2**). After determining the weighted direct-influenced matrix, the parameter s for normalizing the data can be obtained by Eq.19, and s is 11.8102. Then, the normalized initial direct-relation matrix can be obtained by Eqs.20-21 (see the results in Table A3 of the Appendix). According to Eqs.22-33, the total relation matrix can be obtained (as presented in Table A4 of the Appendix).

According to Eqs. 34-35, the total effects that directly and indirectly exerted by each factor and total effect including direct and indirect effects received by each factor can be determined, and the results were presented in Table A5 of the Appendix.

According to Eqs.36-39, $r_i + c_j$ and $r_i - c_j$ can be determined, and the results were presented in Table 6. It is comprehensive economic performances (M_1), total environmental impacts (M_2), and technological superiority (M_4) belong to the cause group, while integrated social acceptability (M_3) and compliance to policy (M_5) belong to the effect group.

Table 6: The results of $r_i + c_j$ and $r_i - c_j$

	M_1	M_2	M_3	M_4	M_5
$r_i + c_j$	5.5139	7.5365	19.3914	16.4488	18.4404
$r_i - c_j$	1.8773	6.4413	-13.0778	16.4488	-11.6896
Type	Cause	Cause	Effect	Cause	Effect
Weights	0.0692	0.1177	0.2777	0.2762	0.2592

The weights of the five metrics can be determined by Eqs.40-41, and they are 0.0692, 0.1177, 0.2777, 0.2762, and 0.2592, respectively. These weights can be used in the interval-valued fuzzy GRA method for ranking the four alternatives for MSW treatment.

The decision-making matrices determined by the three groups of decision-makers were presented in Table 7, and all these linguistic variables can be transformed into IVFNs (the results were presented in Table A6). According to Eq.44 and Eq.45, the interval-valued fuzzy decision-making matrix can be determined, as presented in Table A7.

Table 7: The decision-making matrices by using linguistic variables

DM#1	A_1	A_2	A_3	A_4
M_1	MP	G	P	MG
M_2	VP	F	P	G
M_3	F	VG	P	G
M_4	VG	G	F	P
M_5	P	VG	G	F
DM#2	A_1	A_2	A_3	A_4
M_1	P	MG	VP	F
M_2	VP	G	MP	VG
M_3	MP	G	P	G
M_4	G	MG	F	VP
M_5	VP	G	VG	MP
DM#3	A_1	A_2	A_3	A_4
M_1	P	F	VP	MP
M_2	P	F	MP	f
M_3	F	G	VP	F
M_4	F	F	MP	P
M_5	P	VG	F	MP

According to Eq.46 and Eq.47, the normalized interval-valued fuzzy decision-making matrix can be obtained. For instance, the biggest value in the first row is 16.3565, thus, the element in cell (1,1) of Table 8 can be normalized by Eq.57. In a similar way, the other normalized data can also be obtained, and the results were summarized in Table A8 of the Appendix.

$$\begin{aligned}\tilde{r}_{11} &= \left[\left(\frac{v_{11}^{1}}{\max\limits_{j}\left\{v_{1j}^{3}\right\}},\frac{v_{11}^{\prime 1}}{\max\limits_{j}\left\{v_{1j}^{3}\right\}}\right);\frac{v_{11}^{2}}{\max\limits_{j}\left\{v_{1j}^{3}\right\}};\left(\frac{v_{11}^{\prime 3}}{\max\limits_{j}\left\{v_{1j}^{3}\right\}},\frac{v_{11}^{3}}{\max\limits_{j}\left\{v_{1j}^{3}\right\}}\right)\right] \\ &= \left[\left(\frac{0}{16.3565},\frac{0.8151}{16.3565}\right);\frac{2.1174}{16.3565};\left(\frac{4.6605}{16.3565},\frac{7.8470}{16.3565}\right)\right] \\ &= \left[(0,0.0498);0.1295;(0.2849,0.4797)\right]\end{aligned} \tag{57}$$

According to Eqs.49-51, the distance between each of the alternatives and the reference series with respect to each evaluation metric can be determined, and the results were summarized in Table 8.

Table 8: The distance between each of the alternatives and the reference series

	A1	A2	A3	A4
M1	[0.8024 0.8697]	[0.5028 0.5940]	[0.9018 0.9425]	[0.5936 0.6800]
M2	[0.9404 0.9679]	[0.5810 0.6672]	[0.8157 0.88117]	[0.4610 0.5533]
M3	[0.6872 0.7656]	[0.4363 0.5295]	[0.8785 0.9276]	[0.4913 0.5875]
M4	[0.4459 0.5371]	[0.5083 0.6001]	[0.6570 0.7369]	[0.8932 0.9367]
M5	[0.8961 0.9385]	[0.4285 0.5201]	[0.4716 0.5645]	[0.7010, 0.7794]

According to Eqs.52-54, the grey relational coefficients can then be determined ($\zeta = 0.5$), and the results were presented in Table 9.

Table 9: The grey relational coefficients

	A_1	A_2	A_3	A_4
M_1	[1.4097 1.4835]	[1.0814 1.1813]	[15187 1.5632]	[1.1809 1.2756]
M_2	[1.5610 1.5911]	[1.1671 1.2615]	[1.4243 1.4960]	[1.0355 1.1367]
M_3	[1.2835 1.3694]	[1.0085 1.1107]	[1.4932 1.5469]	[1.0688 1.1742]
M_4	[1.0190 1.1190]	[1.0874 1.1880]	[1.2504 1.3380]	[1.5092 1.5569]
M_5	[1.5124 1.5589]	[1.0000 1.1004]	[1.0472 1.1490]	[1.2986, 1.3845]

According to Eq.55, the grey relational degree of each alternative can be determined, and the results were presented in Table 10.

Table 10: The grey relational degree of each alternative

	A_1	A_2	A_3	A_4
Grey relational degree	[1.3112 1.3834]	[1.0518 1.1520]	[1.3042 1.3812]	[1.2538 1.3370]

Then, the possibility matrix by comparing each pair of the alternatives can be determined by Eq.56, as presented in Eq.58.

$$\begin{array}{ccccc} & A_1 & A_2 & A_3 & A_4 \\ A_1 & 0.5000 & 1.0000 & 0.5307 & 0.8335 \\ A_2 & 0 & 0.5000 & 0 & 0 \\ A_3 & 0.4693 & 1.0000 & 0.5000 & 0.7948 \\ A_4 & 0.1665 & 1.0000 & 0.2052 & 0.5000 \end{array} \tag{58}$$

Note that the greater the value of the grey relational degree, the more inferior the corresponding alternative will be. The grey relational degrees of the four alternatives from the greatest to the smallest are $d(A_1)$, $d(A_3)$, $d(A_4)$ and $d(A_2)$. Therefore, anaerobic digestion (A_2) is the most sustainable scenario for MSW treatment, followed by gasification (A_4), incineration (A_3) and landfill (A_1) in the descending order.

4. Discussion

Anaerobic digestion was recognized as the best MSW treatment scenario among these four alternatives, the main reasons are the best economic performances, highest social acceptability, the greatest technological superiority, and the highest compliance to policy, and the relatively between environmental performance based on the judgments of the experts. More specifically, the advantages of anaerobic digestion and the implications for promoting the development of anaerobic digestion projects for MWS treatment can be summarized as follows:

(1) Anaerobic digestion has relatively better performances on economic aspect with relatively lower capital cost and operations cost. Meanwhile, it can lead to energy recovery through biogas generation which consists of 55-60% methane and can be used as fuel or for power generation to achieve economic benefits to counteract the capital cost and operations cost (Sharholy *et al*., 2008);

(2) China has abundant experience on anaerobic digestion processes, and China has already set various funds for research, development and demonstration of anaerobic digestion projects as well as various policies for supporting the development of anaerobic digestion scenario for the treatment of MSW (Zhang *et al*., 2010);

(3) Anaerobic digestion cannot only successfully solve the environmental problems caused by MSW, but also generate renewable energy and achieve the reuse &recycling of waste,. As for

the potential of contributing to global warming, anaerobic digestion can also prevent global warming through methane capture (Abbasi *et al*., 2012);

(4) Anaerobic digestion scenario for MSW treatment has high public acceptance for its advantages of better economic performances, lower negative environmental impacts and mature technologies.

The result is comparable to that determined in the work of Tseng (2009), the establishing of thermal process technology for each city and a resource recovery facility was proposed for MSW management though the alternative scenarios for MSW treatment in this study are different from that were investigated in the work of Tseng (2009), but both of the two studies proposed a MSW treatment scenario with the best integrated performances with the considerations of economic, environmental, social and technological aspects simultaneously. However, crisp numbers were employed to describe the opinions and preferences of the decision-makers in the work of Tseng (2009). Accordingly, the ambiguity and vagueness existing in human's judgments due to the lack of information and imprecise information cannot be addressed. The developed interval-valued fuzzy DEMATEL method in this study for determining the weights of the evaluation criteria cannot only address the ambiguity and vagueness, but also incorporate the interdependences among the evaluation criteria for selecting the best MSW treatment scenario. The developed interval-valued fuzzy multi-criteria decision making method which allows the decision-makers/stakeholders to use linguistic variables which correspond to interval-valued fuzzy numbers can accurately rate the alternative MSW treatment scenarios, thus, to some extent, the accuracy and correctness of ranking of the alternative MSW treatment scenarios can be guaranteed. As least, it can accurately determine the priority sequence of the alternative MSW treatment scenarios according to the preferences and opinions of the stakeholders. In other words, it is an object-oriented group multi-criteria decision making method for selecting the best scenario for MWS treatment, and the results can reflect the preferences and opinions of the decision-makers/stakeholders on MSW treatment.

5. Conclusion

This study developed a multi-actor multi-criteria decision making method for sustainability prioritization of the alternative scenarios for MSW treatment. The multi-actor interval-valued fuzzy DEMATEL which can incorporate the interdependences and interactions among the evaluation criteria for sustainability assessment has been developed for determining the weights of the evaluation metrics. Multi-actor interval-valued fuzzy grey relational analysis was developed to rank the alternative scenarios for MSW treatment, and the decision-makers/stakeholders are allowed to use linguistic variables which can capture the ambiguity and vagueness in human judgments to express their preferences/opinions for rating the alternatives with respect to each evaluation criterion. Moreover, the preferences/opinions of different groups of decision-makers/stakeholders can be simultaneously incorporated.

Anaerobic digestion was recognized as the best scenario for MSW treatment under the context of Chongqing, followed by gasification, incineration, and landfill in the descending order among the four MSW treatment scenarios. According to the current conditions of Chongqing in China, the development of anaerobic digestion is the most suitable pathway for MSW treatment. The following measures were suggested for the decision-makers/stakeholders in Chongqing to popularize the development of anaerobic digestion for MSW treatment:

(1) Setting special financial support (i.e. low interest or zero loan and subsides) to the companies which adopt the anaerobic digestion process for MSW treatment;

(2) Training more engineers who are skilled in anaerobic digestion for MSW treatment to establish the talent team;

(3) Demonstration of MSW treatment projects by anaerobic digestion process to increase the public acceptance and technological maturity of anaerobic digestion process for MSW treatment.

Besides the advantages of the developed method for selecting the best MSW treatment scenario, there is also a weak point-the developed method replies on the judgments of the decision-makers to rank the alternative MSW treatment scenarios; however, some real data with units for describing the alternatives with respect to some evaluation criteria cannot be fully used. Therefore, the future work is to develop a multi-actor multi-criteria decision making which can address the decision-making matrix composed by mixed numbers (i.e. interval-valued numbers and crisp numbers) for selecting the best MSW treatment scenario.

Acknowledgment

We would like to thank Prof. Lichun Dong and PhD researcher Xusheng Ren from Chongqing University for their help and assistance on organizing the workshops during November 2016 to February 2017 in Chongqing, China.

Appendix

Table A1: The direct-influenced matrices determined by the three groups by decision-makers/stakeholders using IVFNs

DM#1	M_1	M_2	M_3	M_4	M_5
M_1	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]	[(4.0,4.5);5.0;(5.5,6.0)]	[(0,0);0;(0,0)]	[(1.0,1.5);2.0;(2.5,3.0)]
M_2	[(1.0,1.5);2.0;(2.5,3.0)]	[(0,0);0;(0,0)]	[(5.0,5.5);6.0;(6.5,7.0)]	[(0,0);0;(0,0)]	[(3.0,3.5);4.0;(4.5,5.0)]
M_3	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]	[(5.0,5.5);6.0;(6.5,7.0)]
M_4	[(5.0,5.5);6.0;(6.5,7.0)]	[(5.0,5.5);6.0;(6.5,7.0)]	[(5.0,5.5);6.0;(6.5,7.0)]	[(0,0);0;(0,0)]	[(4.0,4.5);5.0;(5.5,6.0)]
M_5	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]	[(5.0,5.5);6.0;(6.5,7.0)]	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]
DM#2	M_1	M_2	M_3	M_4	M_5
M_1	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]	[(3.0,3.5);4.0;(4.5,5.0)]	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]
M_2	[(1.0,1.5);2.0;(2.5,3.0)]	[(0,0);0;(0,0)]	[(4.0,4.5);5.0;(5.5,6.0)]	[(0,0);0;(0,0)]	[(1.0,1.5);2.0;(2.5,3.0)]
M_3	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]	[(3.0,3.5);4.0;(4.5,5.0)]
M_4	[(4.0,4.5);5.0;(5.5,6.0)]	[(5.0,5.5);6.0;(6.5,7.0)]	[(3.0,3.5);4.0;(4.5,5.0)]	[(0,0);0;(0,0)]	[(3.0,3.5);4.0;(4.5,5.0)]
M_5	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]	[(3.0,3.5);4.0;(4.5,5.0)]	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]
DM#3	M_1	M_2	M_3	M_4	M_5
M_1	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]	[(3.0,3.5);4.0;(4.5,5.0)]	[(0,0);0;(0,0)]	[(1.0,1.5);2.0;(2.5,3.0)]
M_2	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]	[(5.0,5.5);6.0;(6.5,7.0)]	[(0,0);0;(0,0)]	[(4.0,4.5);5.0;(5.5,6.0)]
M_3	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]	[(3.0,3.5);4.0;(4.5,5.0)]
M_4	[(5.0,5.5);6.0;(6.5,7.0)]	[(4.0,4.5);5.0;(5.5,6.0)]	[(3.0,3.5);4.0;(4.5,5.0)]	[(0,0);0;(0,0)]	[(2.0,2.5);3.0;(3.5,4.0)]
M_5	[(2.0,2.5);3.0;(3.5,4.0)]	[(0,0);0;(0,0)]	[(5.0,5.5);6.0;(6.5,7.0)]	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]

Table A2: The weighted direct-influenced matrix

	M_1	M_2	M_3	M_4	M_5
M_1	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]	[(2.0615,3.1353);4.5587;(6.5321,9.5018)]	[(0,0);0;(0,0)]	[(0.3935,0.7904);1.3606;(2.1738,3.3732)]
M_2	[(0.5026,1.0124);1.7568;(2.8438,4.5354)]	[(0,0);0;(0,0)]	[(2.7243,4.0072);5.6803;(7.9804,11.4228)]	[(0,0);0;(0,0)]	[(1.4498,2.3124);3.4822;(5.1267,7.6026)]
M_3	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]	[(2.3749,3.5637);5.1174;(7.2462,10.4216)]
M_4	[(2.7243,4.0072);5.6803;(7.9804,11.4228)]	[(2.8334,4.1552);5.8784;(8.2484,11.8102)]	[(2.3749,3.5637);5.1174;(7.2462,10.4216)]	[(0,0);0;(0,0)]	[(1.9814,3.0368);4.4371;(6.3767,9.2972)]
M_5	[(0.1602,0.2463);0.3648;(0.5439,0.8184)]	[(0,0);0;(0,0)]	[(2.5351,3.7607);5.3606;(7.5570,10.8308)]	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]

Table A3: The normalized initial direct-influenced matrix

	M_1	M_2	M_3	M_4	M_5
M_1	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]	[(0.1746,0.2655);0.3860;(0.5531,0.8045)]	[(0,0);0;(0,0)]	[(0.0333,0.0669);0.1152;(0.1841,0.2856)]
M_2	[(0.0426,0.0857);0.1488;(0.2408,0.3840)]	[(0,0);0;(0,0)]	[(0.2307,0.3393);0.4810;(0.6757,0.9672)]	[(0,0);0;(0,0)]	[(0.1228,0.1958);0.2948;(0.4341,0.6437)]
M_3	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]	[(0.2011,0.3017);0.4333;(0.6136,0.8824)]
M_4	[(0.2307,0.3393);0.4810;(0.6757,0.9672)]	[(0.2399,0.3518);0.4977;(0.6984,1)]	[(0.2011,0.3017);0.4333;(0.6136,0.8824)]	[(0,0);0;(0,0)]	[(0.1678,0.2571);0.3757;(0.5399,0.7872)]
M_5	[(0.0136,0.0209);0.0309;(0.0461,0.0693)]	[(0,0);0;(0,0)]	[(0.2147,0.3184);0.4539;(0.6399,0.9171)]	[(0,0);0;(0,0)]	[(0,0);0;(0,0)]

Table A4: The total relation matrix

	M_1	M_2	M_3	M_4	M_5
M_1	[(0.0010,0.0034);0.0110;(0.0413,0.5666)]	[(0,0);0;(0,0)]	[(0.1901,0.3183);0.5516;(1.1501,8.7584)]	[(0,0);0;(0,0)]	[(0.0716,0.1632);0.3555;(0.8973,8.1761)]
M_2	[(0.0450,0.0929);0.1699;(0.3177,1.4537)]	[(0,0);0;(0,0)]	[(0.2772,0.4738);0.8580;(1.9207,16.2923)]	[(0,0);0;(0,0)]	[(0.1800,0.3450);0.6862;(1.6711,15.4356)]
M_3	[(0.0029,0.0070);0.0168;(0.0484,0.5022)]	[(0,0);0;(0,0)]	[(0.0457,0.1085);0.2540;(0.6999,7.0500)]	[(0,0);0;(0,0)]	[(0.2104,0.3350);0.5453;(1.0519,7.2469)]
M_4	[(0.2446,0.3812);0.5927;(09979,3.8600)]	[(0.2399,0.3518);0.4977;(0.6984,1)]	[(0.3587,0.7017);1.4560;(3.7775,38.1562)]	[(0,0);0;(0,0)]	[(0.2775,0.5633);1.2216;(3.3445,36.2034)]
M_5	[(0.0142,0.0231);0.0389;(0.0790,0.5691)]	[(0,0);0;(0,0)]	[(0.2270,0.3596);0.5862;(1.1407,7.9803]	[(0,0);0;(0,0)]	[(0.0461,0.1101);0.2585;(0.7144,7.2125)]

Table A5: The total effects that directly and indirectly exerted by each factor and total effect including direct and indirect effects received by each factor

	$\tilde{r}_i$	$\tilde{c}_j$
M_1	[(0.2626,0.4850);0.9180;(2.0888,17.5011)]	[(0.3077,0.5076);0.8294;(1.4844,6.9515)]
M_2	[(0.5022,0.9117);1.7142;(3.9095,33.1816)]	[(0.2399,0.3518);0.4977;(0.6984,1.0000)]
M_3	[(0.2589,0.4505);0.8162;(1.8002,14.7990)]	[(1.0986,1.9620);3.7059;(8.6889,78.2462)]
M_4	[(1.1208,1.9980);3.7681;(8.8184,79.2196)]	[(0,0);0;(0,0)]
M_5	[(0.2873,0.4928);0.8836;(1.9340,15.7709)]	[(0.7856,1.5165);3.0671;(7.6792,74.2745)]

Table A6: The decision-making matrices determined by the three groups of decision-makers by using IVFNs

DM#1	A_1	A_2	A_3	A_4
M_1	[(0,1.5);3;(4.5,5.5)]	[(5.5,7.5);9;(9.5,10)]	[(0,0.5);1;(2.5,3.5)]	[(4.5,5.5);7;(8,9.5)]
M_2	[(0,0);0;(1.0,1.5)]	[(2.5,3.5);5;(6.5,7.5)]	[(0,0.5);1;(2.5,3.5)]	[(5.5,7.5);9;(9.5,10)]
M_3	[(2.5,3.5);5;(6.5,7.5)]	[(8.5,9.5);10;(10,10)]	[(0,0.5);1;(2.5,3.5)]	[(5.5,7.5);9;(9.5,10)]
M_4	[(8.5,9.5);10;(10,10)]	[(5.5,7.5);9;(9.5,10)]	[(2.5,3.5);5;(6.5,7.5)]	[(0,0.5);1;(2.5,3.5)]
M_5	[(0,0.5);1;(2.5,3.5)]	[(8.5,9.5);10;(10,10)]	[(5.5,7.5);9;(9.5,10)]	[(2.5,3.5);5;(6.5,7.5)]
DM#2	A_1	A_2	A_3	A_4
M_1	[(0,0.5);1;(2.5,3.5)]	[(4.5,5.5);7;(8,9.5)]	[(0,0);0;(1.0,1.5)]	[(2.5,3.5);5;(6.5,7.5)]
M_2	[(0,0);0;(1.0,1.5)]	[(5.5,7.5);9;(9.5,10)]	[(0,1.5);3;(4.5,5.5)]	[(8.5,9.5);10;(10,10)]
M_3	[(0,1.5);3;(4.5,5.5)]	[(5.5,7.5);9;(9.5,10)]	[(0,0.5);1;(2.5,3.5)]	[(5.5,7.5);9;(9.5,10)]
M_4	[(5.5,7.5);9;(9.5,10)]	[(4.5,5.5);7;(8,9.5)]	[(2.5,3.5);5;(6.5,7.5)]	[(0,0);0;(1.0,1.5)]
M_5	[(0,0);0;(1.0,1.5)]	[(5.5,7.5);9;(9.5,10)]	[(8.5,9.5);10;(10,10)]	[(0,1.5);3;(4.5,5.5)]
DM#3	A_1	A_2	A_3	A_4
M_1	[(0,0.5);1;(2.5,3.5)]	[(2.5,3.5);5;(6.5,7.5)]	[(0,0);0;(1.0,1.5)]	[(0,1.5);3;(4.5,5.5)]
M_2	[(0,0.5);1;(2.5,3.5)]	[(2.5,3.5);5;(6.5,7.5)]	[(0,1.5);3;(4.5,5.5)]	[(2.5,3.5);5;(6.5,7.5)]
M_3	[(2.5,3.5);5;(6.5,7.5)]	[(5.5,7.5);9;(9.5,10)]	[(0,0);0;(1.0,1.5)]	[(2.5,3.5);5;(6.5,7.5)]
M_4	[(2.5,3.5);5;(6.5,7.5)]	[(2.5,3.5);5;(6.5,7.5)]	[(0,1.5);3;(4.5,5.5)]	[(0,0.5);1;(2.5,3.5)]
M_5	[(0,0.5);1;(2.5,3.5)]	[(8.5,9.5);10;(10,10)]	[(2.5,3.5);5;(6.5,7.5)]	[(0,1.5);3;(4.5,5.5)]

Table A7: The interval-valued fuzzy decision-making matrix

	A_1	A_2	A_3	A_4
M_1	[(0,0.8151);2.1174;(4.6605,7.8470)]	[(2.7754,4.9135);7.8742;(11.1813,16.3565)]	[(0,0.2142);0.5587;(2.3641,4.4142)]	[(1.8833,3.3667);5.8742;(9.1642,14.3034)]
M_2	[(0,0.0493);0.1216;(1.5260,2.9838)]	[(2.0244,3.6929);6.2788;(9.6740,14.3530)]	[(0,0.7317);1.8826;(4.3899,7.6006)]	[(3.5322,5.8995);8.8333;(12.0280,16.6525)]
M_3	[(0.9838,2.2139);4.3606;(7.5570,11.6890)]	[(4.1450,6.6573);9.5587;(12.6396,17.1640)]	[(0,0.3375);0.8784;(2.9992,5.5982)]	[(2.9646,5.4065);8.5136;(11.8163,16.6525)]
M_4	[(3.9047,6.2633);9.0723;(12.1734,16.6525)]	[(2.7754,4.9135);7.8742;(11.1813,16.3565)]	[(1.2565,2.5099);4.7568;(8.0930,12.4638)]	[(0,0.2635);0.6803;(2.5972,4.8234)]
M_5	[(0,0.2635);0.6803;(2.5972,4.8234)]	[(4.3853,6.8543);9.6803;(12.7173,17.1640)]	[(3.5322,5.8995);8.8333;(12.0280,16.6525)]	[(0.7835,2.0169);4.1174;(7.2462,11.2798)]

Table A8: The normalized interval-valued fuzzy decision-making matrix

	A_1	A_2	A_3	A_4
M_1	[(0,0.0498);0.1295;(0.2849,0.4797)]	[(0.1697,0.3004);0.4814;(0.6836,1.0000)]	[(0,0.0131);0.0342;(0.1445,0.2699)]	[(0.1151,0.2058);0.3591;(0.5603,0.8745)]
M_2	[(0,0.0030);0.0073;(0.0916,0.1792)]	[(0.1216,0.22189);0.3770;(0.5809,0.8619)]	[(0,0.0439);0.1131;(0.2636,0.4564)]	[(0.2121,0.3543);0.5304;(0.7223,1.0000)]
M_3	[(0.0573,0.1290);0.2541;(0.4403,0.6810)]	[(0.2415,0.38793);0.5569;(0.7364,1.0000)]	[(0,0.01975);0.0512;(0.1747,0.3262)]	[(0.1727,0.3150);0.4960;(0.6884,0.9702)]
M_4	[(0.2345,0.3761);0.5448;(0.7310,1.0000)]	[(0.1667,0.2951);0.4729;(0.6714,0.9822)]	[(0.0755,0.1507);0.2857;(0.4860,0.7485)]	[(0,0.0158);0.0409;(0.1560,0.2897)]
M_5	[(0,0.0153);0.0396;(0.1513,0.2810)]	[(0.2555,0.3993);0.5640;(0.74093,1.0000)]	[(0.2058,0.34375);0.5146;(0.7008,0.9702)]	[(0.0456,0.1175);0.23994;(0.4222,0.6572)]

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