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Sustainability Indicator Selection by a Novel Triangular Intuitionistic Fuzzy Decision-Making Approach in Highway Construction Projects

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Abstract: The construction industry has been criticized as being a non-sustainable industry that requires effective tools to monitor and improve its sustainability performance. The multiplicity of indicators of the three pillars of sustainability—economic, social, and environmental—complicates construction sustainability assessments for project managers. Therefore, prioritizing and selecting appropriate sustainability indicators (SIs) is essential prior to conducting a construction sustainability assessment. The main purpose of this research is to select the most appropriate set of SIs to address all three pillars of highway sustainability by a new group decision-making approach. The proposed approach accounts for risk attitudes of experts and entropy measures under a triangular intuitionistic fuzzy (TIF) environment, to handle the inherent uncertainty and vagueness that is present throughout the evaluation process. Furthermore, new separation measures and ranking scores are introduced to distinguish the preference order of SIs. Eventually, the approach is implemented in a case study of highway construction projects and the applicability of the approach is examined. To investigate the stability and validity of computational results, a sensitivity analysis is carried out and a comparison is made between the obtained ranking outcomes and the traditional decision-making methods.

Keywords: sustainable highway construction; sustainability indicators; triangular intuitionistic fuzzy; multi-criteria decision-making; entropy measure; risk attitudes

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1. Introduction

The preliminary concept of sustainable development was introduced in the 1980s [1]. According to the World Commission on Environment and Development (WCED) report, sustainable development refers to development that can be useful for nature, not harmful and aids in meeting the needs of present generations without compromising the needs of future generations. Sustainable development is generally balanced among three aspects or pillars: economic, environmental and social sustainability and aims to meet all these needs/objectives simultaneously [2].

In recent decades, sustainable construction—as a fundamental contributor towards sustainable development—has been the focus of a great deal of research. Recent research efforts have largely concentrated on the performance measurement process and sustainability assessment in building and construction projects, based on analytical and computational evaluation approaches, sustainable construction tools, standards and rating systems, or a combination of these. Indeed, these studies have attempted—by various techniques—to aid the construction industry in reaching sustainable development ideals and goals. As illustrated below, some of these research studies have been reviewed. Yu et al. [3] provided the project management team with planning strategies using a sustainability-assessing system. The proposed system was developed to monitor and evaluate the sustainability of whole activities throughout the construction projects' life cycle. Goubran and Cucuzzella [4] presented two analytical mapping tools for design teams of building projects to utilize Sustainable Development Goals (SDGs) as a sustainability analyzing framework in the design process. The first tool was constructed based on distinguishing between the architectural, engineering and operational concerns, while the second tool was designed based on the characteristics of the design approach (either product or human-focused) and its inspiration (history vs. future driven). Karaca et al. [5] developed a rapid sustainability assessment method using indicators and their relative weights attained from stakeholders, and an assessment approach based on the responses of buildings' occupants to measure the sustainability performance of residential buildings in Nur-Sultan, Kazakhstan. Li et al. [6] provided a comprehensive analysis of various stakeholder groups associated with sustainable construction in China. In addition, the level of stakeholder influence in decision/evaluations was measured using semi-structured interviews and the Delphi technique. Omer and Noguchi [7] developed a conceptual framework for the selection of appropriate building materials considering the implementation of the 2030 Agenda for Sustainable Development. Indeed, they presented a knowledge-based decision support system to assist policymakers, designers and construction stakeholders in making appropriate decisions towards the achievement of SDGs. Xu et al. [8] evaluated the sustainability of the construction industry by an assessment model based on the entropy method in China. The level of sustainability in construction projects was determined by two indices named the social, economic, and environmental benefits index and the ecological costs index. Illankoon et al. [9] suggested a scoring model regarding the inter-links between the Leadership in Energy and Environmental Design (LEED) credits and SDGs to evaluate buildings constructed in Australia. Their proposed model identified a Comprehensive Contribution to Development Index (CCDI) to policymakers as a guideline for evaluating building projects in order to achieve the United Nations (UN)'s SDGs. Olawumi et al. [10] introduced a grading system of buildings in Nigeria, named the Building Sustainability Assessment Method (BSAM) scheme. The scheme involves the identification of key sustainability assessment criteria and assigns weighted-scores to the various criteria by the multi-expert consultation method. Mansell et al. [11] used empirical evidence to identify a golden thread between sustainability reporting frameworks at the project level and the organizational level, and impacts of the UN's SDGs. The frameworks benefit from the Ceequal reporting methodology at the project level and the Global Reporting Initiative (GRI) methodology at the organizational level. Accordingly, a database of indicators was extracted that aligned with the specific SDG targets. Additionally, a robust investment appraisal was provided for the design stage of infrastructure projects.

Since highway projects are one of the most important aspects for the development of transportation infrastructure—necessary due to higher population concentrations and greater transportation demands in urban areas [12,13]—they have been considered as one of the most crucial components of sustainable development. Moreover, highway construction projects use a vast quantity of energy and natural materials, generate waste, and produce greenhouse gases that can greatly affect the sustainability of the construction industry.

The sustainability indicators (SIs) are significant factors in the sustainability assessment of highway projects. Various studies and tools have introduced numerous SIs for the assessment of the sustainability of construction projects that has led to the complication of the assessment process. Therefore, the prioritization of indicators and the adoption of an optimal number of SIs are major issues. In addition, the evaluation of SIs is complex for decision-makers, owing to inadequate evidence and uncertainty surrounding highway construction projects [13–15]. Hence, Multi-Criteria Decision-Making (MCDM) techniques under uncertainty are useful tools to cope with these problems [16–20]. While the construction industry plays an important role in global sustainable development, numerous research efforts have studied different subjects regarding the sustainability of the construction industry and the use of multi-criteria decision making to evaluate sustainability in this industry.

Huang and Yeh [21] developed a framework to analyze the green highway projects applying the max-min fuzzy Delphi method to recognize the main classifications and related items. Chen et al. [22] proposed a model called the construction method selection model aimed at lending support to assess the prefabrication feasibility at the initial level utilizing the simple multi-attribute rating technique and subsequently to adopt the best strategy to employ prefabrication at the following level. Reza et al. [23] proposed a thorough assessment technique using Triple Bottom Line (TBL) criteria to assess flooring systems with respect to the combination of Analytic Hierarchy Process (AHP) and Life Cycle Analysis (LCA) techniques. Waris et al. [24] established criteria for selecting sustainable construction equipment based on qualitative and quantitative feedbacks of construction industry experts and finally selected the top five criteria. Li et al. [25] proposed a comprehensive methodology using entropy, which is suitable for calculating weights, and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methods at the same time to evaluate the development of highway transportation. Kucukvar et al. [26] presented a fuzzy MCDM method for prioritizing pavements and selecting the best one based on the respective sustainability performance using the TOPSIS method. Medineckiene et al. [27] proposed a novel MCDM technique to adopt criteria from which their sets and weights are determined in accordance with the Swedish certification system Miljöbyggnad and used AHP for building sustainability assessment. Kamali and Hewage [28] identified sustainability performance indicators to evaluate life cycle sustainability. Subsequently, an organized framework was developed based on designing and conducting a survey to choose the most suitable sustainability performance indicators for modular and conventional construction methods in North America. Pan et al. [29] developed a sustainability indicator framework to reliably assess the performance of construction automation and robotics in the building industry context. Indeed, the study proposed guidelines for sustainable automated and robotic options for advanced construction technology. Zolfani et al. [30] presented a hybrid MCDM methodology applying Step-wise Weight Assessment Ratio Analysis (SWARA) and Complex Proportional Assessment (COPRAS) for criteria weights and prioritizing alternatives, respectively.

Liu and Qian [31] developed an integrated sustainability assessment methodology in accordance with the life cycle sustainability assessment framework. In addition, a combination of AHP and ELimination Et Choice Translating REality (ELECTRE) was applied to derive criteria weights and prioritize alternatives. Reddy et al. [32] introduced a decision-making method to adopt a sustainable material without Life Cycle Inventory (LCI) information requirements. In this method, criteria that highly influence material sustainability were investigated and consequently applied to analyze the performance of materials in different aspects of the material life cycle to develop a sustainable material performance index utilizing AHP. Chen [33] used a new multi-criteria assessment approach integrating the Grey Relational Analysis (GRA) and TOPSIS techniques, which operate according to the intuitionistic fuzzy entropy method, for selection of the appropriate sustainable supplier of construction materials. Roy et al. [34] developed a combinative distance-based evaluation method utilizing Interval-Valued Intuitionistic Fuzzy Numbers (IVIFNs) to decide comprehensively and logically to deal with the problem of material adoption under uncertainty. Tseng et al. [35] introduced various features and measures to build a model and assess the construction projects in Ecuador, employing fuzzy decision-making trials with Decision Making Trial and Evaluation Laboratory (DEMATEL) in addition to an Analytic Network Process (ANP) to evaluate interdependence between the features of a sustainable product–service system. Hendiani and Bagherpour [14] presented a novel social sustainability performance assessment in construction projects using fuzzy numbers to evaluate the present social sustainability position associated with construction. Furthermore, the barriers that reduce the value of the social sustainability index were recognized and addressed. Alawneh et al. [36] proposed a novel framework that identifies and weighs SIs for sustainable non-residential buildings and contributes to achieving the SDGs in Jordan. The framework applies the Delphi technique to identify and categorize SIs and then integrates AHP and Relative Importance Index (RII) methods to weigh SIs. In addition, a management tool (Gantt chart) integrates SIs into the project phases towards sustainable construction management. Dabous et al. [37] proposed a multi-criteria decision-support approach to handle decision-making in sustainable pavement adoption. The main sustainable decision factors were recognized through a hierarchy structure in their approach. In addition, the AHP technique in combination with multi-attribute utility theory was used to rank the networks of pavement sections. For sustainable landfill site selection, Rahimi et al. [38] introduced a Geographical Information System (GIS)-MCDM methodology considering the group fuzzy Best-Worst Method (BWM), fuzzy MULTIMOORA method and GIS-based suitability maps. The methodology was employed in Mahallat city, Iran, and it could provide suitable guidance for the waste management department of municipalities. Navarro et al. [39] developed an assessment methodology to measure the sustainability performance of the concrete bridge deck based on a neutrosophic group AHP approach. In addition, the TOPSIS technique was utilized to aggregate the sustainability criteria.

The aforementioned studies demonstrate that the previous research did not pay much attention to the sustainability performance of highway construction projects. Furthermore, there are no studies focusing on prioritizing and selecting the indicators of the three sustainability pillars. For the recognized gaps, a new multi-criteria weighting and ranking approach, according to group decision-making, is presented in the present study to analyze and adopt SIs in highway construction projects. Initially, SIs and criteria are collected and listed concerning experts' views and the literature review. Thus, triangular intuitionistic fuzzy (TIF) decision matrices are constructed based on experts' views in terms of linguistic variables. Subsequently, the weights of experts are gained according to the concept of entropy. Afterward, primary weight vectors of criteria are specified by entropy measures and experts' views. Finally, SIs are ranked based on the positive and negative ideal separation matrices via presenting a new ranking score. Moreover, a case study in highway construction projects is addressed to demonstrate the efficiency of the presented approach.

The rest of this paper is organized as follows. In Section 2, a novel multi-criteria group decision-making approach is proposed and applied in a case study of a highway construction project. Section 3 presents the results of the approach implementation in detail. The obtained results are compared with the prevalent decision-making methods and other mentioned SIs in the cited literature, and the sensitivity analyses are conducted in Section 4. To conclude the paper, Section 5 depicts the concluding remarks.

2. Materials and Methods

2.1. TIF Group Decision-Making Approach

The proposed approach aims to assist project managers in selecting the most significant SIs for sustainability assessment of highway construction projects based on a novel TIF group decision-making approach. Figure 1 presents the proposed approach for the selection of SIs.

The phases of the presented approach are as follows:

Step 1. Constitute a group of experts $(E_e; e = 1, 2, \ldots, t)$, whose views and judgments will be employed to build and assess the problem.

Step 2. Gather a list of indicators that are possible to be applied for the sustainability evaluation of highway construction projects $(I_i; i = 1, 2, \ldots, m)$.

Step 3. Recognize a set of criteria for analyzing SIs through consensus of experts' views $(C_j; j = 1, 2, \ldots, n)$.

Step 4. Assign the risk attitude to each expert and incorporate it into the related triangular intuitionistic fuzzy numbers (TIFNs) (Definition A1).

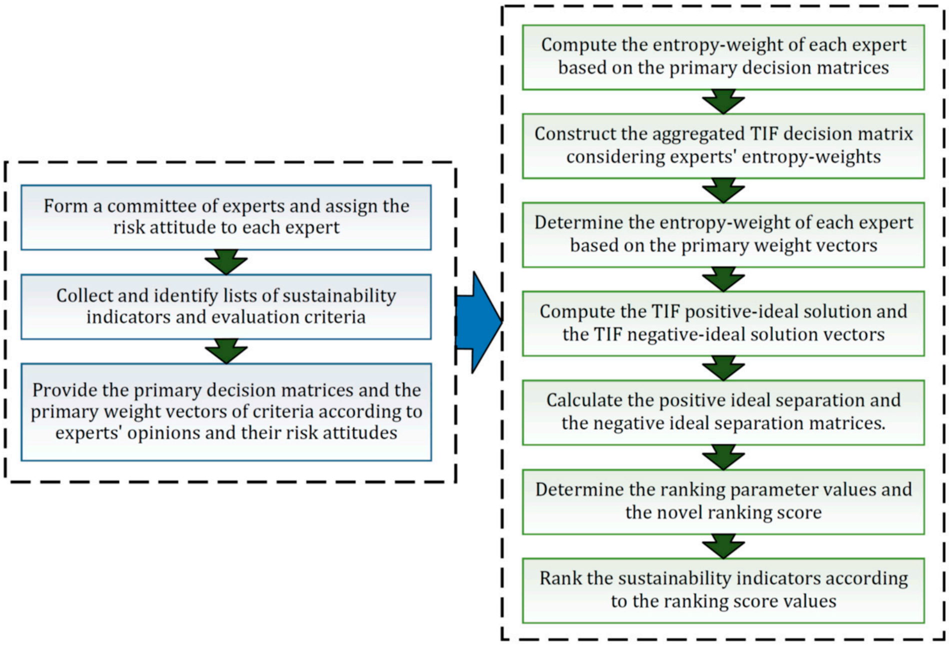


Figure 1. The proposed approach for the selection of sustainability indicators (SIs).

Each expert is assigned a risk attitude according to his or her character. The risk attitudes are able to be specified by a higher management level and expressed by linguistic variables, like absolutely optimistic (AO), optimistic (O), neutral (N), pessimistic (P), and absolutely pessimistic (AP) [40,41], for 5-scale TIFNs (Table 1).

Table 1. Linguistic variables of the risk attitudes assigned to each expert for 5-scale triangular intuitionistic fuzzy numbers (TIFNs).

Linguistic Variables	TIFN Derived from $\langle(a,b,c);\mu,\nu\rangle$ for Benefit Criteria	TIFN Derived from $\langle(a,b,c);\mu,\nu\rangle$ for Cost Criteria
Absolutely optimistic (AO)	$\langle(a,\ c,\ c);\mu+\pi,\ \nu\rangle$	$\langle(a,\ a,\ c);\mu,\ \nu+\pi\rangle$
Optimistic (O)	$\langle(a,\ (b+c)/2,\ c);\mu+\pi/2,\nu\rangle$	$\langle(a,\ (a+b)/2,\ c);\mu,\nu+\pi/2\rangle$
Neutral (N)	$\langle(a,b,\ c);\mu,\ \nu\rangle$	$\langle(a,b,\ c);\mu,\ \nu\rangle$
Pessimistic (P)	$\langle(a,\ (a+b)/2,\ c);\mu,\nu+\pi/2\rangle$	$\langle(a,\ (b+c)/2,\ c);\mu+\pi/2,\nu\rangle$
Absolutely pessimistic (AP)	$\langle(a,\ a,\ c);\mu,\ \nu+\pi\rangle$	$\langle(a,\ c,\ c);\mu+\pi,\ \nu\rangle$

In Table 1, π indicates the hesitation degree of TIFN $\langle(a,b,c);\mu,\ \nu\rangle$ and is equal to $1-\mu-\nu$.

Step 5. Construct the primary decision matrices based on the experts' views.

The primary decision matrices are constructed from the performance rating of each indicator versus each criterion based on the experts' view in terms of linguistic terms (Table 2) and converted into TIFNs.

$$\widetilde{X}^e = \left[\widetilde{x}_{ij}^e\right]_{m\times n} = \left[\left\langle\left(a_{\widetilde{x}_{ij}^e},\ b_{\widetilde{x}_{ij}^e},\ c_{\widetilde{x}_{ij}^e}\right);\mu_{\widetilde{x}_{ij}^e},\ \nu_{\widetilde{x}_{ij}^e}\right\rangle\right]_{m\times n} \tag{1}$$

Table 2. Linguistic variables applied for the rating of SIs.

Linguistic Variables	Triangular Intuitionistic Fuzzy Numbers
Extremely high (EH)	$\langle(0.95,\ 1.00,\ 1.00);0.95,\ 0.05\rangle$
Very very high (VVH)	$\langle(0.90,\ 1.00,\ 1.00);0.90,\ 0.10\rangle$
Very high (VH)	$\langle(0.80,\ 0.90,\ 1.00);0.80,\ 0.10\rangle$
High (H)	$\langle(0.70,\ 0.80,\ 0.90);0.70,\ 0.20\rangle$
Medium high (MH)	$\langle(0.50,\ 0.60,\ 0.70);0.60,\ 0.30\rangle$
Medium (M)	$\langle(0.30,\ 0.50,\ 0.70);0.50,\ 0.40\rangle$
Medium low (ML)	$\langle(0.30,\ 0.40,\ 0.50);0.40,\ 0.50\rangle$
Low (L)	$\langle(0.10,\ 0.20,\ 0.30);0.25,\ 0.60\rangle$
Very low (VL)	$\langle(0.00,\ 0.10,\ 0.20);0.10,\ 0.75\rangle$
Very very low (VVL)	$\langle(0.00,\ 0.00,\ 0.10);0.10,\ 0.90\rangle$

Step 6. Convert the primary decision matrices to the individual decision matrices based on each expert's risk attitude.

The primary decision matrices are converted to decision matrices taking into account each expert's risk attitude according to Table 1.

$$\widetilde{R}^e = \left[\widetilde{r}^e_{ij}\right]_{m\times n} = \left[\left\langle\left(a_{\widetilde{r}^e_{ij}},\ b_{\widetilde{r}^e_{ij}},\ c_{\widetilde{r}^e_{ij}}\right);\mu_{\widetilde{r}^e_{ij}},\ \nu_{\widetilde{r}^e_{ij}}\right\rangle\right]_{m\times n} \tag{2}$$

Step 7. Compute each expert's entropy-weight according to the individual decision matrices.

The entropy measure F^e_{ij} is calculated by [42]:

$$F^e_{ij} = -\frac{f^e_{ij}ln\left(f^e_{ij}\right)}{ln(t)}, \tag{3}$$

where

$$f^e_{ij} = \frac{\left(a_{\widetilde{r}^e_{ij}} + b_{\widetilde{r}^e_{ij}} + c_{\widetilde{r}^e_{ij}}\right)\times\left(1+\mu_{\widetilde{r}^e_{ij}} - \nu_{\widetilde{r}^e_{ij}}\right)}{\sum_{e=1}^{t}\left[\left(a_{\widetilde{r}^e_{ij}} + b_{\widetilde{r}^e_{ij}} + c_{\widetilde{r}^e_{ij}}\right)\times\left(1+\mu_{\widetilde{r}^e_{ij}} - \nu_{\widetilde{r}^e_{ij}}\right)\right]}. \tag{4}$$

Thus, each expert's entropy-weight is determined as follows [42,43]:

$$\alpha^e_{ij} = \frac{\sum_{e=1}^{t} F^e_{ij} + 1 - 2\times F^e_{ij}}{\sum_{e=1}^{t}\left(\sum_{e=1}^{t} F^e_{ij} + 1 - 2\times F^e_{ij}\right)}, \tag{5}$$

where $0 \le \alpha^e_{ij} \le 1$, and $\sum_{e=1}^{t}\alpha^e_{ij} = 1$.

Step 8. Build the aggregated TIF decision matrix taking into account the entropy-weights of experts.

According to the TIF weighted geometric aggregation (TIFWGA) operator [44], the aggregated TIF decision matrix concerning the entropy-weights of experts is gained as follows:

$$\widetilde{R} = \left[\widetilde{r}_{ij}\right]_{m\times n} = \left[\left\langle\left(a_{\widetilde{r}_{ij}},\ b_{\widetilde{r}_{ij}},\ c_{\widetilde{r}_{ij}}\right);\mu_{\widetilde{r}_{ij}},\ \nu_{\widetilde{r}_{ij}}\right\rangle\right]_{m\times n} \tag{6}$$

where $\widetilde{r}_{ij} = \left(\widetilde{r}^1_{ij}\right)^{\alpha^1_{ij}} \otimes \left(\widetilde{r}^2_{ij}\right)^{\alpha^2_{ij}} \otimes\cdots\otimes \left(\widetilde{r}^t_{ij}\right)^{\alpha^t_{ij}}$.

Step 9. Construct the primary weight vectors of criteria based on experts' views.

The significance of criteria is provided based on the experts' views in terms of linguistic terms (Table 3).

$$\widetilde{\omega}^e = \left\{\widetilde{\omega}^e_j\right\} = \left\{\left\langle\left(a_{\widetilde{\omega}^e_j},\ b_{\widetilde{\omega}^e_j},\ c_{\widetilde{\omega}^e_j}\right);\mu_{\widetilde{\omega}^e_j},\ \nu_{\widetilde{\omega}^e_j}\right\rangle\right\}, \tag{7}$$

Table 3. Linguistic variables applied for rating the significance of criteria.

Linguistic Variables	Triangular Intuitionistic Fuzzy Numbers
Very important (VI)	$\langle (0.80,\ 0.90,\ 1.00);0.90,\ 0.10\rangle$
Important (I)	$\langle (0.60,\ 0.70,\ 0.80);0.75, 0.20\rangle$
Medium (M)	$\langle (0.40,\ 0.50,\ 0.60);0.50,\ 0.45\rangle$
Unimportant (UI)	$\langle (0.20,\ 0.30,\ 0.40);0.35,\ 0.60\rangle$
Very unimportant (VUI)	$\langle (0.00,\ 0.10,\ 0.20);0.10,\ 0.90\rangle$

Step 10. Convert the primary weight vectors to the individual weight vectors based on each expert's risk attitude.

The primary weight vectors are converted to the individual weight vectors taking into account each expert's risk attitude according to Table 1.

$$\widetilde{w}^e = \left\{\widetilde{w}^e_j\right\} = \left\{\left\langle\left(a_{\widetilde{w}^e_j},\ b_{\widetilde{w}^e_j},\ c_{\widetilde{w}^e_j}\right);\mu_{\widetilde{w}^e_j},\ \nu_{\widetilde{w}^e_j}\right\rangle\right\}, \tag{8}$$

Step 11. Compute each expert's entropy-weight according to the weight vectors.

The entropy measure G^e_j is calculated by [42]:

$$G^e_j = -\frac{g^e_j ln\left(g^e_j\right)}{ln(t)}, \tag{9}$$

where

$$g^e_j = \frac{\left(a_{\widetilde{w}^e_j} + b_{\widetilde{w}^e_j} + c_{\widetilde{w}^e_j}\right) \times \left(1+\mu_{\widetilde{w}^e_j} - \nu_{\widetilde{w}^e_j}\right)}{\sum_{e=1}^{t}\left[\left(a_{\widetilde{w}^e_j} + b_{\widetilde{w}^e_j} + c_{\widetilde{w}^e_j}\right) \times \left(1+\mu_{\widetilde{w}^e_j} - \nu_{\widetilde{w}^e_j}\right)\right]}. \tag{10}$$

Thus, each expert's entropy-weight according to the expert-based weight vector is determined as follows [42,43]:

$$\beta^e_j = \frac{\sum_{e=1}^{t} G^e_j + 1 - 2\times G^e_j}{\sum_{e=1}^{t}\left(\sum_{e=1}^{t} G^e_j + 1 - 2\times G^e_j\right)}, \tag{11}$$

where $0 \le \beta^e_j \le 1$, and $\sum_{e=1}^{t}\beta^e_j = 1$.

Step 12. Provide the TIF weight vector of the criteria.

The TIF weight vector $\widetilde{W}$ is built according to experts' entropy-weight by using Definition A2 as follows:

$$\widetilde{W} = \left\{\widetilde{W}_j\right\} = \left\{\widetilde{W}_1, \widetilde{W}_2, \cdots, \widetilde{W}_n\right\}, \tag{12}$$

where

$$\widetilde{W}_j = \left\langle\left(a_{\widetilde{W}_j},\ b_{\widetilde{W}_j},\ c_{\widetilde{W}_j}\right);\mu_{\widetilde{W}_j},\ \nu_{\widetilde{W}_j}\right\rangle = \left(\widetilde{w}^1_j\right)^{\beta^1_j} \otimes \left(\widetilde{w}^2_j\right)^{\beta^2_j} \otimes \cdots \otimes \left(\widetilde{w}^t_j\right)^{\beta^t_j}. \tag{13}$$

Step 13. Compute the TIF positive-ideal solution (PIS) and the TIF negative-ideal solution (NIS) vectors.

The TIF PIS $\widetilde{r}^*_j$ and the TIF NIS $\widetilde{r}^-_j$ are, respectively, defined as follows:

$$\widetilde{r}^*_j = \left\{\left\langle\left(a_{\widetilde{r}^*_j},\ b_{\widetilde{r}^*_j},\ c_{\widetilde{r}^*_j}\right);\mu_{\widetilde{r}^*_j},\ \nu_{\widetilde{r}^*_j}\right\rangle\right\} = \begin{cases} \left\{\left\langle\left(\max_i\left(c_{\widetilde{r}_{ij}}\right),\ \max_i\left(c_{\widetilde{r}_{ij}}\right),\ \max_i\left(c_{\widetilde{r}_{ij}}\right)\right);\max_i\left(\mu_{\widetilde{r}_{ij}}\right),\min_i\left(\nu_{\widetilde{r}_{ij}}\right)\right\rangle\right\} & for\ j \in J_1 \\ \left\{\left\langle\left(\min_i\left(a_{\widetilde{r}_{ij}}\right),\ \min_i\left(a_{\widetilde{r}_{ij}}\right),\ \min_i\left(a_{\widetilde{r}_{ij}}\right)\right);\min_i\left(\mu_{\widetilde{r}_{ij}}\right),\max_i\left(\nu_{\widetilde{r}_{ij}}\right)\right\rangle\right\} & for\ j \in J_2, \end{cases} \tag{14}$$

and

$$\widetilde{r_j^-} = \left\{ \left\langle \left(a_{\widetilde{r_j^-}}, b_{\widetilde{r_j^-}}, c_{\widetilde{r_j^-}} \right); \mu_{\widetilde{r_j^-}}, \nu_{\widetilde{r_j^-}} \right\rangle \right\} = \begin{cases} \left\{ \left\langle \left(\underset{i}{min}\left(c_{\widetilde{r}_{ij}}\right), \underset{i}{min}\left(c_{\widetilde{r}_{ij}}\right), \underset{i}{min}\left(c_{\widetilde{r}_{ij}}\right) \right); \underset{i}{min}\left(\mu_{\widetilde{r}_{ij}}\right), \underset{i}{max}\left(\nu_{\widetilde{r}_{ij}}\right) \right\rangle \right\} & for\ j \in J_1 \\ \left\{ \left\langle \left(\underset{i}{max}\left(a_{\widetilde{r}_{ij}}\right), \underset{i}{max}\left(a_{\widetilde{r}_{ij}}\right), \underset{i}{max}\left(a_{\widetilde{r}_{ij}}\right) \right); \underset{i}{max}\left(\mu_{\widetilde{r}_{ij}}\right), \underset{i}{min}\left(\nu_{\widetilde{r}_{ij}}\right) \right\rangle \right\} & for\ j \in J_2, \end{cases} \tag{15}$$

where J_1 and J_2 are the benefit criteria and cost criteria, respectively.

Step 14. Determine the positive-ideal separation (*PISE*) and the negative-ideal separation (*NISE*) matrices.

The *PISE* matrix (Δ^*) and the *NISE* matrix (Δ^-) are defined based on hamming distance [45].

$$\Delta^* = \left[\Delta^*_{ij}\right]_{m\times n} = \begin{bmatrix} \Delta(\widetilde{r}^*_1, \widetilde{r}_{11}) & \Delta(\widetilde{r}^*_2, \widetilde{r}_{12}) & \cdots & \Delta(\widetilde{r}^*_n, \widetilde{r}_{1n}) \\ \Delta(\widetilde{r}^*_1, \widetilde{r}_{21}) & \Delta(\widetilde{r}^*_2, \widetilde{r}_{22}) & \cdots & \Delta(\widetilde{r}^*_n, \widetilde{r}_{2n}) \\ \vdots & \vdots & \ddots & \\ \Delta(\widetilde{r}^*_1, \widetilde{r}_{m1}) & \Delta(\widetilde{r}^*_2, \widetilde{r}_{m2}) & \cdots & \Delta(\widetilde{r}^*_n, \widetilde{r}_{mn}) \end{bmatrix}, \tag{16}$$

and

$$\Delta^- = \left[\Delta^-_{ij}\right]_{m\times n} = \begin{bmatrix} \Delta(\widetilde{r}^-_1, \widetilde{r}_{11}) & \Delta(\widetilde{r}^-_2, \widetilde{r}_{12}) & \cdots & \Delta(\widetilde{r}^-_n, \widetilde{r}_{1n}) \\ \Delta(\widetilde{r}^-_1, \widetilde{r}_{21}) & \Delta(\widetilde{r}^-_2, \widetilde{r}_{22}) & \cdots & \Delta(\widetilde{r}^-_n, \widetilde{r}_{2n}) \\ \vdots & \vdots & \ddots & \\ \Delta(\widetilde{r}^-_1, \widetilde{r}_{m1}) & \Delta(\widetilde{r}^-_2, \widetilde{r}_{m2}) & \cdots & \Delta(\widetilde{r}^-_n, \widetilde{r}_{mn}) \end{bmatrix}. \tag{17}$$

Step 15. Compute the $\mathfrak{A}_i$, $\mathfrak{B}_i$, $\mathfrak{A}'_i$, and $\mathfrak{B}'_i$ values.

The $\mathfrak{A}_i$, $\mathfrak{B}_i$, $\mathfrak{A}'_i$, and $\mathfrak{B}'_i$ values are computed according to the score function [46] as follows:

$$\begin{gathered} \mathfrak{A}_i = \textstyle\sum_{j=1}^{n} \Delta^*_{ij} \cdot \widetilde{W}_j \\ = \frac{1}{4}\left(\sum_{j=1}^{n} \Delta^*_{ij} \cdot a_{\widetilde{W}_j} + 2\Delta^*_{ij} \cdot b_{\widetilde{W}_j} + \Delta^*_{ij} \cdot c_{\widetilde{W}_j}\right)\left(1 - \prod_{j=1}^{n}\left(1 - \mu_{\widetilde{W}_j}\right)^{\Delta^*_{ij}} - \prod_{j=1}^{n} \nu_{\widetilde{W}_j}^{\Delta^*_{ij}}\right) \end{gathered} \tag{18}$$

$$\begin{gathered} \mathfrak{B}_i = \underset{j}{max}\left(d^*_{ij} \cdot \widetilde{W}_j\right) \\ = \underset{j}{max}\left(\frac{1}{4}\left(\Delta^*_{ij} \cdot a_{\widetilde{W}_j} + 2\Delta^*_{ij} \cdot b_{\widetilde{W}_j} + \Delta^*_{ij} \cdot c_{\widetilde{W}_j}\right)\left(1 - \left(1 - \mu_{\widetilde{W}_j}\right)^{\Delta^*_{ij}} - \nu_{\widetilde{W}_j}^{\Delta^*_{ij}}\right)\right) \end{gathered} \tag{19}$$

$$\begin{gathered} \mathfrak{A}'_i = \textstyle\sum_{j=1}^{n} \Delta^-_{ij} \cdot \widetilde{W}_j \\ = \frac{1}{4}\left(\sum_{j=1}^{n} \Delta^-_{ij} \cdot a_{\widetilde{W}_j} + 2\Delta^-_{ij} \cdot b_{\widetilde{W}_j} + \Delta^-_{ij} \cdot c_{\widetilde{W}_j}\right)\left(1 - \prod_{j=1}^{n}\left(1 - \mu_{\widetilde{W}_j}\right)^{\Delta^-_{ij}} - \prod_{j=1}^{n} \nu_{\widetilde{W}_j}^{\Delta^-_{ij}}\right) \end{gathered} \tag{20}$$

$$\begin{gathered} \mathfrak{B}'_i = \underset{j}{max}\left(\Delta^-_{ij} \cdot \widetilde{W}_j\right) \\ = \underset{j}{max}\left(\frac{1}{4}\left(\Delta^-_{ij} \cdot a_{\widetilde{W}_j} + 2\Delta^-_{ij} \cdot b_{\widetilde{W}_j} + \Delta^-_{ij} \cdot c_{\widetilde{W}_j}\right)\left(1 - \left(1 - \mu_{\widetilde{W}_j}\right)^{\Delta^-_{ij}} - \nu_{\widetilde{W}_j}^{\Delta^-_{ij}}\right)\right) \end{gathered} \tag{21}$$

Step 16. Calculate the κ_i and ϑ_i values.

The values of indices κ_i and ϑ_i are calculated as follows:

$$\kappa_i = \chi\left(\frac{\mathfrak{A}_i - \mathfrak{A}^*}{\mathfrak{A}^- - \mathfrak{A}^*}\right) + (1-\chi)\left(\frac{\mathfrak{B}_i - \mathfrak{B}^*}{\mathfrak{B}^- - \mathfrak{B}^*}\right), \tag{22}$$

and

$$\vartheta_i = \psi\left(\frac{\mathfrak{A}'_i - \mathfrak{A}'^-}{\mathfrak{A}'^* - \mathfrak{A}'^-}\right) + (1-\psi)\left(\frac{\mathfrak{B}'_i - \mathfrak{B}'^-}{\mathfrak{B}'^* - \mathfrak{B}'^-}\right), \tag{23}$$

where $\begin{cases} \mathfrak{A}^* = \min_i \mathfrak{A}_i \\ \mathfrak{A}^- = \max_i \mathfrak{A}_i \end{cases}$, $\begin{cases} \mathfrak{B}^* = \min_i \mathfrak{B}_i \\ \mathfrak{B}^- = \max_i \mathfrak{B}_i \end{cases}$, $\begin{cases} \mathfrak{A}'^* = \max_i \mathfrak{A}'_i \\ \mathfrak{A}'^- = \min_i \mathfrak{A}'_i \end{cases}$, $\begin{cases} \mathfrak{B}'^* = \max_i \mathfrak{B}'_i \\ \mathfrak{B}'^- = \min_i \mathfrak{B}'_i \end{cases}$, χ and ψ are regarded as the relative importance for the strategy of the majority attributes, whereas $1-\chi$ and $1-\psi$ are the relative importance of the individual regret.

Step 17. Compute the novel ranking score.

The ranking scores $\mathfrak{C}_i$ are defined as follows:

$$\mathfrak{c}_i = \eta\left(\frac{\kappa_i - \kappa^*}{\kappa^- - \kappa^*} + \frac{\vartheta^* - \vartheta_i}{\vartheta^* - \vartheta^-}\right) + (1-\eta)\left(\frac{\kappa_i - \kappa^*}{\kappa^- - \kappa^*} \times \frac{\vartheta^* - \vartheta_i}{\vartheta^* - \vartheta^-}\right), \tag{24}$$

$$\mathfrak{C}_i = \frac{\mathfrak{c}_i - \gamma}{\lambda - \gamma} \tag{25}$$

where $\begin{cases} \kappa^* = \min_i \kappa_i \\ \kappa^- = \max_i \kappa_i \end{cases}$, $\begin{cases} \vartheta^* = \max_i \vartheta_i \\ \vartheta^- = \min_i \vartheta_i \end{cases}$, $\gamma = \min_i \mathfrak{c}_i$, $\lambda = \max_i \mathfrak{c}_i$ and $0 \leq \eta \leq 1$.

Step 18. Rank the SIs according to the ranking score ($\mathfrak{C}_i$ values).

The SIs are sorted by the $\mathfrak{C}_i$ values in decreasing order. The maximum value of the $\mathfrak{C}_i$ indicates the higher importance.

2.2. Case Study

The efficiency of the presented approach was examined through a case study of a highway construction project. To that end, an Iranian construction firm was involved in transportation infrastructures. The firm has numerous highway construction projects being built in various areas of the country. To evaluate the projects according to sustainable construction principles, the firm managers intended to recognize and prioritize SIs to adopt the key evaluation indicators from a pool of numerous SIs in these projects.

According to step 1, five experts working on highway projects were adopted from employees of the firm. The participants comprised construction project managers and sustainable construction experts. They had enough experience and knowledge of nearly all the sustainable aspects of construction projects. As such, a group of five experts (E_1, E_2, ... , E_5) was considered for analyzing potential SIs. After forming the committee, the experts picked out a set of potential SIs in addition to a set of relevant criteria for SIs assessment (Steps 2 and 3). To that end, a brainstorming session was held with the experts and thirty sustainability indicators (SoI_1, SoI_2, ... , SoI_9, EcI_1, EcI_2, ... , EcI_9, EnI_1, EnI_2, ... , EnI_{12}), as well as seven criteria (C_1, C_2, ... ,C_7) were obtained from the various investigations in the literature (e.g., [22,47–64]) and the consensus opinion of the group members (Tables 4 and 5). Furthermore, the project manager utilizing Table 1 specifies the experts' risk attitude according to his or her recognition of them. The outcomes are represented in Table 6 (Step 4).

Table 4. List of obtained sustainability indicators.

		Sustainability Indicators	Description
Sustainability aspects	Social	SoI_1: Health	Highlighting on-site sanitation, and the provision of health care
		SoI_2: Education	Number and time of training course to different levels of employees
		SoI_3: Culture and heritage	Measure of negative impacts from construction operations on any cultural heritage
		SoI_4: Safety	Number of accidents, the supply rate of on-site supervision and training course to employees to provide a safe and reliable workplace
		SoI_5: Stakeholder satisfaction	Measure of stakeholder satisfaction by using stakeholder management models
		SoI_6: Job opportunities	Providing direct and indirect jobs
		SoI_7: Tourism	Impacts on tourism development
		SoI_8: Traffic	Vehicle traffic congestion
		SoI_9: Access to public transportation	Extension of public transportation services and proximity to it
	Economic	EcI_1: Net present value (NPV)	$NPV = \sum_{t=1}^{n} \frac{R_t}{(1+i)^t}$ where R_t is the net cash inflow-outflows during a single period t, i is the discount rate of return that could be earned in alternative investments and t is the number of time periods
		EcI_2: Payback period	Initial Investment/Net Cash Flow per Period
		EcI_3: Investment planning	Compliance with the investment plan
		EcI_4: Benefit–cost ratio	Relationship between the relative costs and benefits of a proposed project expressed in monetary or qualitative terms
		EcI_5: Debt–asset ratio	(Short-term Debt + Long-term Debt)/Total Assets
		EcI_6: Project budget	Compliance with budget
		EcI_7: Internal rate of return (IRR)	$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+IRR)^t} - C_0 = 0$ where C_t is the net cash inflow during the period t, C_0 is the total initial investment cost and t is the number of time periods
		EcI_8: Financial risk	Possibility of losing money on the investment
		EcI_9: Life-cycle cost	Total cost for a construction project over its life
	Environmental	EnI_1: Material consumption	Efficiency rate of using materials and resources
		EnI_2: Air pollution	Measure of mixture of solid particles and gases in the air
		EnI_3: landscape respect	Protection of landscape features during construction
		EnI_4: Noise emissions	Rate of noise pollution during the construction phase in the environment of the project
		EnI_5: Erosion	Rate of soil erosion during the construction phase in the environment of the project
		EnI_6: Ecological impacts	Measure of negative impacts from project to flora, fauna, and ecosystems
		EnI_7: Habitat loss and damage	Destructive effects on the living environment for both human being and animals
		EnI_8: Soil contamination	Measure of alteration in the physical, chemical and biological characteristics of the soil environment
		EnI_9: Aesthetical and visual impacts	Aesthetic quality of the project during the construction phase
		EnI_{10}: Water pollution	Measure of alteration in the physical, chemical and biological characteristics of water environment
		EnI_{11}: Water saving	Rate of reduction water consumption during the construction phase
		EnI_{12}: Hazardous waste	Production rate of hazardous waste

Table 5. List of obtained criteria.

Criteria	Criteria Type		Description
	Benefit	Cost	
C_1: Measurability	✓		Measurability in qualitative or quantitative terms
C_2: Applicability	✓		Practicality and straightforward use of sustainability indicator (SI) for evaluation
C_3: Data availability	✓		Relative simplicity to gather the necessary data for evaluation of SI
C_4: Acceptant	✓		Acceptance of SI by major stakeholders
C_5: Complexity		✓	Relative difficulty in meaningful interpretation of SI
C_6: Time consuming		✓	Required time for the evaluation of SI
C_7: Uncertainty		✓	Ambiguity in assigning the value to SI during evaluation

Table 6. Experts' risk attitudes.

Experts	E_1	E_2	E_3	E_4	E_5
Risk attitudes	Neutral	Absolutely optimistic	Pessimistic	Optimistic	Neutral

3. Results

The primary decision matrices are constructed by experts employing linguistic terms in Table 2. The matrices are shown in Table 7 (Step 5). Afterward, the primary decision matrices are converted to decision matrices taking into account each expert's risk attitude according to Table 1 (Table 8) (Step 6). Owing to space limitations, only the outcomes associated with three SIs (SoI_6, EcI_4 and EnI_{10}) are shown as a sample of each dimension of sustainability in some of the following tables.

Then, each expert's entropy-weight and aggregated TIF decision matrix is calculated. The outcomes of these steps are represented in Tables 9 and 10, respectively (Steps 7 and 8). In addition, the criteria weight vector is achieved according to experts' preferences and is illustrated in Table 11 (Step 9). According to steps 10 to 12, based on criteria weight vector, expert's risk attitude and expert's entropy-weight, the TIF criteria weight vectors are built. The results are presented in Table 12. Next, the TIF PIS and NIS vectors are specified as given in Table 13 (Step 13). Then, as shown in Table 14, the PISE matrix (D^*) and NISE matrix (D^-) are built (Step 14).

Table 7. Performance rating of each indicator versus each criterion based on experts' views in terms of linguistic terms.

SIs	Experts	Criteria						
		C_1	C_2	C_3	C_4	C_5	C_6	C_7
SoI_1	E_1	H	VH	ML	VH	L	VL	M
	E_2	H	VH	M	VVH	VL	VL	MH
	E_3	VH	H	M	VVH	VL	VVL	M
	E_4	H	VVH	MH	VH	VVL	L	ML
	E_5	VH	VVH	M	VVH	VVL	VL	ML
SoI_2	E_1	H	ML	MH	H	L	L	M
	E_2	M	M	M	MH	VL	ML	M
	E_3	MH	M	H	H	L	ML	ML
	E_4	M	ML	M	MH	ML	M	M
	E_5	MH	L	MH	MH	L	ML	M

Table 7. *Cont.*

SIs	Experts	Criteria						
		C_1	C_2	C_3	C_4	C_5	C_6	C_7
SoI_3	E_1	VL	ML	MH	MH	H	MH	VH
	E_2	L	L	H	H	MH	H	H
	E_3	VVL	L	H	VH	VH	H	VH
	E_4	VL	VL	VH	H	H	MH	VH
	E_5	VL	L	VH	VH	MH	MH	H
SoI_4	E_1	H	MH	H	H	ML	L	ML
	E_2	VH	MH	VH	VH	M	VVL	L
	E_3	H	M	VVH	VH	ML	VL	ML
	E_4	H	M	VH	H	L	VVL	L
	E_5	VH	MH	VH	VVH	ML	VL	L
SoI_5	E_1	L	H	ML	VH	VH	H	H
	E_2	VL	VH	L	H	H	MH	VVH
	E_3	ML	VH	VL	VVH	H	VH	VH
	E_4	ML	VVH	VL	VH	VH	H	VH
	E_5	L	VVH	ML	VH	VVH	VH	H
SoI_6	E_1	VH	VH	H	MH	L	L	L
	E_2	MH	H	H	H	VL	ML	L
	E_3	H	H	MH	MH	VL	L	M
	E_4	H	VH	MH	M	L	ML	M
	E_5	VH	VVH	H	H	L	L	L
SoI_7	E_1	VH	MH	M	H	L	MH	H
	E_2	VH	H	M	MH	VL	MH	VH
	E_3	VVH	H	ML	VH	VL	H	H
	E_4	VH	MH	ML	H	VVL	H	MH
	E_5	VVH	MH	ML	H	VL	VH	MH
SoI_8	E_1	H	MH	M	MH	L	H	VH
	E_2	MH	H	MH	MH	VL	VH	VVH
	E_3	H	H	MH	M	VL	H	VH
	E_4	H	VH	MH	M	VVL	VH	VVH
	E_5	VH	H	M	H	L	VH	VH
SoI_9	E_1	VH	MH	L	ML	VL	M	H
	E_2	H	H	ML	MH	VL	ML	M
	E_3	VH	MH	ML	ML	VL	L	M
	E_4	H	VH	ML	M	VL	L	H
	E_5	H	H	M	M	VVL	ML	MH
EcI_1	E_1	EH	EH	H	ML	VL	VVL	H
	E_2	EH	VVH	VVH	M	VVL	VVL	MH
	E_3	EH	EH	VH	MH	VL	VVL	MH
	E_4	EH	VH	VH	MH	VVL	VVL	M
	E_5	EH	EH	VVH	ML	VVL	VVL	H
EcI_2	E_1	VVH	H	H	M	L	VL	MH
	E_2	VH	VH	H	ML	VL	L	H
	E_3	VH	H	H	L	L	L	VH
	E_4	VH	H	H	L	L	VL	H
	E_5	VVH	H	VH	ML	VL	VL	VH
EcI_3	E_1	H	MH	MH	L	M	ML	H
	E_2	MH	MH	M	VL	M	ML	MH
	E_3	H	H	M	L	MH	M	VH
	E_4	VH	H	ML	VL	MH	M	MH
	E_5	VH	H	M	ML	MH	MH	H

Table 7. *Cont.*

SIs	Experts	Criteria						
		C_1	**C_2**	**C_3**	**C_4**	**C_5**	**C_6**	**C_7**
EcI_4	E_1	EH	EH	VH	M	L	ML	ML
	E_2	EH	VVH	VVH	MH	ML	L	M
	E_3	EH	VVH	VVH	M	L	L	ML
	E_4	EH	EH	VVH	MH	L	ML	ML
	E_5	EH	EH	EH	MH	VL	L	L
EcI_5	E_1	VH	H	H	ML	L	ML	H
	E_2	H	H	MH	L	L	ML	MH
	E_3	VVH	MH	H	L	ML	M	MH
	E_4	H	MH	MH	L	L	M	H
	E_5	H	H	MH	ML	L	M	MH
EcI_6	E_1	H	VH	H	ML	L	M	MH
	E_2	VH	VH	H	M	VL	MH	H
	E_3	H	H	MH	ML	VVL	M	H
	E_4	VH	VH	VH	ML	VL	MH	MH
	E_5	VH	VVH	VH	M	VVL	ML	H
EcI_7	E_1	VVH	EH	VH	ML	VL	VL	MH
	E_2	EH	EH	VH	ML	VVL	VL	H
	E_3	EH	EH	VH	M	VVL	VL	MH
	E_4	EH	EH	H	M	VL	VVL	MH
	E_5	EH	EH	VVH	MH	VVL	VVL	ML
EcI_8	E_1	ML	VVH	M	ML	H	MH	EH
	E_2	M	H	ML	ML	MH	MH	VVH
	E_3	M	H	ML	L	MH	H	VH
	E_4	ML	MH	M	L	M	H	VVH
	E_5	M	VVH	M	ML	M	MH	VH
EcI_9	E_1	MH	H	M	MH	M	VH	H
	E_2	MH	VH	ML	H	ML	H	VH
	E_3	H	VH	ML	H	MH	VH	VH
	E_4	H	H	L	VH	ML	VVH	H
	E_5	H	VVH	ML	H	MH	MH	MH
EnI_1	E_1	H	MH	H	MH	L	L	H
	E_2	H	MH	VH	ML	L	VL	MH
	E_3	H	MH	H	ML	VL	VL	M
	E_4	H	H	VH	MH	L	L	H
	E_5	VH	H	VVH	M	VL	VVL	M
EnI_2	E_1	VH	VH	ML	MH	M	ML	VH
	E_2	H	H	MH	MH	MH	M	H
	E_3	H	H	MH	H	M	ML	VH
	E_4	VH	VH	ML	H	MH	ML	H
	E_5	H	VVH	MH	H	M	L	H
EnI_3	E_1	ML	L	ML	M	MH	H	VH
	E_2	L	L	ML	MH	H	H	H
	E_3	L	ML	ML	M	MH	VH	MH
	E_4	VL	L	ML	M	H	H	MH
	E_5	ML	ML	M	MH	MH	H	VH
EnI_4	E_1	M	M	L	M	ML	MH	H
	E_2	MH	ML	VL	MH	M	M	H
	E_3	ML	ML	L	M	ML	ML	MH
	E_4	ML	M	L	ML	ML	M	VH
	E_5	MH	M	ML	MH	L	ML	MH

Table 7. *Cont.*

SIs	Experts	Criteria						
		C_1	C_2	C_3	C_4	C_5	C_6	C_7
EnI_5	E_1	MH	ML	L	ML	H	H	VH
	E_2	M	L	VL	L	MH	VH	H
	E_3	ML	VL	VL	L	H	VH	VH
	E_4	ML	L	L	VL	VH	H	H
	E_5	MH	L	ML	ML	MH	H	MH
EnI_6	E_1	MH	H	M	M	H	H	H
	E_2	M	MH	ML	MH	VH	MH	VH
	E_3	M	H	M	M	H	MH	H
	E_4	MH	H	M	ML	VH	H	MH
	E_5	H	VH	MH	MH	VVH	VH	MH
EnI_7	E_1	ML	MH	ML	M	ML	MH	H
	E_2	M	ML	L	ML	ML	M	MH
	E_3	MH	MH	ML	L	M	MH	MH
	E_4	M	MH	M	L	M	M	H
	E_5	MH	M	M	M	ML	M	H
EnI_8	E_1	H	VH	H	MH	ML	MH	H
	E_2	MH	H	MH	MH	ML	M	MH
	E_3	H	MH	M	H	VL	M	H
	E_4	MH	MH	MH	H	ML	MH	VH
	E_5	VH	VH	H	H	L	ML	MH
EnI_9	E_1	M	MH	ML	MH	MH	M	VH
	E_2	ML	H	L	H	H	M	H
	E_3	ML	MH	VL	H	H	MH	H
	E_4	ML	MH	L	VH	MH	H	MH
	E_5	M	H	ML	VH	MH	M	MH
EnI_{10}	E_1	H	H	MH	H	M	M	M
	E_2	VH	H	H	H	M	MH	MH
	E_3	H	MH	M	VH	M	M	MH
	E_4	VH	H	M	H	ML	MH	M
	E_5	VVH	VH	MH	VH	ML	M	ML
EnI_{11}	E_1	H	H	MH	H	VL	M	H
	E_2	H	MH	H	MH	VL	ML	VH
	E_3	H	MH	MH	H	VL	MH	H
	E_4	H	H	M	MH	L	ML	H
	E_5	VH	VH	MH	VH	VL	ML	MH
EnI_{12}	E_1	VH	L	MH	MH	VL	ML	VH
	E_2	H	ML	M	H	L	L	H
	E_3	MH	L	H	M	VL	ML	VH
	E_4	MH	ML	MH	MH	VL	ML	H
	E_5	H	L	H	H	VVL	L	MH

Table 8. Experts' view concerning the rating of sample indicators with respect to the criteria by taking into account each expert's risk attitude.

Criteria	Experts	SIs		
		$\boldsymbol{SoI_6}$	$\boldsymbol{EcI_4}$	$\boldsymbol{EnI_{10}}$
C_1	E_1	$\langle(0.800, 0.900, 1.000); 0.800, 0.100\rangle$	$\langle(0.950, 1.000, 1.000); 0.950, 0.050\rangle$	$\langle(0.700, 0.800, 0.900); 0.700, 0.200\rangle$
	E_2	$\langle(0.500, 0.700, 0.700); 0.700, 0.300\rangle$	$\langle(0.950, 1.000, 1.000); 0.950, 0.050\rangle$	$\langle(0.800, 1.000, 1.000); 0.900, 0.100\rangle$
	E_3	$\langle(0.700, 0.750, 0.900); 0.700, 0.250\rangle$	$\langle(0.950, 0.975, 1.000); 0.950, 0.050\rangle$	$\langle(0.700, 0.750, 0.900); 0.700, 0.250\rangle$
	E_4	$\langle(0.700, 0.850, 0.900); 0.750, 0.200\rangle$	$\langle(0.950, 1.000, 1.000); 0.950, 0.050\rangle$	$\langle(0.800, 0.950, 1.000); 0.850, 0.100\rangle$
	E_5	$\langle(0.800, 0.900, 1.000); 0.800, 0.100\rangle$	$\langle(0.950, 1.000, 1.000); 0.950, 0.050\rangle$	$\langle(0.900, 1.000, 1.000); 0.900, 0.100\rangle$
C_2	E_1	$\langle(0.800, 0.900, 1.000); 0.800, 0.100\rangle$	$\langle(0.950, 1.000, 1.000); 0.950, 0.050\rangle$	$\langle(0.700, 0.800, 0.900); 0.700, 0.200\rangle$
	E_2	$\langle(0.700, 0.900, 0.900); 0.800, 0.200\rangle$	$\langle(0.900, 1.000, 1.000); 0.900, 0.100\rangle$	$\langle(0.700, 0.900, 0.900); 0.800, 0.200\rangle$
	E_3	$\langle(0.700, 0.750, 0.900); 0.700, 0.250\rangle$	$\langle(0.900, 0.950, 1.000); 0.900, 0.100\rangle$	$\langle(0.500, 0.550, 0.700); 0.600, 0.350\rangle$
	E_4	$\langle(0.800, 0.950, 1.000); 0.850, 0.100\rangle$	$\langle(0.950, 1.000, 1.000); 0.950, 0.050\rangle$	$\langle(0.700, 0.850, 0.900); 0.750, 0.200\rangle$
	E_5	$\langle(0.900, 1.000, 1.000); 0.900, 0.100\rangle$	$\langle(0.950, 1.000, 1.000); 0.950, 0.050\rangle$	$\langle(0.800, 0.900, 1.000); 0.800, 0.100\rangle$
C_3	E_1	$\langle(0.700, 0.800, 0.900); 0.700, 0.200\rangle$	$\langle(0.800, 0.900, 1.000); 0.800, 0.100\rangle$	$\langle(0.500, 0.600, 0.700); 0.600, 0.300\rangle$
	E_2	$\langle(0.700, 0.900, 0.900); 0.800, 0.200\rangle$	$\langle(0.900, 1.000, 1.000); 0.900, 0.100\rangle$	$\langle(0.700, 0.900, 0.900); 0.800, 0.200\rangle$
	E_3	$\langle(0.500, 0.550, 0.700); 0.600, 0.350\rangle$	$\langle(0.900, 0.950, 1.000); 0.900, 0.100\rangle$	$\langle(0.300, 0.400, 0.700); 0.500, 0.450\rangle$
	E_4	$\langle(0.500, 0.650, 0.700); 0.650, 0.300\rangle$	$\langle(0.900, 1.000, 1.000); 0.900, 0.100\rangle$	$\langle(0.300, 0.600, 0.700); 0.550, 0.400\rangle$
	E_5	$\langle(0.700, 0.800, 0.900); 0.700, 0.200\rangle$	$\langle(0.950, 1.000, 1.000); 0.950, 0.050\rangle$	$\langle(0.500, 0.600, 0.700); 0.600, 0.300\rangle$
C_4	E_1	$\langle(0.500, 0.600, 0.700); 0.600, 0.300\rangle$	$\langle(0.300, 0.500, 0.700); 0.500, 0.400\rangle$	$\langle(0.700, 0.800, 0.900); 0.700, 0.200\rangle$
	E_2	$\langle(0.700, 0.900, 0.900); 0.800, 0.200\rangle$	$\langle(0.500, 0.700, 0.700); 0.700, 0.300\rangle$	$\langle(0.700, 0.900, 0.900); 0.800, 0.200\rangle$
	E_3	$\langle(0.500, 0.550, 0.700); 0.600, 0.350\rangle$	$\langle(0.300, 0.400, 0.700); 0.500, 0.450\rangle$	$\langle(0.800, 0.850, 1.000); 0.800, 0.150\rangle$
	E_4	$\langle(0.300, 0.600, 0.700); 0.550, 0.400\rangle$	$\langle(0.500, 0.650, 0.700); 0.650, 0.300\rangle$	$\langle(0.700, 0.850, 0.900); 0.750, 0.200\rangle$
	E_5	$\langle(0.700, 0.800, 0.900); 0.700, 0.200\rangle$	$\langle(0.500, 0.600, 0.700); 0.600, 0.300\rangle$	$\langle(0.800, 0.900, 1.000); 0.800, 0.100\rangle$
C_5	E_1	$\langle(0.100, 0.200, 0.300); 0.250, 0.600\rangle$	$\langle(0.100, 0.200, 0.300); 0.250, 0.600\rangle$	$\langle(0.300, 0.500, 0.700); 0.500, 0.400\rangle$
	E_2	$\langle(0.000, 0.000, 0.200); 0.100, 0.900\rangle$	$\langle(0.300, 0.300, 0.500); 0.400, 0.600\rangle$	$\langle(0.300, 0.300, 0.700); 0.500, 0.500\rangle$
	E_3	$\langle(0.000, 0.100, 0.200); 0.175, 0.750\rangle$	$\langle(0.100, 0.167, 0.300); 0.325, 0.600\rangle$	$\langle(0.300, 0.400, 0.700); 0.550, 0.400\rangle$
	E_4	$\langle(0.100, 0.150, 0.300); 0.250, 0.675\rangle$	$\langle(0.100, 0.150, 0.300); 0.250, 0.675\rangle$	$\langle(0.300, 0.350, 0.500); 0.400, 0.550\rangle$
	E_5	$\langle(0.100, 0.200, 0.300); 0.250, 0.600\rangle$	$\langle(0.000, 0.100, 0.200); 0.100, 0.750\rangle$	$\langle(0.300, 0.400, 0.500); 0.400, 0.500\rangle$
C_6	E_1	$\langle(0.100, 0.200, 0.300); 0.250, 0.600\rangle$	$\langle(0.300, 0.400, 0.500); 0.400, 0.500\rangle$	$\langle(0.300, 0.500, 0.700); 0.500, 0.400\rangle$
	E_2	$\langle(0.300, 0.300, 0.500); 0.400, 0.600\rangle$	$\langle(0.100, 0.100, 0.300); 0.250, 0.750\rangle$	$\langle(0.500, 0.500, 0.700); 0.600, 0.400\rangle$
	E_3	$\langle(0.100, 0.167, 0.300); 0.325, 0.600\rangle$	$\langle(0.100, 0.167, 0.300); 0.325, 0.600\rangle$	$\langle(0.300, 0.400, 0.700); 0.550, 0.400\rangle$
	E_4	$\langle(0.300, 0.350, 0.500); 0.400, 0.550\rangle$	$\langle(0.300, 0.350, 0.500); 0.400, 0.550\rangle$	$\langle(0.500, 0.550, 0.700); 0.600, 0.350\rangle$
	E_5	$\langle(0.100, 0.200, 0.300); 0.250, 0.600\rangle$	$\langle(0.100, 0.200, 0.300); 0.250, 0.600\rangle$	$\langle(0.300, 0.500, 0.700); 0.500, 0.400\rangle$
C_7	E_1	$\langle(0.100, 0.200, 0.300); 0.250, 0.600\rangle$	$\langle(0.300, 0.400, 0.500); 0.400, 0.500\rangle$	$\langle(0.300, 0.500, 0.700); 0.500, 0.400\rangle$
	E_2	$\langle(0.100, 0.100, 0.300); 0.250, 0.750\rangle$	$\langle(0.300, 0.300, 0.700); 0.500, 0.500\rangle$	$\langle(0.500, 0.500, 0.700); 0.600, 0.400\rangle$
	E_3	$\langle(0.300, 0.400, 0.700); 0.550, 0.400\rangle$	$\langle(0.300, 0.300, 0.500); 0.450, 0.500\rangle$	$\langle(0.500, 0.433, 0.700); 0.650, 0.300\rangle$
	E_4	$\langle(0.300, 0.400, 0.700); 0.500, 0.450\rangle$	$\langle(0.300, 0.350, 0.500); 0.400, 0.550\rangle$	$\langle(0.300, 0.400, 0.700); 0.500, 0.450\rangle$
	E_5	$\langle(0.100, 0.200, 0.300); 0.250, 0.600\rangle$	$\langle(0.100, 0.200, 0.300); 0.250, 0.600\rangle$	$\langle(0.300, 0.400, 0.500); 0.400, 0.500\rangle$

Table 9. Entropy-weight assigned to each expert.

SIs	Experts	Criteria						
		C_1	C_2	C_3	C_4	C_5	C_6	C_7
SoI_6	E_1	0.196	0.199	0.197	0.202	0.187	0.206	0.208
	E_2	0.207	0.202	0.195	0.193	0.228	0.191	0.217
	E_3	0.202	0.205	0.207	0.204	0.208	0.205	0.184
	E_4	0.199	0.198	0.204	0.207	0.190	0.190	0.184
	E_5	0.196	0.197	0.197	0.194	0.187	0.206	0.208
EcI_4	E_1	0.200	0.199	0.202	0.204	0.196	0.188	0.196
	E_2	0.200	0.201	0.200	0.195	0.187	0.214	0.193
	E_3	0.200	0.201	0.200	0.207	0.195	0.204	0.197
	E_4	0.200	0.199	0.200	0.196	0.200	0.189	0.198
	E_5	0.200	0.199	0.198	0.197	0.222	0.205	0.217
EnI_{10}	E_1	0.204	0.199	0.199	0.202	0.196	0.202	0.200
	E_2	0.197	0.197	0.191	0.200	0.200	0.198	0.196
	E_3	0.205	0.210	0.208	0.199	0.196	0.202	0.195
	E_4	0.198	0.198	0.203	0.201	0.205	0.197	0.202
	E_5	0.197	0.195	0.199	0.198	0.203	0.202	0.208

Table 10. Aggregated triangular intuitionistic fuzzy (TIF) decision matrix ($\widetilde{R}$).

Criteria	SIs		
	SoI_6	EcI_4	EnI_{10}
C_1	$\langle(0.688, 0.814, 0.890); 0.748, 0.196\rangle$	$\langle(0.950, 0.995, 1.000); 0.950, 0.050\rangle$	$\langle(0.775, 0.892, 0.958); 0.803, 0.154\rangle$
C_2	$\langle(0.776, 0.895, 0.958); 0.806, 0.153\rangle$	$\langle(0.930, 0.990, 1.000); 0.930, 0.070\rangle$	$\langle(0.670, 0.784, 0.872); 0.724, 0.216\rangle$
C_3	$\langle(0.610, 0.726, 0.812); 0.685, 0.254\rangle$	$\langle(0.888, 0.969, 1.000); 0.888, 0.090\rangle$	$\langle(0.432, 0.596, 0.734); 0.600, 0.338\rangle$
C_4	$\langle(0.512, 0.674, 0.772); 0.642, 0.297\rangle$	$\langle(0.405, 0.557, 0.700); 0.583, 0.355\rangle$	$\langle(0.738, 0.859, 0.938); 0.769, 0.171\rangle$
C_5	$\langle(0.000, 0.000, 0.251); 0.188, 0.746\rangle$	$\langle(0.000, 0.169, 0.302); 0.234, 0.654\rangle$	$\langle(0.300, 0.384, 0.610); 0.465, 0.475\rangle$
C_6	$\langle(0.152, 0.232, 0.365); 0.316, 0.591\rangle$	$\langle(0.151, 0.210, 0.364); 0.315, 0.614\rangle$	$\langle(0.367, 0.487, 0.700); 0.548, 0.390\rangle$
C_7	$\langle(0.150, 0.222, 0.410); 0.328, 0.587\rangle$	$\langle(0.236, 0.300, 0.478); 0.386, 0.533\rangle$	$\langle(0.366, 0.444, 0.653); 0.521, 0.415\rangle$

Table 11. Criteria weight vector based on experts' preferences.

Experts	Criteria						
	C_1	C_2	C_3	C_4	C_5	C_6	C_7
E_1	I	I	I	I	M	M	I
E_2	M	VI	I	VI	I	UI	I
E_3	I	I	I	I	I	M	I
E_4	M	I	VI	I	M	M	VI
E_5	I	VI	I	I	I	M	VI

Table 12. TIF and crisp criteria weight vectors.

Criteria	Weight Vectors
	$\tilde{W}$
C_1	$\langle(0.509,\ 0.637,\ 0.712);0.655,\ 0.317\rangle$
C_2	$\langle(0.672,\ 0.789,\ 0.874);0.811,\ 0.167\rangle$
C_3	$\langle(0.635,\ 0.752,\ 0.836);0.788,\ 0.186\rangle$
C_4	$\langle(0.635,\ 0.750,\ 0.836);0.783,\ 0.186\rangle$
C_5	$\langle(0.509,\ 0.587,\ 0.712);0.640,\ 0.328\rangle$
C_6	$\langle(0.346,\ 0.413,\ 0.552);0.469,\ 0.504\rangle$
C_7	$\langle(0.672,\ 0.751,\ 0.874);0.811,\ 0.173\rangle$

Table 13. TIF positive-ideal solution (PIS) and TIF negative-ideal solution (NIS) vectors.

Criteria	Ideal Solutions	
	TIF PIS	TIF NIS
C_1	$\langle(0.950,\ 0.995,\ 1.000);0.950,\ 0.050\rangle$	$\langle(0.000,\ 0.248,\ 0.332);0.302,\ 0.625\rangle$
C_2	$\langle(0.950,\ 0.995,\ 1.000);0.950,\ 0.050\rangle$	$\langle(0.151,\ 0.263,\ 0.363);0.318,\ 0.584\rangle$
C_3	$\langle(0.888,\ 0.969,\ 1.000);0.888,\ 0.090\rangle$	$\langle(0.000,\ 0.190,\ 0.301);0.243,\ 0.676\rangle$
C_4	$\langle(0.858,\ 0.959,\ 1.000);0.869,\ 0.100\rangle$	$\langle(0.000,\ 0.202,\ 0.278);0.253,\ 0.672\rangle$
C_5	$\langle(0.123,\ 0.176,\ 0.330);0.279,\ 0.637\rangle$	$\langle(0.775,\ 0.788,\ 0.958);0.786,\ 0.171\rangle$
C_6	$\langle(0.151,\ 0.210,\ 0.364);0.315,\ 0.614\rangle$	$\langle(0.758,\ 0.773,\ 0.958);0.769,\ 0.171\rangle$
C_7	$\langle(0.151,\ 0.199,\ 0.363);0.305,\ 0.623\rangle$	$\langle(0.867,\ 0.865,\ 1.000);0.878,\ 0.090\rangle$

Table 14. Positive-ideal separation (PISE) and negative-ideal separation (NISE) matrices.

Ideal Separation	SIs	Criteria						
		C_1	C_2	C_3	C_4	C_5	C_6	C_7
PISE	SoI_6	0.313	0.208	0.344	0.392	0.049	0.006	0.016
	EcI_4	0.000	0.028	0.000	0.490	0.022	0.000	0.063
	EnI_{10}	0.211	0.348	0.486	0.156	0.146	0.215	0.188
NISE	SoI_6	0.554	0.629	0.466	0.392	0.660	0.572	0.718
	EcI_4	0.867	0.810	0.810	0.294	0.633	0.578	0.670
	EnI_{10}	0.656	0.490	0.324	0.628	0.465	0.363	0.545

Ultimately, the $\mathfrak{A}_i$, $\mathfrak{B}_i$, $\mathfrak{A}'_i$, $\mathfrak{B}'_i$, κ_i and ϑ_i values are calculated (χ and ψ are considered 0.5). Then, the novel ranking score is calculated (η considered 0.5), and SIs are prioritized according to ranking score ($\mathfrak{C}_i$ values). The gathered results are presented in Table 15 (Step 15 to 18).

Table 15. Computational results of the proposed approach and final ranking of SIs.

SIs	$\mathfrak{A}_i$	$\mathfrak{B}_i$	$\mathfrak{A}'_i$	$\mathfrak{B}'_i$	κ_i	ϑ_i	$\mathfrak{C}_i$	Final Ranking
SoI_1	0.627	0.093	2.766	0.250	0.208	0.814	0.786	5
SoI_2	1.620	0.273	1.799	0.116	0.601	0.475	0.363	16
SoI_3	2.415	0.384	1.041	0.084	0.873	0.306	0.154	28
SoI_4	0.553	0.128	2.752	0.240	0.239	0.798	0.756	6
SoI_5	2.304	0.276	1.026	0.200	0.717	0.458	0.295	21
SoI_6	0.684	−0.002	2.639	0.227	0.095	0.761	0.822	4
SoI_7	1.502	0.134	1.937	0.066	0.405	0.432	0.438	14
SoI_8	1.960	0.213	1.466	0.055	0.580	0.339	0.302	20
SoI_9	1.595	0.181	1.848	0.023	0.479	0.360	0.361	17
EcI_1	0.548	0.075	2.850	0.308	0.171	0.903	0.870	3
EcI_2	1.276	0.183	2.199	0.104	0.429	0.526	0.480	13
EcI_3	2.003	0.250	1.336	0.011	0.635	0.259	0.238	23
EcI_4	0.106	0.032	3.121	0.320	0.044	0.965	1.000	1
EcI_5	1.527	0.205	1.837	0.009	0.498	0.340	0.341	18
EcI_6	1.171	0.113	2.244	0.189	0.322	0.645	0.610	9
EcI_7	0.480	0.088	2.902	0.347	0.176	0.963	0.907	2
EcI_8	2.489	0.240	0.777	0.100	0.702	0.283	0.220	24
EcI_9	1.742	0.177	1.621	0.160	0.499	0.504	0.430	15
EnI_1	1.180	0.077	2.276	0.164	0.278	0.618	0.618	8
EnI_2	1.444	0.090	1.917	0.160	0.338	0.553	0.544	10
EnI_3	2.818	0.338	0.396	0.000	0.881	0.088	0.062	29
EnI_4	2.346	0.267	0.933	−0.008	0.713	0.167	0.161	27
EnI_5	3.135	0.390	0.119	−0.004	1.000	0.036	0.000	30
EnI_6	2.265	0.092	1.061	0.058	0.476	0.275	0.315	19
EnI_7	2.318	0.174	0.972	−0.031	0.590	0.142	0.197	26
EnI_8	1.364	0.007	2.008	0.040	0.220	0.408	0.515	11
EnI_9	2.152	0.266	1.182	0.082	0.680	0.326	0.251	22
EnI_{10}	1.004	0.031	2.309	0.125	0.191	0.572	0.637	7
EnI_{11}	1.354	0.037	2.073	0.035	0.256	0.413	0.500	12
EnI_{12}	1.857	0.347	1.572	0.008	0.733	0.294	0.211	25

4. Discussion

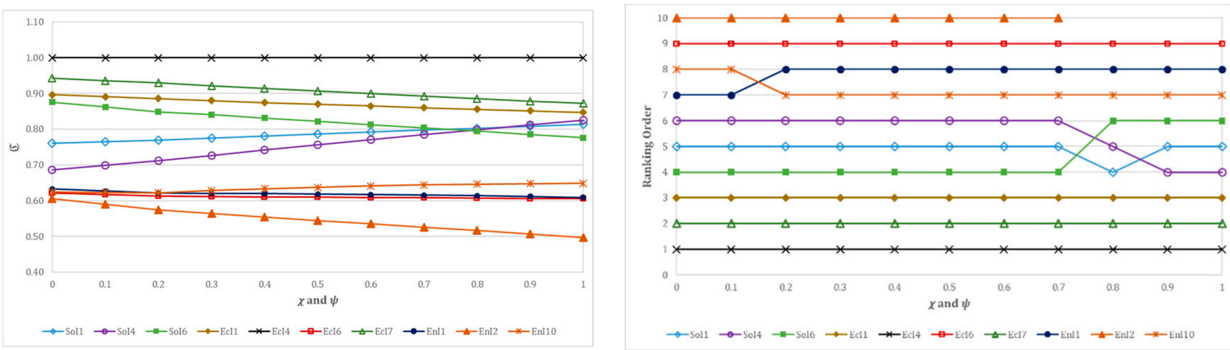
The results achieved from the presented approach are examined comprehensively, and the accuracy, precision, and sensitivity of the answers are investigated in this section. A thorough sensitivity analysis is performed on ten SIs with a higher priority for various values of approach variables. Furthermore, the comparisons are made between the outcomes of the presented approach and other cited literature.

4.1. Sensitivity Analysis

A comprehensive sensitivity analysis is conducted in this subsection. First, the sensitivity of ranking score ($\mathfrak{C}$ values) and ranking orders are investigated for values of χ, ψ and η ranging from 0 to 1 (Figures 2 and 3).

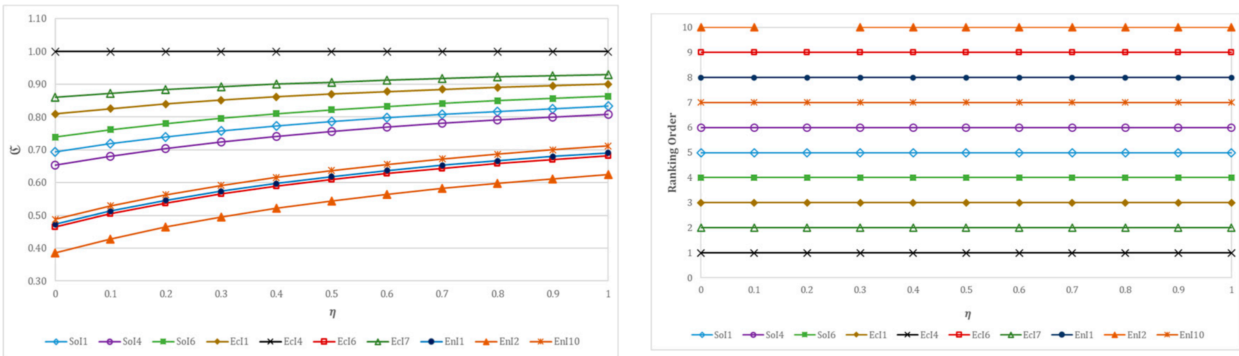
In Figure 2a,b, the $\mathfrak{C}$ values and ranking orders are represented for various values of χ and ψ ranging from 0 to 1, respectively. As represented in Figure 2a, the graph of the $\mathfrak{C}$ values for various SIs versus χ and ψ values ranging from 0 to 1 has three states of almost constant, ascending or descending. However, in most cases, the graphs of indicators are parallel, and only a few intersections are represented for χ and ψ values above 0.7.

As can be seen in Figure 2b, changing the graph for χ and ψ values above 0.7 leads to few changes in the ranking order of SIs. In addition, for variations of χ and ψ between 0.2 and 0.7, the rank of all SIs remains unchanged, and also a set of the top ten SIs remains in a range from 1 to 10. Hence, the conclusion can be drawn that the top ten SIs have the lowest sensitivity to the values of χ and ψ between 0.2 and 0.7, and the assumed value of 0.5 for this variable in the case study is suitable.



(**a**) (**b**)

Figure 2. (**a**) Sensitivity analysis on the ℭ values and (**b**) preference ranking order of top ten SIs related to majority attributes (χ and ψ).



(**a**) (**b**)

Figure 3. (**a**) Sensitivity analysis on the ℭ values and (**b**) preference ranking order of top ten SIs related to η coefficient.

In Figure 3a,b, ℭ values and ranking orders versus η values ranging from 0 to 1 are represented, respectively. Figure 3a represents that the graph of ℭ values for all SIs is ascending by increasing the η value from 0 to 1. However, according to the figure, the gap between the values of ℭ increases by decreasing η. Thus, for smaller values of η, the gap between the ℭ values of different SIs is larger, allowing an accurate distinction for decision-makers. In addition, according to Figure 3b, it can be concluded that the ranking order of all top SIs is constant for η values other than EnI_2 for the value of $\eta = 0.2$.

With these in mind, this conclusion can be drawn that ℭ values and ranking orders have no sensitivity to η. Hence, choosing 0.5 as a median number of the interval for η in the case study is a suitable choice.

4.2. Comparison between the Proposed Approach and Other Cited Literature

To validate the presented approach outcomes, a comparison is made between the achieved results by the proposed approach and the traditional fuzzy MCDM methods. Table 16 shows the outcomes of this comparison. The comparison results for the top ten SIs are also represented in Figure 4.

Table 16. Comparative outcomes of the presented approach and other traditional fuzzy multi-criteria decision-making (MCDM) methods.

SIs	Proposed Approach		Fuzzy MCDM Methods					
			Fuzzy VIKOR [65]		Fuzzy SAW [66]		Fuzzy TOPSIS [67]	
	Ranking Score	Preference Order Ranking	Ranking Score	Preference Order Ranking	Ranking Score	Preference Order Ranking	Ranking Score	Preference Order Ranking
SoI_1	0.786	5	0.178	5	0.866	5	0.648	5
SoI_2	0.363	16	0.486	15	0.756	16	0.483	16
SoI_3	0.154	28	0.721	25	0.678	24	0.391	23
SoI_4	0.756	6	0.160	4	0.876	3	0.680	2
SoI_5	0.295	21	0.755	26	0.685	23	0.401	21
SoI_6	0.822	4	0.241	6	0.851	6	0.628	6
SoI_7	0.438	14	0.490	16	0.757	15	0.490	15
SoI_8	0.302	20	0.707	23	0.701	21	0.389	24
SoI_9	0.361	17	0.491	17	0.755	17	0.465	17
EcI_1	0.870	3	0.150	3	0.875	4	0.667	4
EcI_2	0.480	13	0.380	10	0.796	10	0.537	10
EcI_3	0.238	23	0.607	20	0.712	20	0.405	20
EcI_4	1.000	1	0.000	1	0.937	1	0.735	1
EcI_5	0.341	18	0.459	14	0.766	14	0.492	14
EcI_6	0.610	9	0.367	9	0.798	9	0.560	9
EcI_7	0.907	2	0.125	2	0.885	2	0.674	3
EcI_8	0.220	24	0.839	28	0.646	28	0.306	28
EcI_9	0.430	15	0.586	19	0.731	18	0.457	18
EnI_1	0.618	8	0.353	8	0.802	8	0.564	8
EnI_2	0.544	10	0.450	13	0.770	13	0.503	13
EnI_3	0.062	29	0.916	29	0.612	29	0.250	29
EnI_4	0.161	27	0.704	22	0.677	25	0.370	25
EnI_5	0.000	30	1.000	30	0.588	30	0.195	30
EnI_6	0.315	19	0.802	27	0.662	27	0.310	27
EnI_7	0.197	26	0.712	24	0.674	26	0.364	26
EnI_8	0.515	11	0.426	12	0.775	12	0.529	11
EnI_9	0.251	22	0.661	21	0.692	22	0.396	22
EnI_{10}	0.637	7	0.304	7	0.820	7	0.603	7
EnI_{11}	0.500	12	0.420	11	0.778	11	0.527	12
EnI_{12}	0.211	25	0.557	18	0.730	19	0.441	19

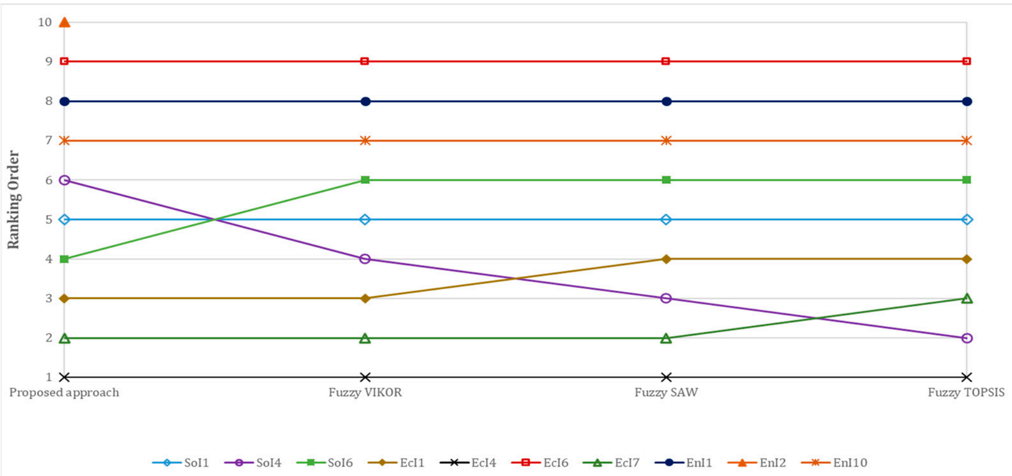


Figure 4. Preference order ranking of top ten SIs prioritized by the proposed approach and other fuzzy MCDM methods.

As presented in Table 16 and Figure 4, the priority of SIs derived from the presented approach is not very different from other methods in most cases (in most cases, the number of ranks is changed by up to three or four rank shifts in SIs priority). Besides, EcI_4 has the first priority in all methods, and EnI_5 has the last priority in the presented approach and all methods. For the ten first priorities that are key indicators, despite some changes of ranks (at most four ranks) in some methods, the priorities of indicators remain within the ten first priorities except EnI_2. Furthermore, as can be observed in the figure, most key indicators have the same ranks in the proposed approach and all traditional methods. However, SoI_4 had relatively more changes, which can be considered as the most sensitive key indicator.

From the above, the conclusion can be drawn that the proposed approach is reliable and its results benefit from the merits of taking into account risk attitudes of experts, concepts of entropy in determining weights of experts, and a new TIFS-ranking approach concurrently.

As another aspect, the results of the approach for ten SIs with a higher priority are compared with the indicators provided by seven cited literature studies and tools. The comparison results are indicated in Table 17.

Table 17. Comparison of ten SIs with higher priority and other literature studies and tools.

Related Literature		**Social**			**Economic**				**Environmental**		
		SoI_1	SoI_4	SoI_6	EcI_1	EcI_4	EcI_6	EcI_7	EnI_1	EnI_2	EnI_{10}
Awasthi et al. [47]	S **	✓*	✓	– *	–	✓	–	–	–	✓	–
Shen et al. [56]	S	✓	✓	✓	✓	–	✓	✓	–	✓	✓
Shen et al. [57]	S	✓	✓	✓	–	–	✓	✓	–	✓	✓
Yao et al. [59]	S	✓	✓	✓	✓	✓	✓	✓	–	✓	✓
CEEQUAL [62]	T **	✓	✓	✓	–	✓	–	–	✓	✓	✓
Invest [63]	T	✓	✓	–	–	✓	–	–	✓	✓	✓
Envision [64]	T	✓	✓	✓	–	✓	✓	–	✓	✓	✓

* Note: The symbol ✓indicates that the study/tool includes the SI, whereas—indicates that it does not. ** S: Study; T: Tool.

As presented in Table 17, most of the ten first priorities have been utilized as SIs' assessment in the cited literature. Much higher adaptation is related to Yao et al. [59] and Envision [64] and less adaptation is related to Awasthi et al. [47]. Three SIs of ten key indicators, SoI_1, SoI_4 and EnI_2, exist in all cited literature. In addition, EnI_{10} is introduced in all the literature except Awasthi et al. [47]. In addition, it can be observed that the social and environmental indicators have been incorporated in all cited tools (except SoI_6 in Invest) but economic indicators have not been considered in the cited tools (except EcI_4). These comparisons demonstrate that the outcomes of the approach are reliable and can be employed in a sustainable assessment of highway construction projects.

5. Concluding Remarks

Analyzing sustainability indicators (SIs) in construction projects between different potential indicators and considering various assessment criteria concurrently can be considered as a complicated group decision problem. A new triangular intuitionistic fuzzy set (TIFS) group decision approach for the multi-criteria evaluation is presented in this study to deal with this problem under uncertainty. A novel multi-criteria group decision-making approach considers experts' risk attitudes and views and entropy concepts were developed in the TIFS environment. Furthermore, new ranking scores were proposed through similarity to ideal solutions by the concept of closeness coefficient to prioritize and choose the sustainable indicators. A case study regarding highway construction projects was presented to analyze the sustainable indicators under uncertainty. The considered case study was solved using the introduced group-decision approach.

The primary aim of this paper is to present a sound approach for the assessment and adoption of SIs in highway construction projects. The principal novelties of this study are as follows:

- To cope with uncertainty in highway construction projects, triangular intuitionistic fuzzy sets (TIFSs) are used. The TIFSs make the process of decision-making more flexible regarding degrees of agreement, disagreement, and hesitancy utilizing a triangular function.
- Risk attitudes of experts are considered within the assessment and process of group decision-making because they can have various perspectives, such as optimistic or pessimistic, in their views owing to their various backgrounds and characteristics.
- A novel methodology is proposed to specify experts' weights within the process of group decision-making based on the concepts of entropy.
- A new compromise ranking score is proposed to evaluate and choose sustainability indicators in highway construction projects.

Ultimately, some sensitivity analyses were performed on the preference order ranking of the top ten SIs in a case study according to the change of approach coefficients and different risk attitudes of experts. The drawn conclusion of the sensitivity analyses was that approach coefficients selected in the case study were suitable choices. Moreover, the presented approach was compared with the traditional fuzzy MCDM techniques, including fuzzy SAW and fuzzy VIKOR. The computational results represented that there was no major difference between the proposed approach and other fuzzy MCDM techniques regarding the priority of SIs in most cases. In addition, both the first and last priorities derived from this approach were the same in all the aforementioned methods.

The introduced comprehensive approach has proposed an efficient decision-making method for highway construction regarding sustainable development principles. In fact, it presented a dependable model in which the results benefited from the merits of taking into account the risk attitudes of experts and the new TIFS-ranking method. Furthermore, the applied fundamental concepts were intelligible to the committee of experts and project managers, and the required calculations were straightforward. Hence, by introducing evaluated sustainable indicators, this paper helps project managers improve highway projects' sustainability and make the most sustainable decisions. As future research, a holistic framework can be developed that utilizes the mentioned criteria and considers environmental and social impacts as criteria in the evaluation of sustainability indicators. In addition, the ranked SIs with higher priority can be used as key indicators in the sustainability assessment of highway construction projects.

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Appendix A

Definition A1. [68] *The membership function of TIFN* $\widetilde{A} = \langle (a,b,c)\,;\mu,\nu\rangle$ *is defined as follows:*

$$\mu_{\widetilde{A}}(x) = \begin{cases} \frac{x-a}{b-a}\mu & if\ a \le x < b \\ \mu & if\ x = b \\ \frac{c-x}{c-b}\mu & if\ b < x \le c \\ 0 & otherwise \end{cases} \tag{A1}$$

and non-membership function is defined as follows:

$$\nu_{\widetilde{A}}(x) = \begin{cases} \frac{b-x+(x-a)\nu}{b-a} & if\ a \le x < b \\ \nu & if\ x = b \\ \frac{x-b+(c-x)\nu}{c-b} & if\ b < x \le c \\ 0 & otherwise \end{cases} \tag{A2}$$

where a, b and c are real numbers, $0 \le \mu \le 1$, $0 \le \nu \le 1$ *and* $0 \le \mu + \nu \le 1$.

Definition A2. [44] *Let* $\widetilde{A} = \langle (a, b, c); \mu, \nu \rangle$ *and* $\widetilde{B} = \langle (a', b', c'); \mu', \nu' \rangle$ *be two TIFNs, then the arithmetic operations are defined as follows:*

$$\widetilde{A} \oplus \widetilde{B} = \langle (a + a', b + b', c + c'); \mu + \mu' - \mu.\mu', \nu.\nu' \rangle, \tag{A3}$$

$$\widetilde{A} \otimes \widetilde{B} = \langle (a.a', b.b', c.c'); \mu.\mu', \nu + \nu' - \nu.\nu' \rangle, \tag{A4}$$

$$\lambda\widetilde{A} = \langle (\lambda a, \lambda b, \lambda c); 1 - (1-\mu)^{\lambda}, \nu^{\lambda} \rangle \ (\lambda \ge 0), \tag{A5}$$

$$\widetilde{A}^{\lambda} = \left\langle \left(a^{\lambda}, b^{\lambda}, c^{\lambda}\right); \mu^{\lambda}, 1 - (1-\nu)^{\lambda} \right\rangle \ (\lambda \ge 0). \tag{A6}$$

References

1. WCED. *Our Common Future-Brundtland Report*; Oxford University Press: Oxford, UK, 1987.
2. Shen, L.Y.; Li Hao, J.; Tam, V.W.Y.; Yao, H. A checklist for assessing sustainability performance of construction projects. *J. Civ. Eng. Manag.* **2007**, *13*, 273–281. [CrossRef]
3. Yu, W.D.; Cheng, S.T.; Ho, W.C.; Chang, Y.H. Measuring the sustainability of construction projects throughout their lifecycle: A Taiwan lesson. *Sustainability* **2018**, *10*, 1523. [CrossRef]
4. Goubran, S.; Cucuzzella, C. Integrating the sustainable development goals in building projects. *J. Sustain. Res.* **2019**, *1*, e190010. [CrossRef]
5. Karaca, F.; Guney, M.; Kumisbek, A.; Kaskina, D.; Tokbolat, S. A new stakeholder opinion-based rapid sustainability assessment method (RSAM) for existing residential buildings. *Sustain. Cities Soc.* **2020**, *60*, 102155. [CrossRef]
6. Li, H.; Zhang, X.; Ng, S.T.; Skitmore, M. Quantifying stakeholder influence in decision/evaluations relating to sustainable construction in China—A Delphi approach. *J. Clean. Prod.* **2018**, *173*, 160–170. [CrossRef]
7. Omer, M.A.; Noguchi, T. A conceptual framework for understanding the contribution of building materials in the achievement of Sustainable Development Goals (SDGs). *Sustain. Cities Soc.* **2020**, *52*, 101869. [CrossRef]
8. Xu, X.; Wang, Y.; Tao, L. Comprehensive evaluation of sustainable development of regional construction industry in China. *J. Clean. Prod.* **2019**, *211*, 1078–1087. [CrossRef]
9. Illankoon, I.C.S.; Tam, V.W.; Le, K.N. United Nation's sustainable development goals: Establishing baseline for Australian building sector. *Intell. Build. Int.* **2020**. [CrossRef]
10. Olawumi, T.O.; Chan, D.W.; Chan, A.P.; Wong, J.K. Development of a building sustainability assessment method (BSAM) for developing countries in sub-Saharan Africa. *J. Clean. Prod.* **2020**, *263*, 121514. [CrossRef]
11. Mansell, P.; Philbin, S.P.; Broyd, T.; Nicholson, I. Assessing the impact of infrastructure projects on global sustainable development goals. *Proc. Inst. Civ. Eng. Eng. Sustain.* **2020**, *173*, 196–212. [CrossRef]
12. Mousavi, S.M.; Tavakkoli-Moghaddam, R.; Azaron, A.; Mojtahedi, S.M.H.; Hashemi, H. Risk assessment for highway projects using jackknife technique. *Expert Syst. Appl.* **2011**, *38*, 5514–5524. [CrossRef]
13. Ghoddousi, P.; Nasirzadeh, F.; Hashemi, H. Evaluating Highway Construction Projects' Sustainability Using a Multicriteria Group Decision-Making Model Based on Bootstrap Simulation. *J. Constr. Eng. Manag.* **2018**, *144*, 04018092. [CrossRef]
14. Hendiani, S.; Bagherpour, M. Developing an integrated index to assess social sustainability in construction industry using fuzzy logic. *J. Clean. Prod.* **2019**, *230*, 647–662. [CrossRef]
15. Rostamnezhad, M.; Nasirzadeh, F.; Khanzadi, M.; Jarban, M.J.; Ghayoumian, M. Modeling social sustainability in construction projects by integrating system dynamics and fuzzy-DEMATEL method: A case study of highway project. *Eng. Constr. Archit. Manag.* **2020**, *27*, 1595–1618. [CrossRef]
16. Hashemi, H.; Mousavi, S.M.; Zavadskas, E.K.; Chalekaee, A.; Turskis, Z. A new group decision model based on grey-intuitionistic fuzzy-ELECTRE and VIKOR for contractor assessment problem. *Sustainability* **2018**, *10*, 1635. [CrossRef]
17. Mousavi, S.M.; Antuchevičienė, J.; Zavadskas, E.K.; Vahdani, B.; Hashemi, H. A new decision model for cross-docking center location in logistics networks under interval-valued intuitionistic fuzzy uncertainty. *Transport* **2019**, *34*, 30–40. [CrossRef]

18. Stojčić, M.; Zavadskas, E.K.; Pamučar, D.; Stević, Ž.; Mardani, A. Application of MCDM methods in sustainability engineering: A literature review 2008–2018. *Symmetry* **2019**, *11*, 350. [CrossRef]
19. Zavadskas, E.K.; Antucheviciene, J.; Kar, S. Multi-Objective and Multi-Attribute Optimization for Sustainable Development Decision Aiding. *Sustainability* **2019**, *11*, 3069. [CrossRef]
20. Hashemi, H.; Bazargan, J.; Mousavi, S.M.; Vahdani, B. An extended compromise ratio model with an application to reservoir flood control operation under an interval-valued intuitionistic fuzzy environment. *Appl. Math. Model.* **2014**, *38*, 3495–3511. [CrossRef]
21. Huang, R.Y.; Yeh, C.H. Development of an assessment framework for green highway construction. *J. Chin. Inst. Eng.* **2008**, *31*, 573–585. [CrossRef]
22. Chen, Y.; Okudan, G.E.; Riley, D.R. Sustainable performance criteria for construction method selection in concrete buildings. *Autom. Constr.* **2010**, *19*, 235–244. [CrossRef]
23. Reza, B.; Sadiq, R.; Hewage, K. Sustainability assessment of flooring systems in the city of Tehran: An AHP-based life cycle analysis. *Constr. Build. Mater.* **2011**, *25*, 2053–2066. [CrossRef]
24. Waris, M.; Liew, M.S.; Khamidi, M.F.; Idrus, A. Criteria for the selection of sustainable onsite construction equipment. *Int. J. Sustain. Built Environ.* **2014**, *3*, 96–110. [CrossRef]
25. Li, Y.; Zhao, L.; Suo, J. Comprehensive assessment on sustainable development of highway transportation capacity based on entropy weight and TOPSIS. *Sustainability* **2014**, *6*, 4685–4693. [CrossRef]
26. Kucukvar, M.; Gumus, S.; Egilmez, G.; Tatari, O. Ranking the sustainability performance of pavements: An intuitionistic fuzzy decision making method. *Autom. Constr.* **2014**, *40*, 33–43. [CrossRef]
27. Medineckiene, M.; Zavadskas, E.K.; Björk, F.; Turskis, Z. Multi-criteria decision-making system for sustainable building assessment/certification. *Arch. Civ. Mech. Eng.* **2015**, *15*, 11–18. [CrossRef]
28. Kamali, M.; Hewage, K. Development of performance criteria for sustainability evaluation of modular versus conventional construction methods. *J. Clean. Prod.* **2017**, *142*, 3592–3606. [CrossRef]
29. Pan, M.; Linner, T.; Pan, W.; Cheng, H.; Bock, T. A framework of indicators for assessing construction automation and robotics in the sustainability context. *J. Clean. Prod.* **2018**, *182*, 82–95. [CrossRef]
30. Zolfani, S.H.; Pourhossein, M.; Yazdani, M.; Zavadskas, E.K. Evaluating construction projects of hotels based on environmental sustainability with MCDM framework. *Alex. Eng. J.* **2018**, *57*, 357–365. [CrossRef]
31. Liu, S.; Qian, S. Towards sustainability-oriented decision making: Model development and its validation via a comparative case study on building construction methods. *Sustain. Dev.* **2019**, *27*, 860–872. [CrossRef]
32. Reddy, A.S.; Kumar, P.R.; Raj, P.A. Preference based multi-criteria framework for developing a Sustainable Material Performance Index (SMPI). *Int. J. Sustain. Eng.* **2019**, *12*, 390–403. [CrossRef]
33. Chen, C.H. A new multi-criteria assessment model combining GRA techniques with intuitionistic fuzzy entropy-based TOPSIS method for sustainable building materials supplier selection. *Sustainability* **2019**, *11*, 2265. [CrossRef]
34. Roy, J.; Das, S.; Kar, S.; Pamučar, D.; Roy, J.; Das, S.; Kar, S.; Pamučar, D. An extension of the CODAS approach using interval-valued intuitionistic fuzzy set for sustainable material selection in construction projects with incomplete weight information. *Symmetry* **2019**, *11*, 393. [CrossRef]
35. Tseng, M.L.; Lin, S.; Chen, C.C.; Sarmiento, L.S.C.; Tan, C.L. A causal sustainable product-service system using hierarchical structure with linguistic preferences in the Ecuadorian construction industry. *J. Clean. Prod.* **2019**, *230*, 477–487. [CrossRef]
36. Alawneh, R.; Ghazali, F.; Ali, H.; Sadullah, A.F. A novel framework for integrating United Nations Sustainable Development Goals into sustainable non-residential building assessment and management in Jordan. *Sustain. Cities Soc.* **2019**, *49*, 101612. [CrossRef]
37. Dabous, S.A.; Zeiada, W.; Zayed, T.; Al-Ruzouq, R. Sustainability-informed multi-criteria decision support framework for ranking and prioritization of pavement sections. *J. Clean. Prod.* **2020**, *244*, 118755. [CrossRef]
38. Rahimi, S.; Hafezalkotob, A.; Monavari, S.M.; Hafezalkotob, A.; Rahimi, R. Sustainable landfill site selection for municipal solid waste based on a hybrid decision-making approach: Fuzzy group BWM-MULTIMOORA-GIS. *J. Clean. Prod.* **2020**, *248*, 119186. [CrossRef]
39. Navarro, I.J.; Yepes, V.; Martí, J.V. Sustainability assessment of concrete bridge deck designs in coastal environments using neutrosophic criteria weights. *Struct. Infrastruct. Eng.* **2020**, *16*, 949–967. [CrossRef]
40. Ebrahimnejad, S.; Mousavi, S.M.; Tavakkoli-Moghaddam, R.; Hashemi, H.; Vahdani, B. A novel two-phase group decision making approach for construction project selection in a fuzzy environment. *Appl. Math. Model.* **2012**, *36*, 4197–4217. [CrossRef]
41. Fenton, N.; Wang, W. Risk and confidence analysis for fuzzy multicriteria decision making. *Knowl. Based Syst.* **2006**, *19*, 430–437. [CrossRef]
42. Zhang, X.; Jin, F.; Liu, P. A grey relational projection method for multi-attribute decision making based on intuitionistic trapezoidal fuzzy number. *Appl. Math. Model.* **2013**, *37*, 3467–3477. [CrossRef]
43. Zhou, H.C.; Zhang, G.H.; Wang, G.L. Multi-objective decision making approach based on entropy weights for reservoir flood control operation. *J. Hydraul. Eng.* **2007**, *38*, 100–106.
44. Chen, Y.; Li, B. Dynamic multi-attribute decision making model based on triangular intuitionistic fuzzy numbers. *Sci. Iran.* **2011**, *18*, 268–274. [CrossRef]
45. Wan, S.P.; Wang, F.; Lin, L.L.; Dong, J.Y. Some new generalized aggregation operators for triangular intuitionistic fuzzy numbers and application to multi-attribute group decision making. *Comput. Ind. Eng.* **2016**, *93*, 286–301. [CrossRef]

46. Wang, J.Q.; Nie, R.; Zhang, H.Y.; Chen, X.H. New operators on triangular intuitionistic fuzzy numbers and their applications in system fault analysis. *Inf. Sci.* **2013**, *251*, 79–95. [CrossRef]
47. Awasthi, A.; Chauhan, S.S.; Omrani, H. Application of fuzzy TOPSIS in evaluating sustainable transportation systems. *Expert Syst. Appl.* **2011**, *38*, 12270–12280. [CrossRef]
48. Diabat, A.; Kannan, D.; Mathiyazhagan, K. Analysis of enablers for implementation of sustainable supply chain management—A textile case. *J. Clean. Prod.* **2014**, *83*, 391–403. [CrossRef]
49. Govindan, K.; Shankar, K.M.; Kannan, D. Sustainable material selection for construction industry—A hybrid multi criteria decision making approach. *Renew. Sustain. Energy Rev.* **2016**, *55*, 1274–1288. [CrossRef]
50. Kandziora, M.; Burkhard, B.; Müller, F. Interactions of ecosystem properties, ecosystem integrity and ecosystem service indicators—A theoretical matrix exercise. *Ecol. Indic.* **2013**, *28*, 54–78. [CrossRef]
51. Michael, F.L.; Noor, Z.Z.; Figueroa, M.J. Review of urban sustainability indicators assessment—Case study between Asian countries. *Habitat Int.* **2014**, *44*, 491–500. [CrossRef]
52. Nasirzadeh, F.; Ghayoumian, M.; Khanzadi, M.; Rostamnezhad Cherati, M. Modelling the social dimension of sustainable development using fuzzy cognitive maps. *Int. J. Constr. Manag.* **2020**, *20*, 223–236. [CrossRef]
53. Niemeijer, D.; de Groot, R.S. A conceptual framework for selecting environmental indicator sets. *Ecol. Indic.* **2008**, *8*, 14–25. [CrossRef]
54. Oltean-Dumbrava, C.; Watts, G.; Miah, A. Transport infrastructure: Making more sustainable decisions for noise reduction. *J. Clean. Prod.* **2013**, *42*, 58–68. [CrossRef]
55. Roy, R.; Chan, N.W. An assessment of agricultural sustainability indicators in Bangladesh: Review and synthesis. *Environmentalist* **2012**, *32*, 99–110. [CrossRef]
56. Shen, L.Y.; Tam, V.W.; Tam, L.; Ji, Y.B. Project feasibility study: The key to successful implementation of sustainable and socially responsible construction management practice. *J. Clean. Prod.* **2010**, *18*, 254–259. [CrossRef]
57. Shen, L.; Wu, Y.; Zhang, X. Key assessment indicators for the sustainability of infrastructure projects. *J. Constr. Eng. Manag.* **2010**, *137*, 441–451. [CrossRef]
58. Ugwu, O.O.; Haupt, T.C. Key performance indicators and assessment methods for infrastructure sustainability—A South African construction industry perspective. *Build. Environ.* **2007**, *42*, 665–680. [CrossRef]
59. Yao, H.; Shen, L.; Tan, Y.; Hao, J. Simulating the impacts of policy scenarios on the sustainability performance of infrastructure projects. *Autom. Constr.* **2011**, *20*, 1060–1069. [CrossRef]
60. Yuan, H. Key indicators for assessing the effectiveness of waste management in construction projects. *Ecol. Indic.* **2013**, *24*, 476–484. [CrossRef]
61. Zhao, Z.Y.; Zhao, X.J.; Davidson, K.; Zuo, J. A corporate social responsibility indicator system for construction enterprises. *J. Clean. Prod.* **2012**, *29*, 277–289. [CrossRef]
62. CEEQUAL Version 6: Technical Manual—International Projects. Watford, UK. Available online: https://www.ceequal.com/version-6/ (accessed on 30 September 2019).
63. Reid, L.; Bevan, T.; Davis, A.; Neuman, T.; Penney, K.; Seskin, S.; VanZerr, M.; Anderson, J.; Muench, S.; Weiland, C.; et al. Invest v1.3: Sustainable Highways Self-Evaluation Tool. Available online: https://www.sustainablehighways.org/files/4735.pdf (accessed on 12 February 2019).
64. Envision v3: Sustainable Infrastructure Framework Manual. Available online: https://sustainableinfrastructure.org/envision-version-3/ (accessed on 18 February 2019).
65. Opricovic, S. Fuzzy VIKOR with an application to water resources planning. *Expert Syst. Appl.* **2011**, *38*, 12983–12990. [CrossRef]
66. Chou, S.Y.; Chang, Y.H.; Shen, C.Y. A fuzzy simple additive weighting system under group decision-making for facility location selection with objective/subjective attributes. *Eur. J. Oper. Res.* **2008**, *189*, 132–145. [CrossRef]
67. Chu, T.C. Facility location selection using fuzzy TOPSIS under group decisions. *Int. J. Uncertain. Fuzziness Knowl. Based* **2002**, *10*, 687–701. [CrossRef]
68. Li, D.F. A ratio ranking method of triangular intuitionistic fuzzy numbers and its application to MADM problems. *Comput. Math. Appl.* **2010**, *60*, 1557–1570. [CrossRef]