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An EDAS Method for Multiple Attribute Group Decision-Making under Intuitionistic Fuzzy Environment and Its Application for Evaluating Green Building Energy-Saving Design Projects

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Abstract: Multiple attribute group decision-making (MAGDM) methods have a significant influence on decision-making in a variety of strategic fields, including science, business and real-life studies. The problem of evaluation in green building energy-saving design projects could be regarded as a type of MAGDM problem. The evaluation based on distance from average solution (EDAS) method is one of the MAGDM methods, which simplifies the traditional decision-making process. Symmetry among some attributes that are known and unknown as well as between pure attribute sets and fuzzy attribute membership sets can be an effective way to solve MAGDM problems. In this paper, the classical EDAS method is extended to intuitionistic fuzzy environments to solve some MAGDM issues. First, some concepts of intuitionistic fuzzy sets (IFSs) are briefly reviewed. Then, by integrating the EDAS method with IFSs, we establish an IF-EDAS method to solve the MAGDM issues and present all calculating procedures in detail. Finally, we provide an empirical application for evaluating green building energy-saving design projects to demonstrate this novel method. Some comparative analyses are also made to show the merits of the method.

Keywords: multiple attribute group decision-making (MAGDM); intuitionistic fuzzy sets (IFSs); EDAS method; intuitionistic fuzzy weighted average (IFWA) operators; intuitionistic fuzzy weighted geometric (IFWG) operators; green building energy-saving design projects

1. Introduction

There are various issues regarding uncertainty and vagueness that can impact the process of decision-making [1–4]. Thus, in order to improve the accuracy of decision-making, Zadeh [5] initially presented the theory of fuzzy sets (FSs). Atanassov [6] introduced the concept of intuitionistic fuzzy sets (IFSs). Gou et al. [7] pointed out a novel exponential operational law about IFNs (Intuitionistic Fuzzy Numbers) and offered a method used to aggregate intuitionistic fuzzy information. Li and Wu [8] presented a comprehensive decision method based on the intuitionistic fuzzy cross entropy distance and the grey correlation analysis. Khan, Lohani and Ieee [9] put forward a novel similarity measure about IFNs depending on the distance measure of a double sequence of a bounded variation. Li et al. [10] developed a grey target decision-making method in the form of IFNs on the basis of grey relational analysis [11]. Chen et al. [12] developed a novel MCDM (Multiple Criteria Decision Making) method on the basis of the TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) method and similarity measures in the context of intuitionistic fuzzy. Gupta et al. [13] modified the superiority and inferiority ranking (SIR) method and combined it under IFSs. Lu and Wei [14] designed the TODIM (an acronym in Portuguese for Interactive Multi-criteria Decision Making) method for performance appraisal on social-integration-based rural reconstruction under IVIFSs (Interval-valued

Intuitionistic Fuzzy Numbers). Wu et al. [15] provided the VIKOR (Vlse Kriterijumska Optimizacija Kompromisno Resenje) method for financing risk assessment of rural tourism projects under IVIFSs (Interval-values Intuitionistic Fuzzy Sets). Wu et al. [16] proposed some interval-valued intuitionistic fuzzy Dombi Heronian mean operators for evaluating the ecological value of forest ecological tourism demonstration areas. Wu et al. [17] designed the algorithms for competitiveness evaluation of tourist destinations with some interval-valued intuitionistic fuzzy Hamy mean operators.

Ghorabaee et al. [18] designed a novel method called evaluation based on distance from average solution (EDAS) to tackle multi-criteria inventory classification (MCIC) issues. Ghorabaee et al. [19] modified the EDAS method to tackle supplier selection issues. Zhang et al. [20] provided the EDAS method for MCGDM (Multi-Criteria Group Decision Making) issues with picture fuzzy information. Peng and Liu [21] designed the neutrosophic soft decision-making algorithms on the basis of EDAS and novel similarity measures. Feng et al. [22] integrated the EDAS method with an extended hesitant fuzzy linguistic environment. He et al. [23] designed the EDAS method for MAGDM with probabilistic uncertain linguistic information. Karasan and Kahraman [24] designed a novel interval-valued neutrosophic EDAS method. Li et al. [25] defined the EDAS method for MAGDM issues under a q-rung orthopair fuzzy environment. Wang et al. [26] proposed the EDAS method for MAGDM under a 2-tuple linguistic neutrosophic environment. Ghorabaee et al. [27] presented the EDAS method with normally distributed data to tackle stochastic issues. Zhang et al. [28] extended the EDAS method to picture a 2-tuple linguistic environment. Li et al. [29] developed a novel method by extending the traditional EDAS method to picture fuzzy environment.

To the authors' knowledge, there is no research available which investigates the EDAS method based on the criteria importance using the CRiteria Importance Through Intercriteria Correlation (CRITIC) method with IFNs. Therefore, investigating an EDAS method with IFNs is a suitable research topic. The fundamental objective of our research was to develop an original method that could be used more effectively to address some MAGDM issues in the context of the EDAS method and IFNs. Thus, the main contribution of this paper can be outlined as follows: (1) The EDAS method was modified in the intuitionistic fuzzy environment; (2) the CRITIC method was used to derive the attributes' weights; (3) the EDAS method under an intuitionistic fuzzy environment was proposed to solve the MAGDM issues; (4) an application for evaluating green building energy-saving design projects was provided to show the superiority of this novel method, and a comparative analysis between the IF-EDAS method and other methods was also used to further verify the merits of this method. Some fundamental knowledge of IFSs is concisely reviewed in Section 2. The extended EDAS method was integrated with IFNs and the calculating procedures are depicted in Section 3. An empirical application for evaluating green building energy-saving design projects is provided to show the superiority of this approach, and some comparative analyses are also offered to further show the merits of this method in Section 4. Finally, we provide an overall conclusion of our work in Section 5.

2. Preliminaries

Intuitionistic Fuzzy Sets

Definition 1 [6]. *An intuitionistic fuzzy set (IFS) on the universe* X is an object of the form

$$I = \{\langle x, \mu_I(x), \nu_I(x)\rangle | x \in X\} \tag{1}$$

where $\mu_I(x) \in [0,1]$ *is called the "degree of membership of* I*" and* $\nu_I(x) \in [0,1]$ *is called the "degree of non-membership of* I*", and* $\mu_I(x)$, $\nu_I(x)$ *satisfy the following condition:* $0 \leq \mu_I(x) + \nu_I(x) \leq 1$, $\forall\, x \in X$.

Definition 2 [30]. *Let $I_1 = (\mu_1, \nu_1)$ and $I_2 = (\mu_2, \nu_2)$ be two intuitionistic fuzzy numbers (IFNs); the operation formula can then be defined as:*

$$I_1 \oplus I_2 = (\mu_1 + \mu_2 - \mu_1\mu_2, \nu_1\nu_2) \tag{2}$$

$$I_1 \otimes I_2 = (\mu_1\mu_2, \nu_1 + \nu_2 - \nu_1\nu_2) \tag{3}$$

$$\lambda I_1 = \left(1 - (1 - \mu_1)^\lambda, \nu_1^\lambda\right), \lambda > 0 \tag{4}$$

$$I_1^\lambda = \left(\mu_1^\lambda, 1 - (1 - \nu_1)^\lambda\right), \lambda > 0 \tag{5}$$

Definition 3 [31]. *Let $I_1 = (\mu_1, \nu_1)$ and $I_2 = (\mu_2, \nu_2)$ be IFNs; the score and accuracy functions of I_1 and I_2 can then be expressed as:*

$$S(I_1) = \mu_1 + \mu_1(1 - \mu_1 - \nu_1), S(I_2) = \mu_2 + \mu_2(1 - \mu_2 - \nu_2) \tag{6}$$

$$H(I_1) = \mu_1 + \nu_1, H(I_2) = \mu_2 + \nu_2 \tag{7}$$

For the two IFNs I_1 and I_2, regarding Definition 3, then:

$$\begin{aligned}
&(1)\ if\ s(I_1) < s(I_2),\ then\ I_1 < I_2;\\
&(2)\ if\ s(I_1) > s(I_2),\ then\ I_1 > I_2;\\
&(3)\ if\ s(I_1) = s(I_2), h(I_1) < h(I_2),\ then\ I_1 < I_2;\\
&(4)\ if\ s(I_1) = s(I_2),\ h(I_1) > h(I_2), then\ I_1 > I_2;\\
&(5)\ if\ s(I_1) = s(I_2), h(I_1) = h(I_2),\ then\ I_1 = I_2.
\end{aligned}$$

Under the context of the IFSs, some aggregation operators are introduced in this section, including an intuitionistic fuzzy weighted averaging (IFWA) operator and an intuitionistic fuzzy weighted geometric (IFWG) operator.

Definition 4. [30]. *Let $I_j = \left(\mu_{I_j}, \nu_{I_j}\right)(j = 1, 2, \cdots, n)$ be a collection of IFNs; the intuitionistic fuzzy weighted averaging (IFWA) operator can then be defined as:*

$$IFWA_\omega(I_1, I_2, \ldots, I_n) = \overset{n}{\underset{j=1}{\oplus}}\left(\omega_j I_j\right) \tag{8}$$

where $\omega = (\omega_1, \omega_2, \ldots, \omega_n)^T$ is the weight vector of $I_j (j = 1, 2, \ldots, n)$ and $\omega_j > 0, \sum_{j=1}^{n} \omega_j = 1$.

From Definition 4, the following result can be obtained:

Theorem 1. *The aggregated value using an IFWA operator is also an IFN, where*

$$IFWA_\omega(I_1, I_2, \ldots, I_n) = \overset{n}{\underset{j=1}{\oplus}}\left(\omega_j I_j\right) = \left(1 - \prod_{j=1}^{n}\left(1 - \mu_{I_j}\right)^{\omega_j}, \prod_{j=1}^{n}\left(\nu_{I_j}\right)^{\omega_j}\right) \tag{9}$$

where $\omega = (\omega_1, \omega_2, \ldots, \omega_n)^T$ be the weight vector of $I_j (j = 1, 2, \ldots, n)$ and $\omega_j > 0, \sum_{j=1}^{n} \omega_j = 1$.

Definition 5 [30]**.** *Let $I_j(j = 1, 2, \cdots, n)$ be a collection of IFNs; the intuitionistic fuzzy weighted geometric (IFWG) operator can then be defined as:*

$$IFWG_\omega(I_1, I_2, \ldots, I_n) = \underset{j=1}{\overset{n}{\otimes}} \left(I_j\right)^{\omega_j} \tag{10}$$

where $\omega = (\omega_1, \omega_2, \ldots, \omega_n)^T$ is the weight vector of $I_j(j = 1, 2, \ldots, n)$ and $\omega_j > 0$, $\sum\limits_{j=1}^{n} \omega_j = 1$.

Derived from Definition 5, the following result can be obtained:

Theorem 2. *The aggregated value using an IFWG operator is also an IFN, where*

$$IFWG_\omega(I_1, I_2, \ldots, I_n) = \underset{j=1}{\overset{n}{\otimes}} \left(I_j\right)^{\omega_j} = \left(\prod_{j=1}^{n} \left(\mu_{I_j}\right)^{\omega_j}, 1 - \prod_{j=1}^{n} \left(1 - \nu_{I_j}\right)^{\omega_j} \right) \tag{11}$$

where $\omega = (\omega_1, \omega_2, \ldots, \omega_n)^T$ is the weight vector of $I_j(j = 1, 2, \ldots, n)$ and $\omega_j > 0$, $\sum\limits_{j=1}^{n} \omega_j = 1$.

3. The EDAS Method with Intuitionistic Fuzzy Information

Integrating the EDAS method with IFSs, we built the IF-EDAS method in which the assessment values were given by IFNs. The calculating procedures of the developed method are described below. Let $Z = \{Z_1, Z_2, \ldots Z_n\}$ be the set of attributes, $z = \{z_1, z_2, \ldots z_n\}$ be the weight vector of attributes Z_j, where $z_j \in [0, 1]$, $j = 1, 2, \ldots, n$, $\sum_{j=1}^{n} z_j = 1$. Assume that $D = \{D_1, D_2, \ldots D_l\}$ is a set of decision makers that have a significant degree of $d = \{d_1, d_2, \ldots d_l\}$, where $d_k \in [0, 1]$, $k = 1, 2, \ldots, l$. $\sum_{k=1}^{l} d_k = 1$. Let $Y = \{Y_1, Y_2, \ldots Y_m\}$ be a discrete collection of alternatives. $Q = \left(q_{ij}\right)_{m \times n}$ is the overall intuitionistic fuzzy decision matrix, where q_{ij} means the value of alternative Y_i regarding the attribute Z_j. The specific calculating procedures are presented below.

Step 1. Set up each decision maker's intuitionistic fuzzy decision matrix $Q^{(k)} = \left(q_{ij}^k\right)_{m \times n}$ and calculate the overall intuitionistic fuzzy decision matrix $Q = \left(q_{ij}\right)_{m \times n}$.

$$Q^{(k)} = \left[q_{ij}^k\right]_{m \times n} = \begin{bmatrix} q_{11}^k & q_{12}^k & \cdots & q_{1n}^k \\ q_{21}^k & q_{22}^k & \cdots & q_{2n}^k \\ \vdots & \vdots & \vdots & \vdots \\ q_{m1}^k & q_{m2}^k & \cdots & q_{mn}^k \end{bmatrix} \tag{12}$$

$$Q = \left[q_{ij}\right]_{m \times n} = \begin{bmatrix} q_{11} & q_{12} & \cdots & q_{1n} \\ q_{21} & q_{22} & \cdots & q_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ q_{m1} & q_{m2} & \cdots & q_{mn} \end{bmatrix} \tag{13}$$

$$q_{ij} = \left(1 - \prod_{k=1}^{l} \left(1 - \mu_{q_{ij}^k}\right)^{d_k}, \prod_{k=1}^{l} \left(\nu_{q_{ij}^k}\right)^{d_k} \right) \tag{14}$$

where q_{ij}^k is the assessment value of the alternative $Y_i(i = 1, 2, \ldots, m)$ on the basis of the attribute $Z_j(j = 1, 2, \ldots, n)$ and the decision maker $D_k(k = 1, 2, \ldots, l)$.

Step 2. Normalize the overall intuitionistic fuzzy decision matrix $Q = \left(q_{ij}\right)_{m\times n}$ to $Q^N = \left[q_{ij}^N\right]_{m\times n}$.

$$q_{ij}^N = \begin{cases} \left(\mu_{ij}, \nu_{ij}\right), Z_j \text{ is a benefit criterion} \\ \left(\nu_{ij}, \mu_{ij}\right), Z_j \text{ is a cost criterion} \end{cases} \tag{15}$$

Step 3. Use the CRiteria Importance Through Intercriteria Correlation (CRITIC) method to determine the weighting matrix of attributes.

The CRITIC method was designed in this part to decide the attributes' weights. The calculating procedures of this method are presented below.

(1) Depending on the normalized overall intuitionistic fuzzy decision matrix $Q^N = \left(q_{ij}^N\right)_{m\times n}$, the correlation coefficient between attributes can be calculated as:

$$IC_{jt} = \frac{\sum_{i=1}^{m}\left(S\left(q_{ij}^N\right) - S\left(q_j^N\right)\right)\left(S\left(q_{it}^N\right) - S\left(q_t^N\right)\right)}{\sqrt{\sum_{i=1}^{m}\left(S\left(q_{ij}^N\right) - S\left(q_j^N\right)\right)^2}\sqrt{\sum_{i=1}^{m}\left(S\left(q_{it}^N\right) - S\left(q_t^N\right)\right)^2}}, j, t = 1, 2, \ldots, n \tag{16}$$

where $q_j^N = \frac{1}{m}\sum_{i=1}^{m} S\left(q_{ij}^N\right)$ and $q_t^N = \frac{1}{m}\sum_{i=1}^{m} S\left(q_{it}^N\right)$.

(2) Calculate the attributes' standard deviation.

$$IS_j = \sqrt{\frac{1}{m-1}\sum_{i=1}^{m}\left(S\left(q_{ij}^N\right) - S\left(q_j^N\right)\right)^2}, j = 1, 2, \ldots, n \tag{17}$$

where $q_j^N = \frac{1}{m}\sum_{i=1}^{m} S\left(q_{ij}^N\right)$.

(3) Calculate the attributes' weights.

$$z_j = \frac{IS_j \sum_{t=1}^{n}\left(1 - IC_{jt}\right)}{\sum_{j=1}^{n}\left(IS_j \sum_{t=1}^{n}\left(1 - IC_{jt}\right)\right)}, j = 1, 2 \ldots, n \tag{18}$$

where $z_j \in [0, 1]$ and $\sum_{j=1}^{n} z_j = 1$.

Step 4. Calculate the value of average solution (AV) regarding all proposed attributes.

$$AV = \left[AV_j\right]_{1\times n} = \left[\frac{\sum_{i=1}^{m} \hat{q}_{ij}^N}{m}\right]_{1\times n} \tag{19}$$

$$\left[AV_j\right]_{1\times n} = \left[\frac{\sum_{i=1}^{m} \hat{q}_{ij}^N}{m}\right]_{1\times n} = \left(1 - \prod_{i=1}^{m}\left(1 - \mu_{ij}^N\right)^{\frac{1}{m}}, \prod_{i=1}^{m}\left(\nu_{ij}^N\right)^{\frac{1}{m}}\right)_{1\times n} \tag{20}$$

Step 5. Depending on the AV results, the positive distance from average (PDA) and negative distance from average (NDA) can be calculated as:

$$PDA_{ij} = \left[PDA_{ij}\right]_{m\times n} = \frac{\max\left(0, \left(s\left(q_{ij}^{N}\right) - s\left(AV_j\right)\right)\right)}{s\left(AV_j\right)} \tag{21}$$

$$NDA_{ij} = \left[NDA_{ij}\right]_{m\times n} = \frac{\max\left(0, \left(s\left(AV_j\right) - s\left(q_{ij}^{N}\right)\right)\right)}{s\left(AV_j\right)} \tag{22}$$

Step 6. Calculate the values of SP_i and SN_i which denote the weighted sum of PDA and NDA.

$$SP_i = \sum_{j=1}^{n} z_j \cdot PDA_{ij}, \ \ NP_i = \sum_{j=1}^{n} z_j \cdot NDA_{ij} \tag{23}$$

Step 7. Depending on the above calculated results, SP_i and SN_i can be normalized as:

$$NSP_i = \frac{SP_i}{\max\limits_{i}(SP_i)}, \ \ NSN_i = 1 - \frac{SN_i}{\max\limits_{i}(SN_i)} \tag{24}$$

Step 8. Calculate the values of the appraisal score (AS) regarding each alternative's NSP_i and NSN_i:

$$AS_i = \frac{1}{2}(NSP_i + NSN_i) \tag{25}$$

Step 9. In terms of the calculated results of AS, all the alternatives can be ranked. The higher the value of AS, the higher the value of the optimal alternative that is selected.

4. The Empirical Example and Comparative Analysis

4.1. An Empirical Example

The energy conservation of a building, considering industrial, construction, and transportation aspects, is one of three key energy-saving fields. Following the implementation of the Chinese energy consumption and pollution reduction policy, the emergence and development of green architecture construction practices have become the trend with respect to sustainable development. Chinese construction energy conservation presents not only a pressing situation but also a tremendous potential, but it has been overlooked because of the lack of consideration for green architecture energy-saving designs. People rarely consider the economic benefits of green architecture to be achieved from energy-saving designs. They have not formed a standardized evaluation method for the energy-saving design for economic benefits. Thus, choosing a green building energy-saving design program for economic assessment methods to conduct research has a certain theoretical guidance significance and application value. In this section, an empirical example for evaluating green building energy-saving design projects considered as complex MAGDM issues [32–39] is provided using the IF-EDAS method. Taking its own business development into consideration, a building company requires a green building energy-saving design project for a school. There are five potential green building energy-saving design projects $Y_i(i = 1, 2, 3, 4, 5)$. In order to select the optimal green building energy-saving design project, the building company invites five experts $D = \{D_1, D_2, D_3, D_4, D_5\}$ (expert's weight $d = (0.20, 0.20, 0.20, 0.20, 0.20)$) to assess these green building energy-saving design projects. All experts give their assessment information depending on the four following attributes: ① Z_1 is traffic convenience; ② Z_2 is product price; ③ Z_3 is green environmental protection ability; and ④ Z_4 is service quality. Evidently, Z_2 is the building cost attribute, while Z_1, Z_3, and Z_4 are the benefit attributes. To obtain the optimal green building energy-saving design project, the calculating procedures are as follows.

Step 1. Set up each decision maker's intuitionistic fuzzy evaluation matrix $Q^{(k)} = \left(q_{ij}^{k}\right)_{m\times n}$ $(i = 1, 2, \ldots, m, j = 1, 2, \ldots, n)$ as shown in Tables 1–5. From these tables and Equations (12)–(14), the overall intuitionistic fuzzy decision matrix can be calculated. The results are presented in Table 6.

Table 1. Intuitionistic fuzzy evaluation information by D_1.

	Z_1	Z_2	Z_3	Z_4
Y_1	(0.35,0.65)	(0.52,0.48)	(0.24,0.76)	(0.43,0.57)
Y_2	(0.39,0.61)	(0.66,0.34)	(0.75,0.25)	(0.61,0.39)
Y_3	(0.40,0.60)	(0.33,0.67)	(0.56,0.44)	(0.28,0.72)
Y_4	(0.67,0.33)	(0.58,0.42)	(0.41,0.59)	(0.47,0.53)
Y_5	(0.26,0.74)	(0.42,0.58)	(0.52,0.48)	(0.62,0.38)

Table 2. Intuitionistic fuzzy evaluation information by D_2.

	Z_1	Z_2	Z_3	Z_4
Y_1	(0.38,0.62)	(0.43,0.57)	(0.29,0.71)	(0.55,0.45)
Y_2	(0.63,0.37)	(0.34,0.66)	(0.48,0.52)	(0.52,0.48)
Y_3	(0.50,0.50)	(0.27,0.73)	(0.41,0.59)	(0.16,0.84)
Y_4	(0.46,0.54)	(0.62,0.38)	(0.57,0.43)	(0.29,0.71)
Y_5	(0.60,0.40)	(0.46,0.54)	(0.42,0.58)	(0.33,0.67)

Table 3. Intuitionistic fuzzy evaluation information by D_3.

	Z_1	Z_2	Z_3	Z_4
Y_1	(0.44,0.56)	(0.58,0.42)	(0.31,0.69)	(0.40,0.60)
Y_2	(0.58,0.42)	(0.65,0.35)	(0.42,0.58)	(0.74,0.26)
Y_3	(0.35,0.65)	(0.48,0.52)	(0.18,0.82)	(0.62,0.38)
Y_4	(0.27,0.73)	(0.26,0.74)	(0.62,0.38)	(0.31,0.69)
Y_5	(0.46,0.54)	(0.44,0.56)	(0.34,0.66)	(0.65,0.35)

Table 4. Intuitionistic fuzzy evaluation information by D_4.

	Z_1	Z_2	Z_3	Z_4
Y_1	(0.52,0.48)	(0.37,0.63)	(0.25,0.75)	(0.22,0.78)
Y_2	(0.51,0.49)	(0.64,0.36)	(0.77,0.23)	(0.42,0.58)
Y_3	(0.43,0.57)	(0.58,0.42)	(0.41,0.59)	(0.66,0.34)
Y_4	(0.68,0.32)	(0.32,0.68)	(0.64,0.36)	(0.15,0.85)
Y_5	(0.37,0.63)	(0.63,0.37)	(0.52,0.48)	(0.27,0.73)

Table 5. Intuitionistic fuzzy evaluation information by D_5.

	Z_1	Z_2	Z_3	Z_4
Y_1	(0.63,0.37)	(0.45,0.55)	(0.39,0.61)	(0.53,0.47)
Y_2	(0.53,0.47)	(0.37,0.63)	(0.60,0.40)	(0.59,0.41)
Y_3	(0.47,0.53)	(0.29,0.71)	(0.52,0.48)	(0.27,0.73)
Y_4	(0.41,0.59)	(0.53,0.47)	(0.56,0.44)	(0.19,0.81)
Y_5	(0.33,0.67)	(0.48,0.52)	(0.54,0.46)	(0.21,0.79)

Table 6. Overall intuitionistic fuzzy evaluation information.

	Z_1	Z_2	Z_3	Z_4
Y_1	(0.4745,0.5255)	(0.4752,0.5248)	(0.2981,0.7019)	(0.4373,0.5627)
Y_2	(0.5346,0.4654)	(0.5532,0.4468)	(0.6300,0.3700)	(0.5901,0.4099)
Y_3	(0.4324,0.5676)	(0.4030,0.5970)	(0.4298,0.5702)	(0.4361,0.5639)
Y_4	(0.5235,0.4765)	(0.4808,0.5192)	(0.5667,0.4333)	(0.2913,0.7087)
Y_5	(0.4168,0.5832)	(0.4923,0.5077)	(0.4732,0.5268)	(0.4477,0.5523)

Step 2. Normalize the evaluation matrix $Q = \left[q_{ij}\right]_{m \times n}$ to $Q^N = \left[q_{ij}^N\right]_{m \times n}$ (See Table 7).

Table 7. The normalized intuitionistic fuzzy evaluation information.

	Z_1	Z_2	Z_3	Z_4
Y_1	(0.4745,0.5255)	(0.5248,0.4752)	(0.2981,0.7019)	(0.4373,0.5627)
Y_2	(0.5346,0.4654)	(0.4468,0.5532)	(0.6300,0.3700)	(0.5901,0.4099)
Y_3	(0.4324,0.5676)	(0.5970,0.4030)	(0.4298,0.5702)	(0.4361,0.5639)
Y_4	(0.5235,0.4765)	(0.5192,0.4808)	(0.5667,0.4333)	(0.2913,0.7087)
Y_5	(0.4168,0.5832)	(0.5077,0.4923)	(0.4732,0.5268)	(0.4477,0.5523)

Step 3. Decide the attribute weights $z_j (j = 1, 2, \ldots, n)$ using the CRITIC method as presented in Table 8.

Table 8. The attributes weights z_j.

	Z_1	Z_2	Z_3	Z_4
z_j	0.1410	0.2263	0.3234	0.3093

Step 4. Depending on the calculated results of Table 8, the value of the average solution (AV) can be obtained based on all proposed attributes using Equations (19) and (20) (see Table 9).

Table 9. The value of the average solution.

	Average Solution
Z_1	$(0.4785, 0.5215)$
Z_2	$(0.5216, 0.4784)$
Z_3	$(0.4921, 0.5079)$
Z_4	$(0.4487, 0.5513)$

Step 5. Based on the results of AV, the positive distance from average (PDA) and negative distance from average (NDA) can be calculated using Equations (21) and (22) (see Tables 10 and 11).

Table 10. The results of PDA_{ij}.

	Z_1	Z_2	Z_3	Z_4
Y_1	0.0000	0.0063	0.0000	0.0000
Y_2	0.1173	0.0000	0.2802	0.3150
Y_3	0.0000	0.1447	0.0000	0.0000
Y_4	0.0941	0.0000	0.1517	0.0000
Y_5	0.0000	0.0000	0.0000	0.0000

Table 11. The results of NDA_{ij}.

	Z_1	Z_2	Z_3	Z_4
Y_1	0.0084	0.0000	0.3942	0.0255
Y_2	0.0000	0.1433	0.0000	0.0000
Y_3	0.0963	0.0000	0.1266	0.0282
Y_4	0.0000	0.0044	0.0000	0.3508
Y_5	0.1289	0.0265	0.0384	0.0023

Step 6. Based on Equation (23) and the attributes' weighting vector $\omega = (0.1410, 0.2263, 0.3234, 0.3093)$, the values of SP_i and SN_i can be calculated:

$$SP_1 = 0.0014,\ SP_2 = 0.2046,\ SP_3 = 0.0327,\ SP_4 = 0.0623,\ SP_5 = 0.0000$$

$$SN_1 = \ 0.1365\ , SN_2 = \ 0.0324\ , SN_3 = \ 0.0633\ , SN_4 = \ 0.1095\ , SN_5 = \ 0.0373$$

Step 7. The results of Step 6 can be normalized using Equation (24):

$$NSP_1 = 0.0069,\ NSP_2 = 1.0000,\ NSP_3 = 0.1600,\ NSP_4 = 0.3046,\ NSP_5 = 0.0000$$

$$NSN_1 = 0.0000, NSN_2 = 0.7626, NSN_3 = 0.5367, NSN_4 = 0.1979, NSN_5 = 0.7269$$

Step 8. Based on each alternative's NSP_i and NSN_i, the values of AS can be calculated:

$$AS_1 = 0.0035, AS_2 = 0.8813, AS_3 = 0.3483, AS_4 = 0.2512, AS_5 = 0.3634$$

Step 9. Based on the calculated results of AS, all the alternatives can be ranked; the higher the value of AS, the higher the optimal alternative that is selected. Evidently, the rank of all alternatives is $Y_2 > Y_5 > Y_3 > Y_4 > Y_1$ and Y_2 is the best green building energy-saving design project.

4.2. Comparative Analysis

In this section, our developed method is compared with other methods to illustrate its superiority. First, our presented method was compared with IFWA and IFWG operators [30]. For the IFWA operator, the calculated result is $S(Y_1) = 0.4263$, $S(Y_2) = 0.5703$, $S(Y_3) = 0.4756$, $S(Y_4) = 0.4842$, and $S(Y_5) = 0.4650$. Thus, the ranking order is $Y_2 > Y_4 > Y_3 > Y_5 > Y_1$. For the IFWG operator, the calculated result is $S(Y_1) = 0.4096$, $S(Y_2) = 0.5607$, $S(Y_3) = 0.4659$, $S(Y_4) = 0.4572$, and $S(Y_5) = 0.4631$. Therefore, the ranking order is $Y_2 > Y_3 > Y_5 > Y_4 > Y_1$.

Furthermore, our presented method was compared with the modified VIKOR method with IFSs [40]. Then, we obtained the following calculated results. The closest ideal score values were determined as follows: $CI^*(Y_1) = 1.0000$, $CI^*(Y_2) = 0.1803$, $CI^*(Y_3) = 0.3301$, $CI^*(Y_4) = 0.6522$, and $CI^*(Y_5) = 0.3962$. The worst score values were determined as follows: $CI^-(Y_1) = 0.0000$, $CI^-(Y_2) = 0.5000$, $CI^-(Y_3) = 0.7144$, $CI^-(Y_4) = 0.1755$, and $CI^-(Y_5) = 0.1038$. Then, each alternative's relative closeness was calculated as follows: $DRC_1 = 1.0000$, $DRC_2 = 0.2650$, $DRC_3 = 0.3161$, $DRC_4 = 0.7880$, and $DRC_5 = 0.7925$. Hence, the ranking order of alternatives is $Y_2 > Y_3 > Y_4 > Y_5 > Y_1$.

Finally, our presented method was compared with GRA (Grey Relational Analysis)-based intuitionistic fuzzy [41]. Then, we obtained the following calculated results. The grey relational grades of each alternative were calculated as follows: $\gamma_1 = 0.8297$, $\gamma_2 = 1.0000$, $\gamma_3 = 0.8206$, $\gamma_4 = 0.8717$, and $\gamma_5 = 0.8533$. Therefore, the ranking order of alternatives is $Y_2 > Y_4 > Y_5 > Y_1 > Y_3$. The results of dissimilar methods are recorded in Table 12.

Table 12. Evaluation results of dissimilar methods.

Methods	Ranking Order	The Optimal Alternative	The Worst Alternative
IFWA	$Y_2 > Y_4 > Y_3 > Y_5 > Y_1$	Y_2	Y_1
IFWG	$Y_2 > Y_3 > Y_5 > Y_4 > Y_1$	Y_2	Y_1
The modified VIKOR	$Y_2 > Y_3 > Y_4 > Y_5 > Y_1$	Y_2	Y_1
The GRA method	$Y_2 > Y_4 > Y_5 > Y_1 > Y_3$	Y_2	Y_3
The developed method	$Y_2 > Y_5 > Y_3 > Y_4 > Y_1$	Y_2	Y_1

From Table 12, it is evident that the optimal green building energy-saving design project is Y_2 in the mentioned methods, while the poorest choice is Y_1 in most situations. Therefore, these method ranking results are slightly different.

5. Conclusions

In this paper, an IF-EDAS method was developed to tackle the MAGDM issues based on the description of the EDAS method and some fundamental notions of IFSs. Initially, the fundamental information of IFSs was simply reviewed. Second, the IFWA and IFWG operators were used to integrate the intuitionistic fuzzy information. Subsequently, based on the CRITIC method, the attributes' weights were decided. In addition, applying the EDAS method to the intuitionistic fuzzy environment, a novel method was designed, and the calculating procedures were briefly depicted. Finally, an application for evaluating a green building energy-saving design project was provided to confirm the superiority of this novel method, and a comparative analysis between an IF-EDAS method and other methods was also made to further verify the merits of this method. In our future work, an IF-EDAS method may be extended to interval-valued intuitionistic fuzzy sets and extensively applied to different uncertain situations [42–45] and ambiguous environments [46–50].

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