

Article

An Integrated Multi-Criteria Decision Model to Select Sustainable Construction Projects under Intuitionistic Fuzzy Conditions

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Abstract: Choosing a proper construction project is a vital subject for entrepreneurs to reduce their costs. In real cases, vagueness and uncertain data drive decisions based on uncertainty. The intuitionistic fuzzy sets (IFSs) theory could assist decision-makers (DMs) in inscribing inadequate knowledge. Nevertheless, this paper provides a new integrated decision analysis model with IFSs. The suggested procedure includes a new decision flow under uncertain situations to define the significance of criteria. In this regard, the weighting of subjective DMs is required for this manner; the only input data needed are an alternative evaluation matrix. Then, a case study on sustainable energy project selection is explained to show the purpose of the suggested model. In this regard, four main criteria, technological, economic, social, and environmental, and seven alternatives from different kinds of energies are introduced to select the appropriate energy project. In this model, the weights of criteria are defined based on a new combined method based on two CRITIC and ideal points approaches. The proposed soft computing model computed the ranking of main alternatives by integrating the ARAS and EDAS approaches; the final outcomes indicate that the second alternative has higher values than other alternatives concerning nuclear energy. Afterward, sensitivity and comparative analyses are generated to determine the efficiency and validity of the proposed model. The sensitivity analysis changes the criteria weights. The comparative analysis compares the IF-TOPSIS method and the proposed model and computes the different degrees to confirm the efficiency of the introduced soft computing model.

Keywords: sustainable construction projects; MCDM method; intuitionistic fuzzy sets; CRITIC method; ideal point approach; ARAS method; EDAS method



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1. Introduction

Nowadays, one of the most important projects in various types of industries is construction projects. This kind of project has different significant practices, which affect management operations [1]. Prior papers have determined that the construction project and its operations have considerable effects on the environment [2,3]. Moreover, the construction sector is distinguished from other industrial sectors by the long-term nature of its output [4]. The sustainable execution of a construction project over its life cycle is an essential perspective in achieving sustainable development goals. The reports of the World Commission on Environment and Development describe sustainable development as meeting the basic needs of society and satisfying their hopes for better life without compromising the capabilities of future generations. The concept of sustainable development is based on the balance among social, economic, and environmental dimensions [4,5].

Sustainability has diverse varieties of criteria that are related to its different aspects. The selection of each criterion is critical in the management of construction projects. The selection of criteria is performed regularly by decision-makers (DMs) and/or through

participatory procedures, as well as by integrating existing sets of criteria provided in the literature. However, the knowledge about the robustness of the selection phase, its utility, accuracy, validity, and feasibility are usually limited [6]. In this respect, the multi-criteria decision-making (MCDM) approaches are utilized to select the appropriate criteria for the evaluation of construction projects. Furthermore, the main alternatives for the construction projects are chosen using MCDM methods.

In the procedure of decision making, the data about attributes are regularly uncertain or fuzzy due to the expanding complexity of the real application situation and the vagueness of the natural subjective reality of human thinking. This reality has encouraged many authors to utilize the fuzzy set theory to model the uncertainty and vagueness in decision flows. Moreover, the fuzzy set theory is applied to management decision-making problems [7,8]. However, to overcome the disadvantage of fuzzy sets (FSs), the intuitionistic fuzzy set (IFS) was proposed by joining a non-membership degree. The notion of IFSs is introduced as an extension of the FS. Apart from the degree of membership, which is presented in the FS, in IFSs, a degree of non-membership is added. These two degrees may not add up to one, and the complement of their sum to one is the so-called degree of uncertainty. The IFS represents an object simultaneously from both the advantage and disadvantage aspects. The last two decades have observed the strong expansion of the IFSs since they address the fuzziness of things more comprehensively [9]. The IFS helps to increase the closeness of the problem to real-world applications [10].

In the literature, the use of fuzzy logic in solving various problems in the construction sector, where incomplete and imprecise information exists, has been widely recognized [11]. Many fuzzy-based methods and techniques have been proposed to solve various decision-making problems. One of the main aims of reviewing the literature is to determine the strength points of the proposed integrated soft computing model and the lack of this method to select the appropriate alternatives in different uncertain conditions. For instance, Florez et al. [12] described the effect of sustainability on the selection of optimal materials in a construction project. They aimed at maximizing the number of LEED material-related credits. Ebrahimnejad et al. [13] proposed a two-phase group decision-making approach to evaluate and select a construction project under fuzzy conditions. Rezakhani [14] introduced the fuzzy MCDM technique to choose the appropriate risk factor in construction projects. Tsai et al. [15] generated the MCDM-based approach for the selection of construction methods in green building projects. Dėjus and Antuchevičienė [16] proposed an MCDM method based on WASPAS and entropy approaches to assess the safety and health solutions in the construction site. Tamošaitienė et al. [17] assessed the risk of a commercial center construction project with an MCDM method under fuzzy conditions. The study used a technique for order of preference by similarity to the ideal solution (TOPSIS)-F method to rank objects with an optimality degree. Taylan et al. [18] proposed a selection procedure to assess the construction project risk with the analytic hierarchy process (AHP) and TOPSIS methods in fuzzy environments. Mousavi et al. [10] introduced a fuzzy grey approach to select the options in the inception planning of the manufacturing process. Gitinavard and Mousavi [19] assessed a construction project with a new MCDM approach based on IF conditions. Mousavi and Mousavi et al. [20] presented an IF VIKOR multi-attribute group decision-making approach for complex decision-making problems. The paper used two application examples to validate the provided approach. Prascevic and Prascevic [21] expanded a fuzzy AHP method to select and rank the alternatives for the construction project management. Pavlovskis et al. [22] evaluated the redevelopment building possibilities with an MCDM method and BIM approach. Chatterjee et al. [23] proposed an integrated MCDM method to assess the management risk of the construction project. Wang et al. [24] evaluated the risks of construction projects with an MCDM approach based on the VIKOR method under fuzzy conditions. Dahooie et al. [25] used the additive ratio assessment (ARAS) method with fuzzy interval values to assess the project. This paper applied a case study of oil and gas drilling. Atanassov et al. [26] proposed a generalized net model by considering the multi-criteria decision-making method using an intercriteria

analysis. This paper introduced an index matrix of elements regarding the dependencies between the criteria under IF situations. Chalekaee et al. [27] proposed an integrated MCDM approach to evaluate the change response delay of the construction project under the grey numbers requirement. Davoudabadi et al. [28] introduced a compromise solution with a linear assignment method under uncertainty conditions to select the construction project. Afterwards, Gunduz and Khader [29] utilized an analytic network process (ANP) approach to evaluate safety performance management in construction projects. Mohandes et al. [30] developed a new risk assessment model to assess construction laborers' safety level. The research integrated the fuzzy best–worst method (FBWM) with the interval-valued fuzzy TOPSIS (IVFTOPSIS). Fallahpour et al. [31] proposed an integrated fuzzy programming with an MCDM method to select an appropriate decision in construction projects under sustainability requirements. This paper developed a combination of fuzzy preference programming (FPP) as a modification of the fuzzy AHP approach to evaluate the sustainability of construction projects. Zhang et al. [32] used a hybrid multi-expert multi-criteria decision-making model by integrating the best–worst method (BWM) and combined compromise solution (CoCoSo) method based on the rough boundary intervals for a supplier selection in housing development. Peng et al. [33] proposed an integrated multi-criteria decision-making framework for sustainable supplier selection under picture fuzzy environment.

Mousavi et al. [34] proposed a hesitant fuzzy ELECTRE I-based MCDM method to evaluate risk preferences in an imprecise setting in flexible manufacturing systems. Banihashemi et al. [35] introduced a fuzzy SWARA–TOPSIS approach for construction scheduling to assess trade-off among time-cost and quality. Tamošaitienė et al. [36] applied the fuzzy analytic hierarchy process (FAHP) technique to prioritize the criteria of appropriate repair and maintenance methods for commercial buildings. Naik et al. [37] introduced an MCDM method based on criteria importance through intercriteria correlation (CRITIC) and evaluation based on distance from the average solution (EDAS) approach to compute the weights and rankings of alternatives, respectively. Kao et al. [38] proposed a fuzzy MCDM model to select the supplier in supply chain management. Li et al. [39] provided LGBWM and IFNs to select personnel with a data-driven decision-making structure. Seker and Kahraman [40] introduced a Pythagorean cubic fuzzy approach based on the TOPSIS and TODIM methods to select suitable software. Zhang and Chen [41] generated the multi-criteria group decision-making approach by considering the cloud model and TOPSIS method to determine the alternative under an uncertain condition. Salimian et al. [42] proposed a new combined model based on extended VIKOR and MARCOS approaches to select a sustainable supplier in organ transplantation networks with respect to interval-valued intuitionistic fuzzy (IVIF). Salimian et al. [43] introduced the integrated IVIF model based on the RPR, MABAC, and WASPAS approaches in an infrastructure project assessment problem. Ghorui et al. [44] introduced the MCDM methodology with IF uncertainty requirements to select the cloud service providers.

This paper proposes the integration of approaches to obtain the weights of criteria and the ranking of alternatives, where weights of criteria are computed by combining the CRITIC and ideal point methods, and the ranks of alternatives are calculated by integrating the EDAS and ARAS approaches under uncertainty. Moreover, this paper utilizes IFSs to increase the accuracy of the decision process from DMs to make a suitable decision in real-world applications. Afterward, a real case study is presented to validate the efficiency of the proposed integrated soft computing model. The main contributions of the paper are as follows:

- Introducing a new integrated weighting method based on the CRITIC and ideal point approaches under uncertainty.
- Extending an ideal point approach for weighting criteria in an IF environment.
- Proposing a new combined ranking method based on the ARAS and EDAS approaches under uncertainty.
- Expanding an MCDM problem for the weighting and ranking of IFS situations.

The rest of this paper is organized as follows. Preliminaries of IFSs are presented in Section 1. The details of the proposed approach are given in Section 2. The real case study is presented in Section 3. The sensitivity analysis and comparative analysis are presented in Sections 4 and 5. Finally, conclusions and future research directions are given.

2. Preliminaries

This section presents the basic definitions related to the notion of IFSs. These formulations are determined as follows.

Definition 1. Let R be a universe of discourse. The IFS P from R is a goal presented in Equation (1) [45]:

$$P = \{ \langle r, \mu_P(r), v_P(r) \rangle | r \in R \}, \quad (1)$$

where $\mu_P : P \rightarrow [0, 1]$ is the value of the membership function, and the value of non-membership function is $v_P : P \rightarrow [0, 1]$. Moreover, $\pi_P = 1 - \mu_P - v_P$ is the hesitance degree. Hence, each $r \in R$ is presented as $0 \leq \mu_P(r) + v_P(r) \leq 1$.

Definition 2. Let Y and T be two IFSs from a set of R . The significant operators are described in Equations (2)–(8) [46,47]:

$$Y \cup T = \{ \langle r, \max(\mu_Y(r), \mu_T(r)), \min(v_Y(r), v_T(r)) \rangle | r \in Y \} \quad (2)$$

$$Y \cap T = \{ \langle r, \min(\mu_Y(r), \mu_T(r)), \max(v_Y(r), v_T(r)) \rangle | r \in Y \}; \quad (3)$$

$$\bar{Y} = \{ \langle r, v_Y(r), \mu_Y(r) \rangle | r \in Y \}; \quad (4)$$

$$Y \oplus T = \{ \langle r, \mu_Y(r) + \mu_T(r) - \mu_Y(r) \cdot \mu_T(r), v_Y(r) \cdot v_T(r) \rangle | r \in Y \}; \quad (5)$$

$$Y \otimes T = \{ \langle r, \mu_Y(r) \cdot \mu_T(r), v_Y(r) + v_T(r) - v_Y(r) \cdot v_T(r) \rangle | r \in Y \}; \quad (6)$$

$$Y^Q = \left\{ \left\langle r, \mu_Y(r)^Q, 1 - (1 - v_Y(r))^Q \right\rangle | r \in Y \right\}, Q > 0; \quad (7)$$

$$QY = \left\{ \left\langle r, 1 - (1 - \mu_Y(r))^Q, v_Y(r) \right\rangle | r \in Y \right\}, Q > 0. \quad (8)$$

Definition 3. Score function ($SF(Y)$) is computed by Equation (9) [48]:

$$SF(Y) = \frac{\mu_Y(r) - v_Y(r) + 1}{2}. \quad (9)$$

Definition 4. Euclidean distance is computed by Equation (10) [49]:

$$d(Y, T) = \sqrt{\frac{1}{2n} \sum_{i=1}^n \left((\mu_Y(r_i) - \mu_T(r_i))^2 + (v_Y(r_i) - v_T(r_i))^2 + (\pi_Y(r_i) - \pi_T(r_i))^2 \right)}. \quad (10)$$

Definition 5. Positive and negative normalized matrixes IF N_{ij} are introduced in Equation (11) ($\forall i = 1, 2, \dots, m; j = 1, 2, \dots, n$):

$$N_{ij} = \begin{cases} \{ [\mu_{ij}, v_{ij}] \}, & \text{for positive criteria} \\ \{ [1 - \mu_{ij}, 1 - v_{ij}] \}, & \text{for negative criteria} \end{cases} \quad (11)$$

3. Proposed New Integrated Soft Computing Model

This section proposes an integrated soft computing approach to obtain the weights of the criteria ($j = 1, 2, \dots, m$) and ranks of alternatives ($i = 1, 2, \dots, n$) through DMs' opinions ($k = 1, 2, \dots, K$). The provided model is based on recent literature [50–53]. This model contains three phases: data gathering in Phase 0, weighting of criteria in Phase 1, and ranking of alternatives in Phase 2. In this respect, the information is collected from each DM,

and the procedure starts to compute the weights of the criteria by an integrated approach based on the CRITIC and ideal point methods. The proposed integrated weighting method has advantages of both the CRITIC and ideal point approaches. The CRITIC method composes total priority data included in the assessment criteria based on the analysis of the evaluation matrix. Therefore, the objective weight is performed by quantifying the inherent knowledge of each estimation criterion. The procedure of specifying objective weight does not contain the criteria's standard deviation; it includes the correlation between criteria and other criteria [54]. Furthermore, the advantage of the ideal point procedure for the complex MCDM problem is that it can develop entire sets of weights for each criterion [55]. Hence, the proposed method has the main advantages of both weighting methods. Afterward, a new integrated method is used to obtain the rankings of alternatives by the ARAS and EDAS methods. The proposed combined ranking method employs advantages of both the ARAS and EDAS approaches. For this reason, the ARAS method is provided to improve the deviations of score values from the optimal degrees [56]. Other advantages of the ARAS method are that the calculations described in the modeling procedure of the decision-making problem are specific; moreover, the issues have a deep sense [57]. The main advantage of the EDAS method is that it has high efficiency and requires less calculation in comparison with other decision-making problems and a variety of approaches [58]. According to the previous explanations, the proposed ranking method is an efficient approach that has advantages of both the ARAS and EDAS methods concurrently. This approach includes an uncomplicated mathematical structure for the purpose of finding the best alternative. The model is presented in an IF environment. In other words, the main usage of this paper is regarded as the selection and evaluation problem that has sensitivity and needs to select the suitable situation in a high-risk environment. The real-world applications need to make an appropriate decision or select the better option. For this reason, the proposed soft computing model has the advantage of using the ARAS and EDAS methods under IF conditions. This method, by gathering expert opinions, helps to compute the ranking of the alternatives based on the best mentions. Moreover, this method adds the weights of the criteria and DMs that have an impact on the final outcomes. In this respect, the main advantages of using the IFS are described below:

- IFSs evaluate both benefits (memberships) and weaknesses (non-memberships) of a considered answer, and the ambiguous area is taken into account, as well [59].
- IFSs transform an unclear practice unit problem into a specific and well-described optimization problem.
- IFSs, unlike ordinary fuzzy sets, keep a metric degree of uncertainty [60].
- The IFS separates the positive and negative information for membership of an element in the set [61].

The steps of the proposed new integrated soft computing model are below:

Phase 0. Gathering the different DMs' opinions.

Step 1. Computing the decision matrix from experts' judgments by Equation (12).

This step creates a decision matrix with dimensions i and j based on the DMs' opinions to compute the weights of the criteria with a proposed integration approach.

$$D^k = \left(D_{ij}^k \right)_{n \times m} = \begin{pmatrix} D_{11}^k & \cdots & D_{1m}^k \\ \vdots & \ddots & \vdots \\ D_{n1}^k & \cdots & D_{nm}^k \end{pmatrix}_{n \times m} . \quad (12)$$

Step 2. Aggregating the decision matrix with subjective DMs' weights.

In this step, the effect of the DMs' opinions is applied by considering the weights of each expert on the decision-making matrix elements.

$$y_{ij} = \frac{\sum_{k=1}^K \omega^k D_{ij}^k}{\sum_{k=1}^K \omega^k} . \quad (13)$$

Step 3. Normalizing the decision matrix $y = (y_{ij})_{n \times m}$ by Definition 5.

In this respect, the aggregated decision matrix with the different DMs' opinions is normalized according to Definition 5 by considering the positive and negative natures of the criteria.

Phase 1. Computing the criteria weights.

Step 4. Calculating the weights of criteria by the CRITIC method with the following sub-steps:

Sub-step 4.1. Computing the score function by Definition 3.

This step computes the score function according to Definition 3 by considering the membership and non-membership values of the criteria.

Sub-step 4.2. Computing the standard deviation of criteria by Equation (14):

$$\varphi_j = \sqrt{\frac{\sum_{i=1}^n (y_{ij} - \bar{y}_j)^2}{m}} \quad (14)$$

$$\bar{y}_j = \frac{\sum_{i=1}^n y_{ij}}{m} \quad (15)$$

This step obtains the standard deviation of the criteria using the aggregation operator to aggregate the alternatives.

Sub-step 4.3. Calculating the correlation degree between pairs of criteria with Equation (16):

$$\phi_{ju} = \frac{\sum_{i=1}^n (y_{ij} - \bar{y}_j) - (y_{iu} - \bar{y}_u)}{\sqrt{\sum_{i=1}^n (y_{ij} - \bar{y}_j)^2 \sum_{i=1}^n (y_{iu} - \bar{y}_u)^2}} \quad (16)$$

where y_{iu} is a symmetric matrix with dimensions $n \times n$.

Sub-step 4.4. Obtaining the quantities of information about criteria by Equation (17):

$$\lambda_j = \varphi_j \sum_{u=1}^n (1 - \phi_{ju}) \quad (17)$$

This step computes the quantities of criteria information by utilizing the correlation degree between criteria, which is calculated from a symmetric matrix.

Sub-step 4.5. Computing the weights of criteria by Equation (18):

$$w_j = \frac{\lambda_j}{\sum_{j=1}^m \lambda_j} \quad (18)$$

The criteria weights are computed from information quantity degrees and take values between 0 and 1.

Step 5. Computing the weights of criteria by an extended ideal point approach.

Sub-step 5.1. Constructing the weighted decision matrix by Equation (19):

$$Y_{ij} = w_j y_{ij} = \begin{pmatrix} w_1 y_{11} & \cdots & w_m y_{1m} \\ \vdots & \ddots & \vdots \\ w_1 y_{n1} & \cdots & w_m y_{nm} \end{pmatrix} = \begin{pmatrix} w_1 [\mu_{11}, \nu_{11}] & \cdots & w_m [\mu_{1m}, \nu_{1m}] \\ \vdots & \ddots & \vdots \\ w_1 [\mu_{n1}, \nu_{n1}] & \cdots & w_m [\mu_{nm}, \nu_{nm}] \end{pmatrix}. \quad (19)$$

In this step, the impact of criteria weights is determined in the decision matrix. The primary values of criteria weights that are used in this step are taken from the CRITIC results.

Sub-step 5.2. Computing the ideal point $Y^* = \{Y_1^*, Y_2^*, \dots, Y_n^*\}$, where $Y_j^* = \max_i \{Y_{ij}\} = w_j \max_i \{y_{ij}\} = y_j^* w_j$. Moreover, the ideal value of each criterion is computed by $y_j^* = \max_i \{y_{ij}\}$.

Sub-step 5.3. Obtaining the difference between alternative i and the ideal point by Equation (20):

$$d_i(Y_{ij}, Y_j^*) = d_i(y_{ij}w_j, y_j^*w_j) = \sqrt{\frac{1}{2m} \sum_{j=1}^m \left((\mu_{ij}w_j - \mu_j^*w_j^*)^2 + (v_{ij}w_j - v_j^*w_j^*)^2 \right)}, \forall i. \tag{20}$$

In this step, the difference degree is computed from the Euclidean distance formulation that is presented in Definition 4.

Sub-step 5.4. Constructing an optimization model using the linear equal weight summation method by Equation (21):

$$Z = \min \sum_{i=1}^n \sqrt{\frac{1}{2m} \sum_{j=1}^m \left((\mu_{ij} - \mu_j^*)^2 + (v_{ij} - v_j^*)^2 \right)} \tag{21}$$

s.t.

$$\sum_{j=1}^m w_j = 1. \tag{22}$$

This step presents a linear mathematical formulation to optimize the summation value weight of the equal linear method.

Sub-step 5.5. Computing the Lagrange form of the model by Equation (23):

$$L = \sum_{i=1}^n \sqrt{\frac{1}{2m} \sum_{j=1}^m \left((\mu_{ij} - \mu_j^*)^2 + (v_{ij} - v_j^*)^2 \right)} + \lambda \left(\sum_{j=1}^m w_j - 1 \right). \tag{23}$$

In this formulation, λ is a Lagrange multiplier. The Hessian matrix of L with regard to w_j is $n \times n$ oblique matrix with oblique details as $2 \sum_{i=1}^n \frac{\sqrt{\frac{1}{2m} (\mu_{ij} - \mu_j^*)^2 + (v_{ij} - v_j^*)^2}}{w_j} > 0$. Because the constraint (22) is a non-empty convex set and the objective function (21) is convex, the optimal solutions would be the global optimal solutions, which are achieved by modifying L with respect to w_j and λ together:

$$\begin{cases} 2 \sum_{i=1}^n \frac{\sqrt{\frac{1}{2m} (\mu_{ij} - \mu_j^*)^2 + (v_{ij} - v_j^*)^2}}{w_j} w_j + \lambda = 0 \\ \sum_{j=1}^m w_j - 1 = 0 \end{cases} \tag{24}$$

Sub-step 5.6. Computing the weights of criteria with differentiations of L form w_j and λ by Equation (25):

$$w_j^* = \frac{1}{\sum_{j=1}^m \left[\frac{\sqrt{\frac{1}{2m} \sum_{i=1}^n (\mu_{ij} - \mu_j^*)^2 + (v_{ij} - v_j^*)^2}}{w_j} \right]^{-1} \times \frac{\sqrt{\frac{1}{2m} \sum_{i=1}^n (\mu_{ij} - \mu_j^*)^2 + (v_{ij} - v_j^*)^2}}{w_j}} \tag{25}$$

Step 6. Obtaining normalized final weights of criteria by Equation (26):

$$WF_j = \partial w_j + (1 - \partial)w_j^* \tag{26}$$

$$W_j = \frac{WF_j}{\sum_{j=1}^n WF_j} \tag{27}$$

where $0 \leq \partial \leq 1$.

This step obtains the final criteria weights by considering the integration approach that uses one aggregation value ∂ . Therefore, the final criteria weights take values between 0 and 1.

Phase 2. Computing the ranking of the alternatives.

Step 7. Computing the ranking of the alternatives by using the ARAS method.

Sub-step 7.1. Obtaining a normalized weighted decision matrix from Equation (28):

$$\mathcal{C}_{ij} = W_j y_{ij} = \begin{pmatrix} W_1 y_{11} & \cdots & W_m y_{1m} \\ \vdots & \ddots & \vdots \\ W_1 y_{n1} & \cdots & W_m y_{nm} \end{pmatrix} \quad (28)$$

This step uses the final criteria weights that are obtained from the proposed integrated weighting approach and shows the effect of the criteria weight on the decision matrix and final ranking results directly.

Sub-step 7.2. Calculating the overall performance rating (PR_i) and utility degree (U_i) from the score function that is computed from the \mathcal{C}_{ij} matrix by Definition 3:

$$PR_i = \sum_{j=1}^m \text{Score}(\mathcal{C}_{ij}), \forall i \quad (29)$$

$$U_i = \frac{PR_i}{PR_0}, \forall i, \quad (30)$$

where U_0 is an optimal value that is introduced in Equations (31) and (32) for benefit and cost nature criteria, respectively:

$$\mathcal{C}_{0j} = \max_i \mathcal{C}_{ij}, \forall i \quad (31)$$

$$\mathcal{C}_{0j} = \min_i \mathcal{C}_{ij}, \forall i \quad (32)$$

Step 8. Calculating the rankings of alternatives by the EDAS method.

Sub-step 8.1. Computing the average value in regards to the criteria by Equation (33):

$$AV_j = \frac{\sum_{i=1}^n y_{ij}}{n}, \forall j \quad (33)$$

This step computes the average value by considering the normalized weighted matrix.

Sub-step 8.2. Calculating the positive and negative ideal distances from the average value by Equations (34) and (35), respectively:

$$PD_{ij} = \frac{\max(0, ([\mu_{ij}, v_{ij}] - AV_j))}{AV_j}, \forall i, j \quad (34)$$

$$ND_{ij} = \frac{\max(0, (AV_j - [\mu_{ij}, v_{ij}]))}{AV_j}, \forall i, j \quad (35)$$

Sub-step 8.3. Computing the weighted summation of the positive and negative distances by Equations (36) and (37):

$$P_i = \sum_{j=1}^m PD_{ij} W_j, \forall i \quad (36)$$

$$N_i = \sum_{j=1}^m ND_{ij} W_j, \forall i \quad (37)$$

Sub-step 8.4. Normalizing the positive and negatives distances by Equations (38) and (39):

$$NP_i = \frac{P_i}{\max_I P_i}, \forall i \quad (38)$$

$$NN_i = \frac{N_i}{\max_I N_i}, \forall i \quad (39)$$

Sub-step 8.5. Obtaining the score function for NP_i and NN_i by Definition 4.

This step considers the score function regarding the membership and non-membership values of each alternative.

Sub-step 8.6. Computing the assessment score of each alternative from Equation (40):

$$S_i = \frac{NP_i + NN_i}{2}, \forall i. \quad (40)$$

Step 9. Calculating the final rankings of alternatives from Equation (41):

$$C_i = \varnothing U_i + (1 - \varnothing) S_i, \forall i \quad (41)$$

where $0 \leq \varnothing \leq 1$.

This step computes the final rankings of alternatives by considering the integrated value \varnothing . The final rank is computed with descending degrees of alternatives' scores. The framework of the introduced model is shown in Figure 1.

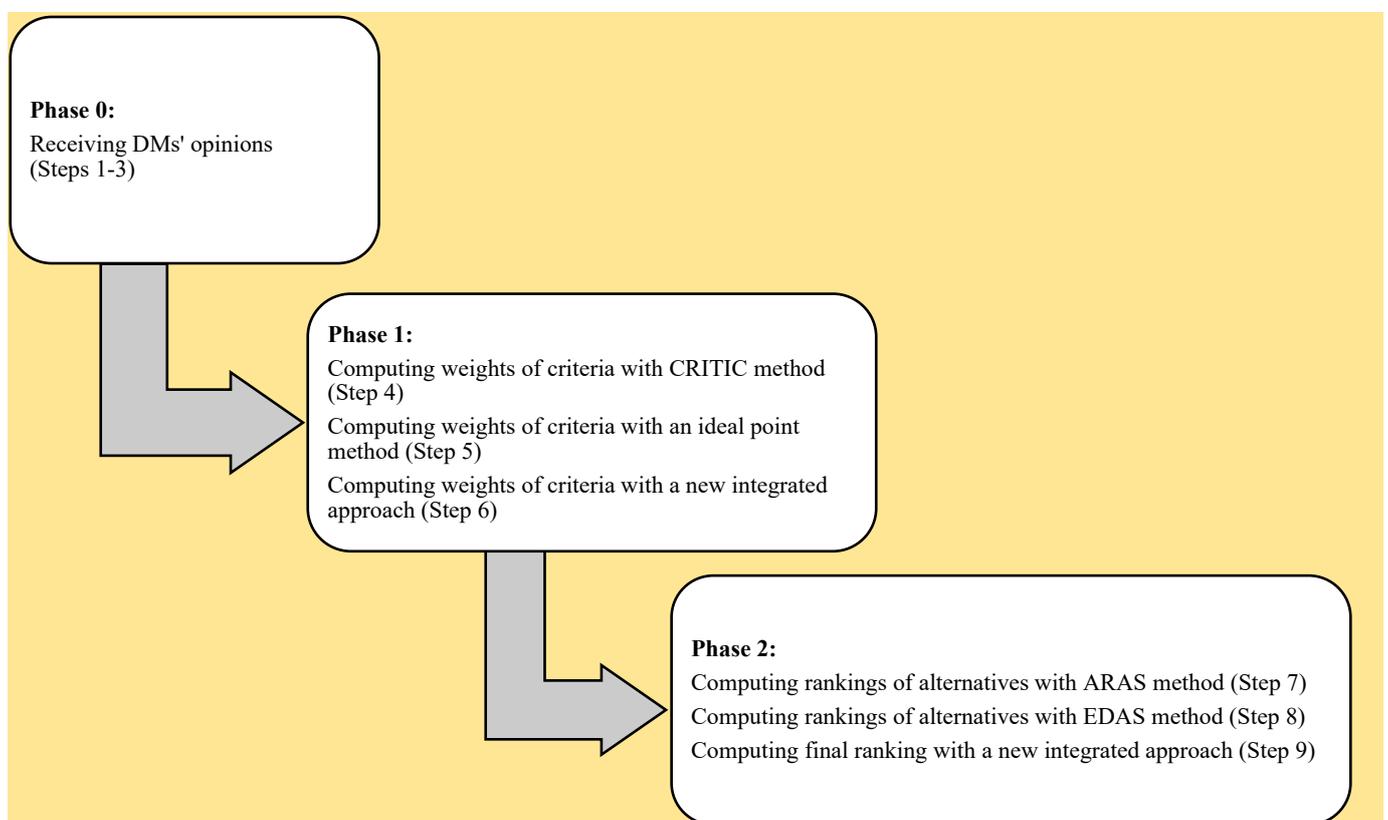


Figure 1. Structure of the introduced model.

4. Case Study

This section introduces a real case study to validate the efficiency of the suggested soft computing approach. This section utilizes the proposed model to select an appropriate sustainable energy project. This case was generated in an energy project environment that was provided by Kaya and Kahraman [62].

In this respect, seven alternatives are proposed with various kinds of energy projects. These alternatives consist of conventional (Al_1), nuclear (Al_2), solar (Al_3), wind (Al_4), hydraulic (Al_5), biomass (Al_6), and combined heat and power (Al_7) energy installations. Moreover, nine criteria are introduced ($Cr_j = Cr_1, \dots, Cr_9$) in four categories: technological, economic, social, and environmental. The interrelations among these criteria are shown in Figure 2 (Kaya and Kahraman, 2011). In this regard, three DMs ($D_k = D_1, D_2, D_3$) are invited to judge the values of decision matrix. In addition, the subjective weights of the DMs

are introduced $\omega^k = \{0.36, 0.31, 0.34\}$ from the study of Davoudabadi et al. [28]. Moreover, Table 1 determines the linguistic values of the IFS (Hashemi et al., 2013). Tables 2–4 present the experts’ opinions to construct the decision matrixes with the linguistic variables. Moreover, the third, fourth, seventh, and eighth criteria have cost nature, and the others have benefit nature. For example, Table 2 shows Cr_3 , which, compared to second alternative, has a very low degree that is kept from the first DM, and this point is shown with IF value [0.10, 0.75].

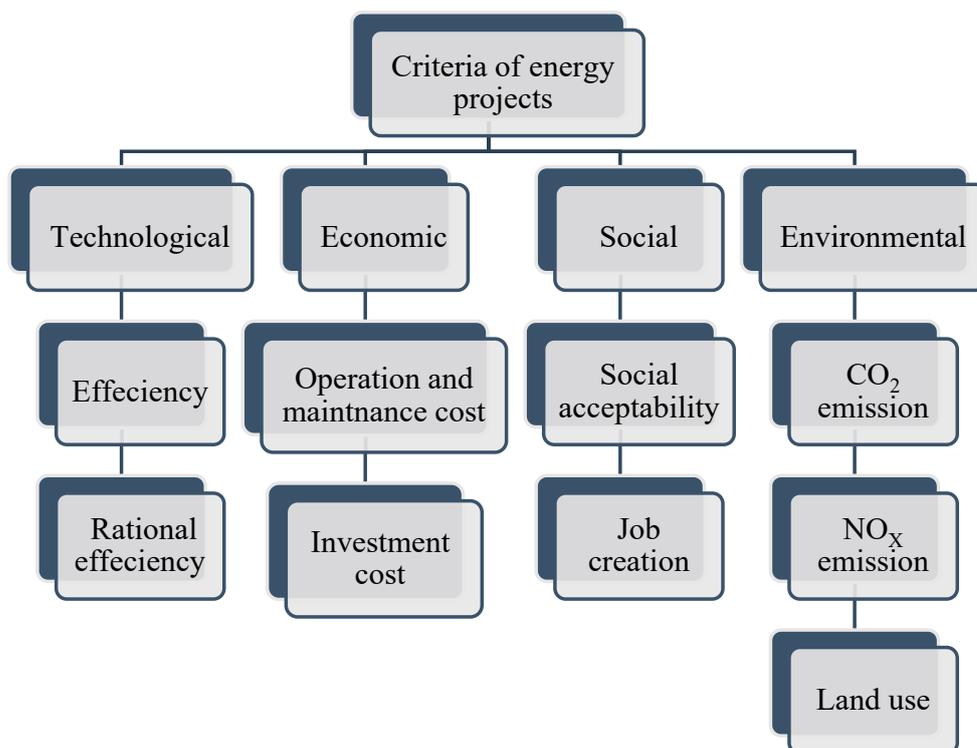


Figure 2. Criteria for assessment of energy projects.

Table 1. Linguistic terms for expert judgments.

Linguistic Variables	Intuitionistic Fuzzy Values
Extremely high (EH)	[0.95, 0.05]
Very very high (VVH)	[0.90, 0.10]
Very high (VH)	[0.80, 0.10]
High (H)	[0.70, 0.20]
Medium high (MH)	[0.60, 0.30]
Medium (M)	[0.50, 0.40]
Medium low (ML)	[0.40, 0.50]
Low (L)	[0.25, 0.60]
Very low (VL)	[0.10, 0.75]
Very very low (VVL)	[0.10, 0.90]

Table 2. Linguistic variables decision matrix from the first DM.

Criteria	Alternatives						
	Al_1	Al_2	Al_3	Al_4	Al_5	Al_6	Al_7
Cr_1	H	VH	M	ML	MH	M	M
Cr_2	H	M	M	MH	H	MH	MH
Cr_3	MH	VL	M	H	MH	M	M
Cr_4	MH	VH	M	H	M	M	ML
Cr_5	VL	ML	VH	H	ML	H	M
Cr_6	VL	ML	H	VH	L	H	M
Cr_7	L	ML	VH	VH	ML	MH	MH
Cr_8	ML	L	H	VH	M	H	H
Cr_9	MH	L	M	M	H	H	MH

Table 3. Linguistic variables decision matrix from the second DM.

Criteria	Alternatives						
	Al_1	Al_2	Al_3	Al_4	Al_5	Al_6	Al_7
Cr_1	VH	H	ML	M	M	M	MH
Cr_2	MH	VH	M	MH	H	M	M
Cr_3	H	ML	MH	H	MH	MH	M
Cr_4	M	VH	M	H	M	M	ML
Cr_5	VL	ML	VH	H	ML	H	M
Cr_6	ML	ML	H	VH	L	H	M
Cr_7	VL	VL	H	H	ML	MH	H
Cr_8	L	ML	H	VH	M	H	MH
Cr_9	H	H	MH	M	MH	H	MH

Table 4. Linguistic variables decision matrix from the third DM.

Criteria	Alternatives						
	Al_1	Al_2	Al_3	Al_4	Al_5	Al_6	Al_7
Cr_1	VH	VH	M	L	H	M	MH
Cr_2	VH	VH	M	MH	H	MH	M
Cr_3	MH	VL	M	H	MH	M	MH
Cr_4	MH	VH	M	VH	M	MH	M
Cr_5	ML	L	H	VH	ML	H	M
Cr_6	ML	ML	H	VH	L	H	M
Cr_7	L	ML	H	H	ML	MH	MH
Cr_8	ML	ML	H	VH	M	H	H
Cr_9	MH	H	M	M	H	MH	MH

The normalized decision matrix is shown in Table 5. The score matrix in the CRITIC method is given in Table 6. Furthermore, the symmetric score matrix with dimensions $n \times n$ is determined in Table 7. These are calculated from Definition 4. The quantities of \bar{y}_j , φ_j , \bar{y}_u , and ϕ_{ju} are demonstrated in Table 8. Moreover, in ideal point method, the amounts of y_j^* and $\sqrt{\frac{\frac{1}{2m} \sum_{i=1}^n (\mu_{ij} - \mu_j^*)^2 + (v_{ij} - v_j^*)^2}{w_j}}$ are determined in Table 9. After that, the values of $d_i(Y_{ij}, Y_j^*)$ are reported in Table 10. Furthermore, the value of $Z = 0.36051$.

Table 5. Normalized decision matrix.

Criteria	Alternatives						
	Al_1	Al_2	Al_3	Al_4	Al_5	Al_6	Al_7
Cr_1	[0.76436 0.13564]	[0.76931 0.13069]	[0.46931 0.43069]	[0.38020 0.50297]	[0.60297 0.29703]	[0.50000 0.40000]	[0.56436 0.33564]
Cr_2	[0.70297 0.19703]	[0.69307 0.20693]	[0.50000 0.40000]	[0.60000 0.30000]	[0.70000 0.20000]	[0.56931 0.33069]	[0.53564 0.36436]
Cr_3	[0.36931 0.73069]	[0.80792 0.32673]	[0.46931 0.63069]	[0.30000 0.80000]	[0.40000 0.70000]	[0.46931 0.63069]	[0.46634 0.63366]
Cr_4	[0.43069 0.66931]	[0.20000 0.90000]	[0.50000 0.60000]	[0.26634 0.83366]	[0.50000 0.60000]	[0.46634 0.63366]	[0.56634 0.53366]
Cr_5	[0.20099 0.66584]	[0.34950 0.53366]	[0.76634 0.13366]	[0.73366 0.16634]	[0.40000 0.50000]	[0.70000 0.20000]	[0.50000 0.40000]
Cr_6	[0.29307 0.58911]	[0.40000 0.50000]	[0.70000 0.20000]	[0.80000 0.10000]	[0.25000 0.60000]	[0.70000 0.20000]	[0.50000 0.40000]
Cr_7	[0.79604 0.35396]	[0.69208 0.42327]	[0.26436 0.83564]	[0.26436 0.83564]	[0.60000 0.50000]	[0.40000 0.70000]	[0.36931 0.73069]
Cr_8	[0.64604 0.46931]	[0.65347 0.46436]	[0.30000 0.80000]	[0.20000 0.90000]	[0.50000 0.60000]	[0.30000 0.80000]	[0.33069 0.76931]
Cr_9	[0.63069 0.26931]	[0.53960 0.34257]	[0.53069 0.36931]	[0.50000 0.40000]	[0.66931 0.23069]	[0.66634 0.23366]	[0.60000 0.30000]

Table 6. Score matrix.

Criteria	Alternatives						
	Al_1	Al_2	Al_3	Al_4	Al_5	Al_6	Al_7
Cr_1	0.81436	0.18317	0.81931	0.33069	0.51931	0.52525	0.43861
Cr_2	0.75297	0.25198	0.74307	0.35347	0.55000	0.40000	0.65000
Cr_3	0.31931	0.46139	0.74059	0.42871	0.41931	0.66535	0.25000
Cr_4	0.38069	0.73465	0.15000	0.70000	0.45000	0.66683	0.21634
Cr_5	0.26757	0.65817	0.40792	0.38366	0.81634	0.20000	0.78366
Cr_6	0.35198	0.59455	0.45000	0.40000	0.75000	0.20000	0.85000
Cr_7	0.72104	0.33094	0.63441	0.57946	0.21436	0.78564	0.21436
Cr_8	0.58837	0.40792	0.59455	0.58218	0.25000	0.80000	0.15000
Cr_9	0.68069	0.36485	0.59851	0.40594	0.58069	0.43465	0.55000

Table 7. Score of symmetric matrixes.

Criteria	Alternatives						
	Al_1	Al_2	Al_3	Al_4	Al_5	Al_6	Al_7
Cr_1	0.81436	0.18317	0.81931	0.33069	0.51931	0.52525	0.43861
Cr_2	0.75297	0.25198	0.74307	0.35347	0.55000	0.40000	0.65000
Cr_3	0.31931	0.46139	0.74059	0.42871	0.41931	0.66535	0.25000
Cr_4	0.38069	0.73465	0.15000	0.70000	0.45000	0.66683	0.21634
Cr_5	0.26757	0.65817	0.40792	0.38366	0.81634	0.20000	0.78366
Cr_6	0.35198	0.59455	0.45000	0.40000	0.75000	0.20000	0.85000
Cr_7	0.72104	0.33094	0.63441	0.57946	0.21436	0.78564	0.21436

Table 8. Amounts of \bar{y}_j , φ_j , \bar{y}_u , and ϕ_{ju} .

Criteria	\bar{y}_j	φ_j	\bar{y}_u	ϕ_{ju}
Cr_1	0.51867	0.57634	0.51867	0.57634
Cr_2	0.52878	0.48504	0.52878	0.48504
Cr_3	0.46924	0.43224	0.46924	0.43224
Cr_4	0.47122	0.58034	0.47122	0.58034
Cr_5	0.50248	0.60954	0.50248	0.60954
Cr_6	0.51379	0.56304	0.51379	0.56304
Cr_7	0.49717	0.58868	0.49717	0.58868

Table 9. Amounts of ideal point method parameters.

Criteria	y_j^*	$\frac{\sqrt{\frac{1}{2m} \sum_{i=1}^n (\mu_{ij} - \mu_j^*)^2 + (v_{ij} - v_j^*)^2}}{w_j}$
Cr_1	[0.01171 0.00766]	0.04459
Cr_2	[0.00758 0.00431]	0.03912
Cr_3	[0.00692 0.00685]	0.04134
Cr_4	[0.00874 0.01389]	0.05349
Cr_5	[0.01305 0.01134]	0.04717
Cr_6	[0.01162 0.00872]	0.04410
Cr_7	[0.01264 0.01327]	0.05501
Cr_8	[0.00912 0.01257]	0.05246
Cr_9	[0.00248 0.00148]	0.02371

Moreover, the weights of the criteria are computed by using the CRITIC method and ideal point approach. Afterwards, the final weights are obtained from Equation (27), and the results are introduced in Table 11. Table 11 presents weights of criteria determined by the CRITIC method, the ideal method, and the final aggregation weights with a new combination procedure.

Table 10. Distance values.

Alternative	$d_i(Y_{ij}Y_j^*)$
A_1	0.05246
A_2	0.05258
A_3	0.05208
A_4	0.05520
A_5	0.04879
A_6	0.05074
A_7	0.04866

Table 11. Weights of criteria.

Criteria	CRITIC Method	Ideal Point Method	Final Weights
Cr_1	0.12337	0.11121	0.11135
Cr_2	0.10383	0.09755	0.09762
Cr_3	0.09253	0.10308	0.10296
Cr_4	0.12423	0.13339	0.13329
Cr_5	0.13048	0.11764	0.11779
Cr_6	0.12053	0.10998	0.11011
Cr_7	0.12601	0.13718	0.13706
Cr_8	0.11816	0.13083	0.13068
Cr_9	0.06087	0.05912	0.05914

Afterwards, the score matrix (C_{ij}) is determined in Table 12. Moreover, the values of PR_i and S_i are shown in Table 13. The ranking values of the alternatives by ARAS, EDAS, and integrated methods are presented in Table 14. The ARAS, EDAS, and final ranking values are computed by using Equations (30), (40), and (41). The results reveal that the second alternative has a higher priority than other projects.

Table 12. Score matrix C_{ij} .

Criteria	Alternatives						
	Al_1	Al_2	Al_3	Al_4	Al_5	Al_6	Al_7
Cr_1	0.53687	0.53745	0.50226	0.49280	0.51794	0.50586	0.51341
Cr_2	0.52547	0.52447	0.50503	0.51510	0.52517	0.51201	0.50862
Cr_3	0.48233	0.52353	0.49211	0.47555	0.48533	0.49211	0.49182
Cr_4	0.48463	0.45492	0.49356	0.46346	0.49356	0.48922	0.50210
Cr_5	0.47116	0.48858	0.53925	0.53519	0.49380	0.53102	0.50620
Cr_6	0.48294	0.49424	0.52881	0.54034	0.47983	0.52881	0.50576
Cr_7	0.52909	0.51769	0.46241	0.46241	0.50658	0.48026	0.47622
Cr_8	0.51100	0.51177	0.46888	0.45643	0.49378	0.46888	0.47270
Cr_9	0.51084	0.50591	0.50484	0.50300	0.51316	0.51298	0.50900

Table 13. PR_i and S_i values.

Alternative	PR_i	S_i
Al_1	4.53434	0.46526
Al_2	4.55856	0.50944
Al_3	4.49715	0.35180
Al_4	4.44428	0.36535
Al_5	4.50914	0.41516
Al_6	4.52115	0.34387
Al_7	4.48584	0.45025

Table 14. Ranking of alternatives.

Alternative	ARAS Method	EDAS Method	Integration Approach	Final Rank
Al_1	8.96086	0.46526	4.71306	2
Al_2	9.00872	0.50944	4.75908	1
Al_3	8.88737	0.35180	4.61959	6
Al_4	8.78289	0.36535	4.57412	7
Al_5	8.91107	0.41516	4.66311	3
Al_6	8.93480	0.34387	4.63934	5
Al_7	8.86502	0.45025	4.65764	4

Based on the information, the DMs agreed with each other for evaluating projects and confirming each other.

5. Discussion of Results

In this section, the two types of analyses are presented to evaluate the efficiency and performance of the proposed soft computing model. In this respect, the sensitivity analysis is introduced to compare the effect of the criteria weights on the final ranking results. Moreover, the ranking outcomes are assessed with different values of \emptyset . Afterward, comparative analysis is introduced to evaluate the performance and reliability of the proposed approach with the IF-TOPSIS method whose results confirm the proposed soft computing model. Furthermore, a different degree is presented to assess the proposed method with the IF-TOPSIS approach.

5.1. Sensitivity Analysis

The sensitivity analysis of the obtained consequences from utilizing the introduced approach was carried out to assess the robustness of the ranking method. Hence, the reliability of the ranking method was analyzed by computing the rankings of alternatives with different values of criteria's weights. Figure 3 determines the reliability of the ranking method by changing the weights of the criteria.

In this respect, CW_{tp} shows the weight of criteria that changes from the t to p value. Hence, this figure demonstrates that the final ranking degrees do not change with the various weights of criteria, and these are independent of the weights of criteria in all stages. Figure 3 determines that the first alternative has higher priority compared to other alternatives.

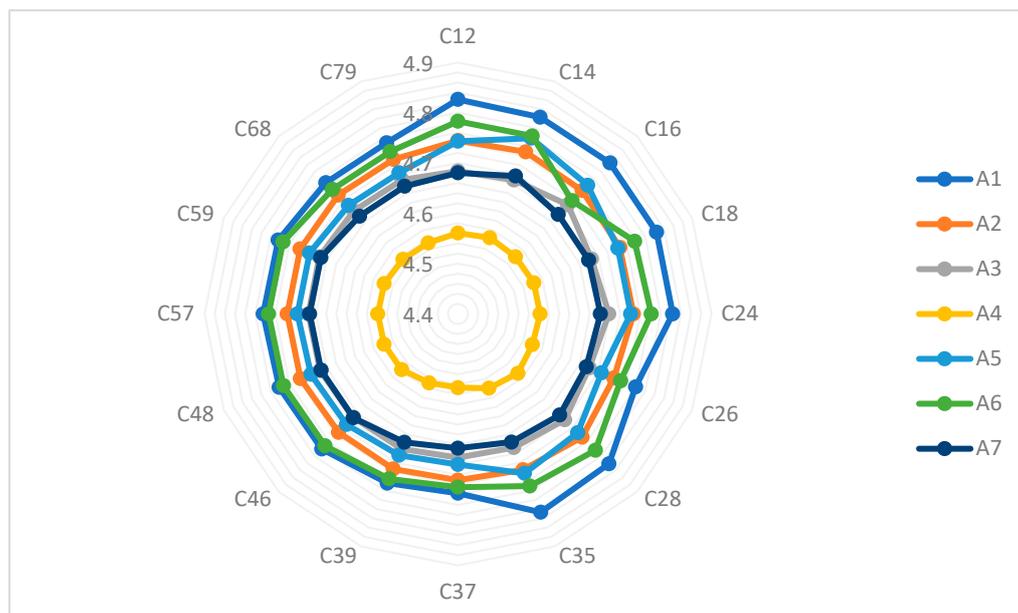


Figure 3. Impact of weights of criteria on final ranks.

The impact of the \emptyset value on results is determined in Table 15. This value obtains the amounts from 0.1 to 0.9, and the final outcomes show that the second alternative has higher value than the others, and the final ranking results are independent of \emptyset .

Table 15. Impact of \emptyset on final ranking results.

\emptyset	Al_1	Al_2	Al_3	Al_4	Al_5	Al_6	Al_7
0.1	8.11130	8.15879	8.03382	7.94113	8.06148	8.07571	8.02354
0.2	7.26174	7.30887	7.18026	7.09938	7.21189	7.21662	7.18207
0.3	6.41218	6.45894	6.32670	6.25763	6.36230	6.35752	6.34059
0.4	5.56262	5.60901	5.47314	5.41587	5.51270	5.49843	5.49911
0.5	4.71306	4.75908	4.61959	4.57412	4.66311	4.63934	4.65764
0.6	3.86350	3.90915	3.76603	3.73236	3.81352	3.78024	3.81616
0.7	3.01394	3.05923	2.91247	2.89061	2.96393	2.92115	2.97468
0.8	2.16438	2.20930	2.05891	2.04886	2.11434	2.06205	2.13321
0.9	1.31482	1.35937	1.20535	1.20710	1.26475	1.20296	1.29173

5.2. Comparative Analysis

This section provides a comparative analysis to measure the performance of the proposed model versus other approaches. For this reason, the proposed soft computing model’s rankings are compared with those of the IF-TOPSIS approach according to Park et al. [63]. Their results are depicted in Table 16 which shows that the proposed model has a higher performance than that of the related literature. The outcome determines the second alternative has a higher degree than other alternatives, and this point is confirmed by the other approach. Therefore, the integrated proposed model is validated to rank the alternatives of the MCDM problems.

Table 16. Performance of the proposed method.

Alternative	IF-TOPSIS Method	IF-TOPSIS rank	Proposed Approach	Final Rank
Al_1	0.50078	2	4.71306	2
Al_2	0.50633	1	4.75908	1
Al_3	0.49654	6	4.61959	6
Al_4	0.49060	7	4.57412	7
Al_5	0.49964	3	4.66311	3
Al_6	0.49783	5	4.63934	5
Al_7	0.49958	4	4.65764	4

Table 16 shows that the final ranking results are similar from three types of approaches, and the proposed model has some different advantages from other methods. The proposed approach has the benefits of using the IF-ARAS method along with the IF-EDAS approach. Moreover, the proposed hybrid method is able to handle the uncertain conditions by considering the membership and non-membership degrees with IFSs. Ultimately, the proposed model is a more efficient tool than the previous approach to rank the main alternatives to the MCDM problem.

Another way to determine the performance of the proposed soft computing method is related to computing the different degrees (DDs) between the proposed method and the IF-TOPSIS approach. According to this issue, DDs are obtained by Equation (42). In this respect, x and y are two alternative values, and $x > y$ [64].

$$DD = \frac{x - y}{y} \times 100 \quad (42)$$

Hence, this procedure determines that the method with a high degree of DDs is better than the other. Table 17 shows that the proposed IF ranking method has higher DD values than other analysis methods and demonstrates the efficiency and reliability of the introduced approach. It is worth mentioning that the high level of DDs in the model provides more special distinction of the ultimate alternative's significance. According to this section, the proposed method has high values in more positions that determine the efficiency of the introduced approach.

Table 17. Different degrees of the proposed approach and IF-TOPSIS method.

Alternative	IF-TOPSIS Method	IF-TOPSIS DD Value	IVIF-TOPSIS Rank	Proposed Approach	Proposed Approach DD Value	Final Rank
Al_4	0.49060	1.21248	7	4.57412	0.99407	7
Al_3	0.49654	0.25792	6	4.61959	0.42752	6
Al_6	0.49783	0.35275	5	4.63934	0.39445	5
Al_7	0.49958	0.01256	4	4.65764	0.11744	4
Al_5	0.49964	0.22662	3	4.66311	1.07117	3
Al_1	0.50078	1.10979	2	4.71306	0.97579	2
Al_2	0.50633		1	4.75905		1

Table 17 is presented to confirm the results of the proposed method and the IF-TOPSIS approach in the final ranking outcomes. This table shows that the second alternative has a higher degree than others. After that, the first alternative has a high value in regard to solar and nuclear energies, respectively.

The proposed introduced approach has several limitations. The proposed model requires experts for its execution and for obtaining deductions from the procedure. Moreover, the introduced model is procedural and orderly; accordingly, every step should be performed with supervision, which consumes significant calculating costs. Moreover, if criteria and/or alternatives become multiple, the model can need assembled computations, and the procedure may be long.

6. Conclusions and Future Suggestions

The multi-criteria decision-making (MCDM) methods are one of the essential tools that can be used by contractors in the selection of the most suitable construction projects. Hence, this paper introduced a new integrated intuitionistic fuzzy (IF) MCDM approach to assess the alternatives of different construction projects. Assurance of sustainability in construction projects usually requires increasing capital expenditures for organizations that are committed to supporting low carbon and more sustainable environment besides economic and social requirements. In this regard, the IF condition helps DMs to cope with vagueness and uncertain situations. For this purpose, this study utilized a linguistic term instead of a crisp value. Moreover, a novel model has proposed an integrated method to compute the weights of the criteria. This model combined the CRITIC method and ideal point approach. The calculations revealed that the seventh criterion (CO₂ emission) had a higher weight value compared to other criteria. Furthermore, to evaluate the rankings of the alternatives, this study used a new combined method that included the ARAS and EDAS methods under uncertainty. Afterwards, this study applied a case study from the current literature to validate the proposed approach. This case determined that the second alternative had a higher priority than the others regarding the nuclear energy type. Finally, this paper introduced a sensitivity analysis to analyze the efficiency of the proposed model. This method performs well in computing the rankings of the alternatives and has high reliability when the weights of criteria are changed. Moreover, a sensitivity analysis of the aggregator value was conducted to determine the dependency of the proposed approach on this value. By changing the values of the criteria weights, the results showed that the first alternative had a higher priority than the others in various situations. Finally, the comparative analysis was conducted to determine the performance of the proposed approach by comparing the proposed method with the IF-TOPSIS approach from the literature. The final outcomes of the IF-TOPSIS method confirmed the performance of and validity of the proposed soft computing model by determining that the second alternative had higher priority than the others with two various ranking approaches. Furthermore, the different degree values were computed to demonstrate the efficiency and reliability of the introduced method. In this process, each method has high degree of different degree that is better than the other; in more situations, the IF proposed model has high different degree values than the IF-TOPSIS approach. This point determined the efficiency and performance of the introduced soft computing model by comparing it with the common approach.

The main advantage of the proposed soft computing model is its ability to select of the appropriate alternative with various natures in different industries by combining the two different and extreme methods, the ARAS and EDAS approaches, under the condition of uncertainty that was handled by the IF set (IFS). This model used the advantages of the ARAS and EDAS methods separately and employed the IFS to cope with an uncertain condition, which is an important case in real-world applications. Moreover, IFS is one of the most powerful uncertainty methods regarding the membership and non-membership degrees and helps to consider real-world situations. This advantage is one of the most critical benefits of the proposed model among the literature approaches.

In future research, the proposed method could be extended in an analysis with interdependent criteria. Furthermore, the DMs' weights could be calculated by use of an objective method. Ultimately, the proposed method could use the interval value IF to cope with uncertain conditions.

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