Neutrosophic Systems with Applications, Vol. 12, 2023
https://doi.org/10.61356/j.nswa.2023.109

An Integrated Neutrosophic Approach for the Urban Energy Internet Assessment under Sustainability Dimensions

Walaa M. Sabry [1]

[1] Faculty of Computers and Informatics, Zagazig University, Zagazig, Sharqiyah, 44519, Egypt; wm.mohamed23@fci.zu.edu.eg.

* Correspondence: wm.mohamed23@fci.zu.edu.eg.

Abstract: The urgent issue of climate change has resulted in an increasing preoccupation with the transition to low-carbon energy. The urban energy internet (UEI) enables the efficient utilization of renewable energy via the integration of contemporary energy grids, smart energy services, and cyber-physical systems. Consequently, the assessment of urban energy is vital for the construction of low-carbon cities. This study intends to provide an integrated decision-making approach for addressing assessment challenges related to UEI, with a focus on sustainability. The introduced approach adopts the opinions of three experts to express their opinions through semantic terms in evaluating sustainability factors and evaluating UEI projects. Determining the most suitable project for sustainable UEI is a difficult task. In addition, there are multiple sustainability dimensions, including: economic, social, technical, environmental and resource dimension. This paper presents an integrated approach through which experts can use semantic terms to express their opinions to evaluate the priorities of sustainability dimensions that affect the sustainability of UEI projects. Therefore, this study applies a hybrid multi-criteria decision making (MCDM) approach that takes into account multiple dimensions. Also, the uncertainty in the study is handled by type 2 neutrosophic numbers (T2NNs). Initially, the CRiteria Importance through Inter-criteria Correlation (CRITIC) method was used to determine the relative importance of the sustainability dimensions used in the study. Also, the evaluation based on distance from average solution (EDAS) method was used to rank the selected alternatives. The results indicate that the technical dimension is the most important with a weight of 0.384. Finally, a sensitivity analysis was conducted to prove the validity and reliability of the developed framework with differences in weights.

Keywords: Urban Energy Internet; Neutrosophic; T2NN; Sustainability; Uncertainty; MCDM; T2NN-CRITIC; T2NN-EDAS.

1. Introduction

Presently, the primary cause of energy issues is overdependence on traditional fossil fuels. The excessive dependence on a single source, together with inefficiencies and the squandering of resources in the generation, distribution, and utilization of energy, results in the depletion of resources and the degradation of the environment. In addition, the increasing worldwide need for energy is also restricted by restrictions on the exploration and use of conventional energy sources. The energy internet has arisen as a solution to meet the current challenges in the energy sector [1].

The urban energy internet (UEI) is an application of the energy internet that is specifically implemented at the city level [2]. It involves the practical application of the idea and technology of the energy internet to the energy system of a city. Scholars are presently giving significant attention to and showing interest in researching the UEI. Research in this area encompasses several subjects, such as the theoretical foundation and core concepts, the utilization of cutting-edge technology in their execution, and the development and enhancement of intelligent energy systems. These studies have played a role in the development of the UEI.

It is the primary goal of the UEI to achieve efficient energy allocation, intelligent management, and green low-carbon supply inside the city [3]. This will result in increased energy utilization efficiency, decreased carbon emissions, and the promotion of sustainable urban development strategies. In spite of the increased interest in UEI and the potential benefits it may provide, there is still a significant research vacuum in the assessment of UEI from the point of view of sustainability. For this reason, it is essential to build a comprehensive collection of assessment index systems and to make use of plausible scientific frameworks in order to evaluate the UEI from the point of view of sustainability [4]. It is possible to frame this issue as a complicated multi-criteria decision-making (MCDM) model because of its complexity [5].

By relying only on accurate information throughout the review process, it is often not possible to adequately portray the complexities of the actual world. It is the inherent ambiguity and subjectivity that are inherent to human decision-making processes that are the source of this insufficiency for humans. It has been shown that neutrosophic set theory is an effective solution to the issue of ambiguity in MCDM [6]. Therefore, the study relies mainly on presenting a multi-criteria decision-making approach consisting of the CRITIC and EDAS methods. The criteria importance through inter-criteria correlation (CRITIC) method is used to evaluate and prioritize sustainability dimensions [7]. Also, the evaluation based on distance from average solution (EDAS) is applied to evaluate and rank alternatives for urban energy internet [8]. In addition, the study is being conducted in a neutrosophic environment and using type 2 neutrosophic numbers (T2NNs).

The rest of this study is planned as follows: Section 2 introduces sustainability dimensions for the urban energy internet. Section 3 describes some definitions and preliminaries related to type 2 neutrosophic numbers and the applied approach. Section 4 shows the application of the introduced approach. In Section 5, the conclusions are demonstrated.

2. Sustainability dimensions

In this section, we present the dimensions of sustainability that have a direct impact on achieving sustainability in the urban energy internet. Figure 1 shows the five dimensions used, which are economic, social, technical, environmental and resource. Also, a detailed explanation of the five dimensions is provided as follows.

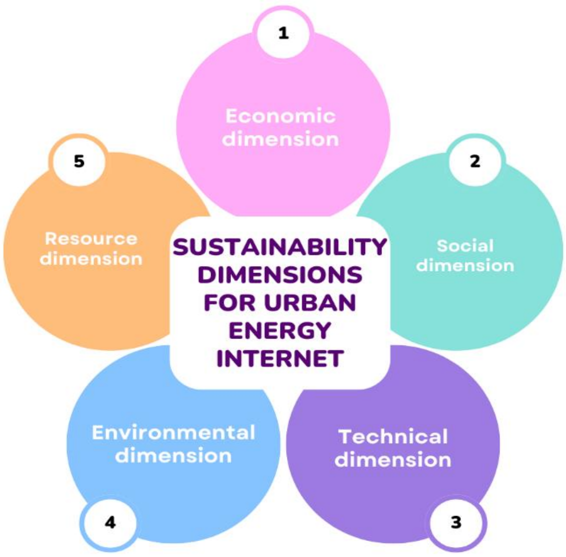

Figure 1. Sustainability dimensions for urban energy internet.

2.1 Economic dimension

The economic feature of an energy internet system pertains to its capacity to function and create sustainable revenues in the long run. Key elements that influence the economic viability of an energy internet system include initial investment expenses, governmental financial aid and inducements, and ongoing operational expenditures. Financial sustainability and return on investment are crucial factors to examine when analyzing energy internet systems, since they determine the viability and profitability of investments in energy infrastructure.

2.2 Social dimension

The social dimension encompasses the incorporation of social considerations into the design and functioning of urban energy systems, with the goal of attaining social fairness, engagement, and inclusiveness. The urban energy internet promotes social innovation and participation by offering open innovation platforms and cooperation methods to use the intellect and inventive capacities of different stakeholders. Moreover, it is crucial for the general populace to comprehend the importance of energy matters and the advantages of using environmentally friendly energy sources and energy-conserving strategies. By implementing educational initiatives and raising awareness via campaigns, society may be motivated to adopt environmentally conscious behaviors and contribute to the shift towards sustainable energy.

2.3 Technical dimension

During the planning, construction, and operation of energy infrastructure, the utilization of environmentally friendly and cutting-edge technology is referred to as the technical dimension. A few examples of these technologies include artificial intelligence, predictive analytics, smart grid technology, and sophisticated energy management systems. Increasing energy efficiency, lowering environmental effects, and contributing to the transformation of energy systems that are more sustainable and resilient are all things that may be accomplished via the use of these modern and environmentally friendly technologies.

2.4 Environmental dimension

Improving the influence that energy systems have on environmental components, including water resources, land, and biodiversity, is what is meant by the environmental dimension. Urban energy has the potential to reduce air pollution and environmental degradation, protect the health of ecosystems, and, as a result, promote environmental sustainability. This is accomplished through the utilization of clean energy and energy strategies that are favorable to the environment.

2.5 Resource dimension

The term "resource dimension" refers to the rational use and management of resources throughout the processes of energy generation, transmission, storage, and utilization. This is done in order to guarantee a sustainable supply and maximize resource efficiency. Internet advocates for the widespread use of renewable energy sources such as solar energy, wind energy, hydropower, and biomass. Urban energy internet advocates for this cause. As a result of their sustainable and renewable properties, these energy sources lessen reliance on limited resources and lessen the negative effects on the environment.

3. Study approach

In this section, the steps of the proposed methodology for conducting a study to evaluate the urban energy internet are presented as exhibited in Figure 2. The presented approach is based on two MCDM methods: CRITIC and TOPSIS. This study is also being conducted in a neutrosophic environment, specifically using T2NNs. In this regard, this section is divided into two parts. The first part provides some preliminaries and definitions about T2NNs. The second part presents the proposed approach for evaluating the urban energy internet.

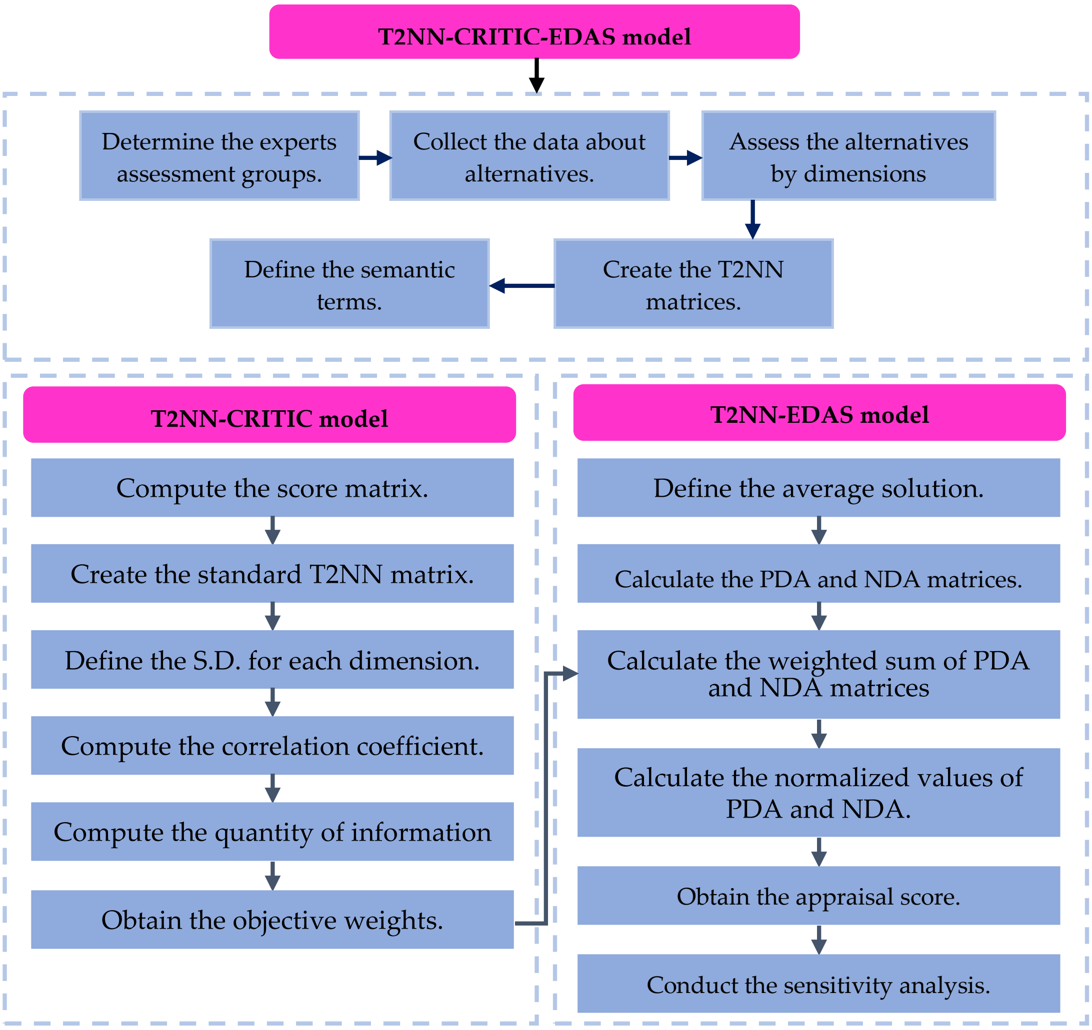

Figure 2. Flowchart of the applied approach.

3.1 Preliminaries and definitions

In this part, a set of definitions and preliminaries related to type 2 neutrosophic numbers are presented.

Definition 1. [9] Let X as the finite universe of discourse and $D[0,1]$, as the set of all triangular neutrosophic sets on$D[0,1]$. A type-2 neutrosophic number set (T2NNS) characterized by $\tilde{Z}$ can be well-defined in X as an object having the form:

$$\tilde{Z} = \{\langle x, \tilde{T}_{\tilde{Z}}(y), \tilde{I}_{\tilde{Z}}(y), \tilde{F}_{\tilde{Z}}(x) \rangle | \; x \in X\}, \tag{1}$$

where, $\tilde{T}_{\tilde{Z}}(x): X \to D[0,1], \tilde{I}_{\tilde{Z}}(x): X \to D[0,1], \tilde{F}_{\tilde{Z}}(x): X \to D[0,1]$. The T2NNS $\tilde{T}_{\tilde{Z}}(x)$ $=\left(T_{T_{\tilde{Z}}}(x), T_{I_{\tilde{Z}}}(x), T_{F_{\tilde{Z}}}(x)\right)$, $\tilde{I}_{\tilde{Z}}(x) =\left(I_{T_{\tilde{Z}}}(x), I_{I_{\tilde{Z}}}(x), I_{F_{\tilde{Z}}}(x)\right)$, $\tilde{F}_{\tilde{Z}}(x) =\left(F_{T_{\tilde{Z}}}(x), F_{I_{\tilde{Z}}}(x), F_{F_{\tilde{Z}}}(x)\right)$, represent the truth, indeterminacy, and falsity memberships of x in $\tilde{Z}$, respectively.

The following conditions are satisfied by the membership parameters:

$$0 \leq \tilde{T}_{\tilde{Z}}(x)^3 + \tilde{I}_{\tilde{Z}}(x)^3 + \tilde{F}_{\tilde{Z}}(x)^3 \leq 3, \; \forall \, x \in X. \tag{2}$$

For ease of simplicity,

$\tilde{Z} = \langle \left(T_{T_{\tilde{Z}}}(x), T_{I_{\tilde{Z}}}(x), T_{F_{\tilde{Z}}}(x)\right), \left(I_{T_{\tilde{Z}}}(x), I_{I_{\tilde{Z}}}(x), I_{F_{\tilde{Z}}}(x)\right), \left(F_{T_{\tilde{Z}}}(x), F_{I_{\tilde{Z}}}(x), F_{F_{\tilde{Z}}}(x)\right) \rangle$ is determined as the T2NN.

Definition 2. [9] Let $\tilde{Z} = \left\langle \left(T_{T_{\tilde{Z}}}(x), T_{I_{\tilde{Z}}}(x), T_{F_{\tilde{Z}}}(x)\right), \left(I_{T_{\tilde{Z}}}(x), I_{I_{\tilde{Z}}}(x), I_{F_{\tilde{Z}}}(x)\right), \left(F_{T_{\tilde{Z}}}(x), F_{I_{\tilde{Z}}}(x), F_{F_{\tilde{Z}}}(x)\right)\right\rangle$ be a T2NN. The score function of the T2NN $\tilde{Z}$ is computed as:

$$S(\tilde{Z}) = \frac{1}{12}\left\langle 8 + \left(T_{T_{\tilde{Z}}}(x) + 2\left(T_{I_{\tilde{Z}}}(x)\right) + T_{F_{\tilde{Z}}}(x)\right) - \left(I_{T_{\tilde{Z}}}(x) + 2\left(I_{I_{\tilde{Z}}}(x)\right) + I_{F_{\tilde{Z}}}(x)\right) - \left(F_{T_{\tilde{Z}}}(x) + 2\left(F_{I_{\tilde{Z}}}(x)\right) + F_{F_{\tilde{Z}}}(x)\right)\right\rangle \quad (3)$$

Definition 3. [9] Let $\tilde{Z}_S = \left\langle \left(T_{T_{\tilde{Z}_S}}(x), T_{I_{\tilde{Z}_S}}(x), T_{F_{\tilde{Z}_S}}(x)\right), \left(I_{T_{\tilde{Z}_S}}(x), I_{I_{\tilde{Z}_S}}(x), I_{F_{\tilde{Z}_S}}(x)\right), \left(F_{T_{\tilde{Z}_S}}(x), F_{I_{\tilde{Z}_S}}(x), F_{F_{\tilde{Z}_S}}(x)\right)\right\rangle$ $(S = 1, 2, \dots, p)$ is a set of T2NNs, and $w = (w_1, \dots, w_S, \dots, w_q)^T$ be the weight vector of them with $w_j \in [0, 1]$ and $\sum_{S=1}^{p} w_S = 1$. A type 2 neutrosophic numbers weighted average (T2NNWA) operator is determined as follows:

$$T2NNWA_w\ (\tilde{Z}_1, \tilde{Z}_S, \dots, \tilde{Z}_p) = w_1\tilde{Z}_1 \oplus w_S\tilde{Z}_S \oplus \dots \oplus w_p\tilde{Z}_p = \bigoplus_{S=1}^{p} (w_S\tilde{Z}_S) = \quad (4)$$

$$\left\langle \begin{array}{c} \left(1-\prod_{S=1}^{p}\left(1-T_{T_{\tilde{Z}_S}}(x)\right)^{w_S}, 1-\prod_{S=1}^{p}\left(1-T_{I_{\tilde{Z}_S}}(x)\right)^{w_S}, 1-\prod_{S=1}^{p}\left(1-T_{F_{\tilde{Z}_S}}(x)\right)^{w_S}\right), \\ \left(\prod_{S=1}^{p}\left(I_{T_{\tilde{Z}_S}}(x)\right)^{w_S}, \prod_{S=1}^{p}\left(I_{I_{\tilde{Z}_S}}(x)\right)^{w_S}, \prod_{S=1}^{p}\left(I_{F_{\tilde{Z}_S}}(x)\right)^{w_S}\right), \\ \left(\prod_{S=1}^{p}\left(F_{T_{\tilde{Z}_S}}(x)\right)^{w_S}, \prod_{S=1}^{p}\left(F_{I_{\tilde{Z}_S}}(x)\right)^{w_S}, \prod_{S=1}^{p}\left(F_{F_{\tilde{Z}_S}}(x)\right)^{w_S}\right) \end{array} \right\rangle \quad (5)$$

3.2 The suggested model

In this section, the steps of the proposed approach to solve the urban energy internet selection problem are presented. The proposed approach consists of two MCDM methods, namely the DEMATEL method and the TOPSIS method. The proposed approach is implemented using T2NNs. Accordingly, the T2NN- CRITIC method is applied to evaluate and determine the weights of the dimensions used in the evaluation process. In addition, the T2NN-TOPSIS method is used to evaluate and rank the selected alternatives in the study.

Step 1. The problem is studied and the sustainability factors affecting the arrangement of five urban energy internet projects are identified. Also, the experts participating in the study are identified provided that they belong to the business and academic fields, as presented in Table 1.

Table 1. Information of experts participating in the study.

K	Expert	Experience (Years)	Occupation	Background	Academic degree
1	$Expert_1$	20	Academia	Energy management	Ph.D.
2	$Expert_2$	15	Industry	Energy management	Ph.D.
3	$Expert_3$	15	Industry	Energy management	M.Sc.

Step 2. The dimensions are determined through an analysis of the related literature, in addition to the opinions of the participating experts. $D_j = (D_1, D_2, \dots, D_n)$, with *j = 1, 2, …, n*. Let $w = (w_1, w_2, \dots, w_n)$ be the vector set used for outlining the dimensions weights, where $w_j > 0$ and $\sum_{j=1}^{n} w_j = 1$. Finally, the set $A_i = \{A_1, A_2, \dots, A_m\}$, having i = 1, 2, …, m alternatives, is measured by n dimensions of set $D_j = \{D_1, D_2, \dots, D_n\}$, with *j = 1, 2, …, n*.

Step 3. A set of semantic terms and their corresponding T2NNs are defined for experts to use in the evaluation process, whether the dimensions or the selected alternatives, as exhibited in Table 2.

Table 2. T2NN semantic terms for weighing dimensions and assessing alternatives.

Semantic terms	Acronyms	Type-2 neutrosophic number
Extremely low	ETL	$\langle(0.20, 0.20, 0.10); (0.65, 0.80, 0.85); (0.45, 0.80, 0.70)\rangle$
Low	LLO	$\langle(0.35, 0.35, 0.10); (0.50, 0.75, 0.80); (0.50, 0.75, 0.65)\rangle$
Medium low	MDM	$\langle(0.40, 0.30, 0.35); (0.50, 0.45, 0.60); (0.45, 0.40, 0.60)\rangle$
Medium	MEM	$\langle(0.50, 0.45, 0.50); (0.40, 0.35, 0.50); (0.35, 0.30, 0.45)\rangle$
Medium high	MGH	$\langle(0.60, 0.45, 0.50); (0.20, 0.15, 0.25); (0.10, 0.25, 0.15)\rangle$
High	HIH	$\langle(0.70, 0.75, 0.80); (0.15, 0.15, 0.25); (0.10, 0.15, 0.15)\rangle$
Extremely high	ELH	$\langle(0.95, 0.90, 0.95); (0.10, 0.10, 0.05); (0.05, 0.05, 0.05)\rangle$

3.2.1 T2NN-CRITIC method

Step 4. Construct a pairwise comparison matrix for dimensions by all experts to show their preferences for these dimensions. A pairwise decision matrix is created by using semantic terms that presented in Table 2, then by using T2NNs exhibited in Table 2 according to Eq. (6). Suppose a set of n dimensions is represented by $D = \{D_1, D_2, \ldots, D_n\}$ is assessed by a set of experts $K_t(t = 1, 2\ldots l)$ who presented their assessment report for each criterion $D_j(j = 1, 2\ldots n)$.

$$\widetilde{M} = \begin{array}{c} \\ K_1 \\ \vdots \\ K_t \end{array} \begin{array}{c} \begin{array}{ccc} D_1 & \cdots & D_n \end{array} \\ \left[\begin{array}{ccc} \left[\begin{array}{c} \left(T_{T_{\tilde{Z}_1}^{(1)}}(x), T_{I_{\tilde{Z}_1}^{(1)}}(x), T_{F_{\tilde{Z}_1}^{(1)}}(x)\right), \\ \left(I_{T_{\tilde{Z}_1}^{(1)}}(x), I_{I_{\tilde{Z}_1}^{(1)}}(x), I_{F_{\tilde{Z}_1}^{(1)}}(x)\right), \\ \left(F_{T_{\tilde{Z}_1}^{(1)}}(x), F_{I_{\tilde{Z}_1}^{(1)}}(x), F_{F_{\tilde{Z}_1}^{(1)}}(x)\right) \end{array}\right] & \cdots & \left[\begin{array}{c} \left(T_{T_{\tilde{Z}_t}^{(t)}}(x), T_{I_{\tilde{Z}_t}^{(t)}}(x), T_{F_{\tilde{Z}_t}^{(t)}}(x)\right), \\ \left(I_{T_{\tilde{Z}_t}^{(t)}}(x), I_{I_{\tilde{Z}_t}^{(t)}}(x), I_{F_{\tilde{Z}_t}^{(t)}}(x)\right), \\ \left(F_{T_{\tilde{Z}_t}^{(t)}}(x), F_{I_{\tilde{Z}_t}^{(t)}}(x), F_{F_{\tilde{Z}_t}^{(t)}}(x)\right) \end{array}\right] \\ \vdots & \cdots & \vdots \\ \left[\begin{array}{c} \left(T_{T_{\tilde{Z}_1}^{(1)}}(x), T_{I_{\tilde{Z}_1}^{(1)}}(x), T_{F_{\tilde{Z}_1}^{(1)}}(x)\right), \\ \left(I_{T_{\tilde{Z}_1}^{(1)}}(x), I_{I_{\tilde{Z}_1}^{(1)}}(x), I_{F_{\tilde{Z}_1}^{(1)}}(x)\right), \\ \left(F_{T_{\tilde{Z}_1}^{(1)}}(x), F_{I_{\tilde{Z}_1}^{(1)}}(x), F_{F_{\tilde{Z}_1}^{(1)}}(x)\right) \end{array}\right] & \cdots & \left[\begin{array}{c} \left(T_{T_{\tilde{Z}_t}^{(t)}}(x), T_{I_{\tilde{Z}_t}^{(t)}}(x), T_{F_{\tilde{Z}_t}^{(t)}}(x)\right), \\ \left(I_{T_{\tilde{Z}_t}^{(t)}}(x), I_{I_{\tilde{Z}_t}^{(t)}}(x), I_{F_{\tilde{Z}_t}^{(t)}}(x)\right), \\ \left(F_{T_{\tilde{Z}_t}^{(t)}}(x), F_{I_{\tilde{Z}_t}^{(t)}}(x), F_{F_{\tilde{Z}_t}^{(t)}}(x)\right) \end{array}\right] \end{array}\right] \end{array} \quad (6)$$

Step 5. Transform the T2NNs to real values according to Eq. (3).

Step 6. Compute the normalized decision matrix for dimensions according to Eq. (7) and Eq. (8).

For benefit dimensions:

$$x_{ij}{}^* = \frac{x_{ij} - min(x_{ij})}{max(x_{ij}) - min(x_{ij})} \quad \text{i = 1, 2...m and j = 1, 2...n.} \quad (7)$$

For cost dimensions:

$$x_{ij}{}^* = 1 - \frac{x_{ij} - min(x_{ij})}{max(x_{ij}) - min(x_{ij})} \quad \text{i = 1, 2...m and j = 1, 2...n.} \quad (8)$$

Step 7. Computation of the values of the matrix's standard deviation and linear correlation per column. Then, determining the amount of information of dimensions according to Eq. (9).

$$u_j = \sigma_j \ . \sum_{q=1}^{m} \left(1 - r_{jq}\right) \quad (9)$$

where σ_j is the standard deviation of the indices, and r_{jq} is linear correlation coefficient for the dimensions.

Step 8. Determine the dimensions weights according to Eq. (10).

$$w_j = \frac{u_j}{\sum_{q=1}^{m} u_q} \quad (10)$$

3.2.2 T2NN-EDAS method

Step 9. Construct an evaluation decision matrix $[\tilde{Q}_{ij}{}^{s}]_{m\times n}$ among dimensions determined and the alternatives by all experts according to Eq. (11) using semantic terms and T2NNs exhibited in Table 2.

$$\tilde{Q} = \begin{array}{c c} & \begin{array}{ccc} D_1 & \cdots & D_n \end{array} \\ \begin{array}{c} A_1 \\ \vdots \\ A_m \end{array} & \begin{bmatrix} \begin{bmatrix} \left(T_{T_{\tilde{Q}_{11}}{}^{(s)}}(x), T_{I_{\tilde{Q}_{11}}{}^{(s)}}(x), T_{F_{\tilde{Q}_{11}}{}^{(s)}}(x)\right), \\ \left(I_{T_{\tilde{Q}_{11}}{}^{(s)}}(x), I_{I_{\tilde{Q}_{11}}{}^{(s)}}(x), I_{F_{\tilde{Q}_{11}}{}^{(s)}}(x)\right), \\ \left(F_{T_{\tilde{Q}_{11}}{}^{(s)}}(x), F_{I_{\tilde{Q}_{11}}{}^{(s)}}(x), F_{F_{\tilde{Q}_{11}}{}^{(s)}}(x)\right) \end{bmatrix} & \cdots & \begin{bmatrix} \left(T_{T_{\tilde{Q}_{1n}}{}^{(s)}}(x), T_{I_{\tilde{Q}_{1n}}{}^{(s)}}(x), T_{F_{\tilde{Q}_{1n}}{}^{(s)}}(x)\right), \\ \left(I_{T_{\tilde{Q}_{1n}}{}^{(s)}}(x), I_{I_{\tilde{Q}_{1n}}{}^{(s)}}(x), I_{F_{\tilde{Q}_{1n}}{}^{(s)}}(x)\right), \\ \left(F_{T_{\tilde{Q}_{1n}}{}^{(s)}}(x), F_{I_{\tilde{Q}_{1n}}{}^{(s)}}(x), F_{F_{\tilde{Q}_{1n}}{}^{(s)}}(x)\right) \end{bmatrix} \\ \vdots & \cdots & \vdots \\ \begin{bmatrix} \left(T_{T_{\tilde{Q}_{m1}}{}^{(s)}}(x), T_{I_{\tilde{Q}_{m1}}{}^{(s)}}(x), T_{F_{\tilde{Q}_{m1}}{}^{(s)}}(x)\right), \\ \left(I_{T_{\tilde{Q}_{m1}}{}^{(s)}}(x), I_{I_{\tilde{Q}_{m1}}{}^{(s)}}(x), I_{F_{\tilde{Q}_{m1}}{}^{(s)}}(x)\right), \\ \left(F_{T_{\tilde{Q}_{m1}}{}^{(s)}}(x), F_{I_{\tilde{Q}_{m1}}{}^{(s)}}(x), F_{F_{\tilde{Q}_{m1}}{}^{(s)}}(x)\right) \end{bmatrix} & \cdots & \begin{bmatrix} \left(T_{T_{\tilde{Q}_{mn}}{}^{(s)}}(x), T_{I_{\tilde{Q}_{mn}}{}^{(s)}}(x), T_{F_{\tilde{Q}_{mn}}{}^{(s)}}(x)\right), \\ \left(I_{T_{\tilde{Q}_{mn}}{}^{(s)}}(x), I_{I_{\tilde{Q}_{mn}}{}^{(s)}}(x), I_{F_{\tilde{Q}_{mn}}{}^{(s)}}(x)\right), \\ \left(F_{T_{\tilde{Q}_{mn}}{}^{(s)}}(x), F_{I_{\tilde{Q}_{mn}}{}^{(s)}}(x), F_{F_{\tilde{Q}_{mn}}{}^{(s)}}(x)\right) \end{bmatrix} \end{bmatrix} \end{array}, \tag{11}$$

Step 10. Transform the T2NNs to real values according to Eq. (3).
Step 11. Calculate the average value for each dimension according to Eq. (12).

$$AV_j = \sum_{i=1}^{n} x_{ij}/n \tag{12}$$

Step 12. Compute the positive distance from average matrix PDA = $[PDA_j]_{n\times m}$ according to Eq. (13), and the negative distance from average matrix NDA = $[NDA_j]_{n\times m}$ according to Eq. (14), accordingly with the type of criterion.

$$PDA_{ij} = max\left(0, \left(x_{ij} - AV_j\right)\right)/AV_j \ , \ NDA_{ij} = max\left(0, \left(AV_j - x_{ij}\right)\right)/AV_j \tag{13}$$

$$PDA_{ij} = max\left(0, \left(AV_j - x_{ij}\right)\right)/AV_j \ , \ NDA_{ij} = max\left(0, \left(x_{ij} - AV_j\right)\right)/AV_j \tag{14}$$

Step 13. Compute the weighted sum of PDA according to Eq. (15) and NDA according to Eq. (16) for each of the m alternatives according to n dimensions.

$$SP_i = \sum_{j=1}^{m} w_j PDA_{ij} \tag{15}$$

$$SN_i = \sum_{j=1}^{m} w_j NDA_{ij} \tag{16}$$

Step 14. Obtain the normalized values for each SP_i and SN_i according to Eq. (17) and Eq. (18).

$$NSP_i = SP_i/max_{i\in\{1,\dots,n\}}(SP_i) \tag{17}$$

$$NSN_i = 1 - SN_i/max_{i\in\{1,\dots,n\}}(SN_i) \tag{18}$$

Step 15. Determine the assessment score AS_i for each alternative according to Eq. (19).

$$AS_i = 0.5\ (NSP_i + NSN_i) \tag{19}$$

Step 16. Order the alternatives from largest to smallest according to AS_i. The best alternative has the greatest AS_i.

4. Application

4.1 Application of the suggested approach

In this part, the steps of the T2NN-CRITIC-EDAS approach are applied to evaluate and rank five Urban Energy Internet projects.

Step 1. Initially, the problem was studied in detail and its main goal was set, which was to arrange five urban energy internet projects.

Step 2. Three experts in the field of energy management were agreed to assist the authors in evaluating the sustainability dimensions used in the evaluation process as well as ranking the five urban energy projects selected for the study. The five sustainability dimensions used are: economic (D_1), social (D_2), technical (D_3), environmental (D_4) and resource (D_5). Also, the five selected urban energy internet projects are symbolized by A_1, A_2, A_3, A_4, and A_5.

Step 3. A decision matrix for dimensions was constructed by all experts to show their preferences for these dimensions. The decision matrix is created by applying semantic terms in Table 2 and then by T2NNs in Table 2 according to Eq. (6), as presented in Table 3 and Table 4, respectively.

Step 4. The T2NNs were transformed to real values according to Eq. (3). Then, the normalized decision matrix was calculated by applying Eq. (7) as exhibited in Table 5.

Step 5. The values of the matrix's standard deviation and linear correlation per column were calculated. Then, the amount of information of dimensions was identified according to Eq. (9) as shown in Table 5.

Step 6. The dimensions weights were obtained according to Eq. (10) as exhibited in Table 6 and shown in Figure 3.

Table 3. Assessment matrix of dimensions by the three experts using semantic terms.

Dimensions	D_1	D_2	D_3	D_4	D_5
$Expert_1$	ETL	LLO	ETL	MEM	ETL
$Expert_2$	ELH	MDM	ETL	HIH	ELH
$Expert_3$	HIH	MEM	LLO	MGH	MEM

Table 4. Assessment matrix of dimensions by the three experts using T2NN.

Ds.	$Expert_1$	$Expert_2$
D_1	$\langle(0.20, 0.20, 0.10); (0.65, 0.80, 0.85); (0.45, 0.80, 0.70)\rangle$	$\langle(0.95, 0.90, 0.95); (0.10, 0.10, 0.05); (0.05, 0.05, 0.05)\rangle$
D_2	$\langle(0.35, 0.35, 0.10); (0.50, 0.75, 0.80); (0.50, 0.75, 0.65)\rangle$	$\langle(0.40, 0.30, 0.35); (0.50, 0.45, 0.60); (0.45, 0.40, 0.60)\rangle$
D_3	$\langle(0.20, 0.20, 0.10); (0.65, 0.80, 0.85); (0.45, 0.80, 0.70)\rangle$	$\langle(0.20, 0.20, 0.10); (0.65, 0.80, 0.85); (0.45, 0.80, 0.70)\rangle$
D_4	$\langle(0.50, 0.45, 0.50); (0.40, 0.35, 0.50); (0.35, 0.30, 0.45)\rangle$	$\langle(0.70, 0.75, 0.80); (0.15, 0.15, 0.25); (0.10, 0.15, 0.15)\rangle$
D_5	$\langle(0.20, 0.20, 0.10); (0.65, 0.80, 0.85); (0.45, 0.80, 0.70)\rangle$	$\langle(0.95, 0.90, 0.95); (0.10, 0.10, 0.05); (0.05, 0.05, 0.05)\rangle$
Ds.	$Expert_3$	
D_1	$\langle(0.70, 0.75, 0.80); (0.15, 0.15, 0.25); (0.10, 0.15, 0.15)\rangle$	
D_2	$\langle(0.50, 0.45, 0.50); (0.40, 0.35, 0.50); (0.35, 0.30, 0.45)\rangle$	
D_3	$\langle(0.35, 0.35, 0.10); (0.50, 0.75, 0.80); (0.50, 0.75, 0.65)\rangle$	
D_4	$\langle(0.60, 0.45, 0.50); (0.20, 0.15, 0.25); (0.10, 0.25, 0.15)\rangle$	
D_5	$\langle(0.50, 0.45, 0.50); (0.40, 0.35, 0.50); (0.35, 0.30, 0.45)\rangle$	

Table 5. Normalized decision matrix of dimensions.

Criteria	D_1	D_2	D_3	D_4	D_5
$Expert_1$	0.0000	0.0000	0.0000	0.0000	0.0000
$Expert_2$	1.0000	0.5618	0.0000	1.0000	1.0000
$Expert_3$	0.8321	1.0000	1.0000	0.5588	0.4877
σ_j	0.5355	0.5013	0.5774	0.5012	0.5001

Table 6. Final weights for sustainability dimensions.

Ds.	D_1	D_2	D_3	D_4	D_5	σ_j	u_j	w_j
D_1	1.0000	0.8198	0.3581	0.9558	0.9285	0.5355	0.5022	0.121
D_2	0.8198	1.0000	0.8282	0.6152	0.5486	0.5013	0.5956	0.144
D_3	0.3581	0.8282	1.0000	0.0678	-0.0142	0.5774	1.5936	0.384
D_4	0.9558	0.6152	0.0678	1.0000	0.9966	0.5012	0.6839	0.165
D_5	0.9285	0.5486	-0.0142	0.9966	1.0000	0.5001	0.7703	0.186

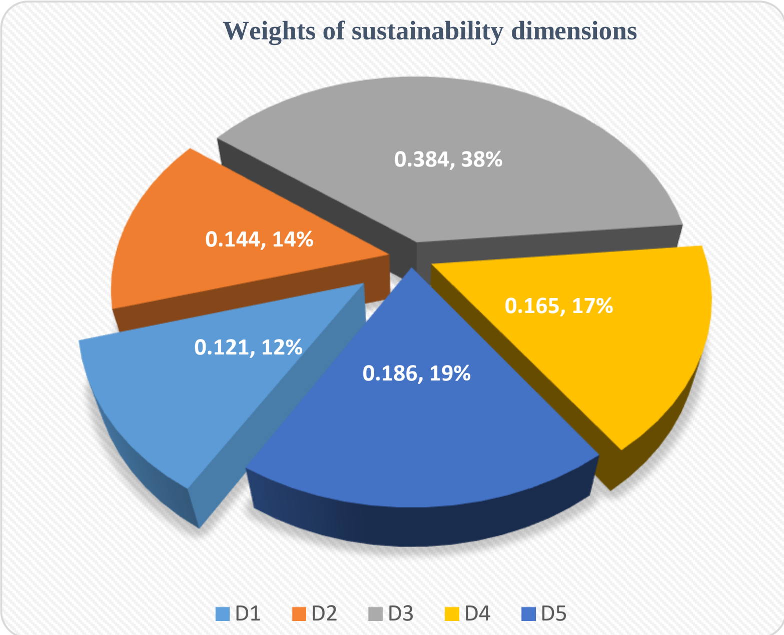

Figure 3. Final weights of dimensions using the T2NN-CRITIC method.

Step 7. An assessment decision matrix among the five dimensions determined and the five projects for urban energy internet was constructed by all experts according to Eq. (11) using semantic terms as shown in Table 7, and then by applying T2NNs.
Step 8. An assessment decision matrix among the five dimensions determined and the five projects for urban energy internet was constructed by all experts according to Eq. (11) using semantic terms as shown in Table 7, and by using T2NNs as presented in Table 8.
Step 9. The T2NNs were transformed to real values by applying Eq. (3) as shown in Table 9. Then, the average value for each dimension was computed according to Eq. (12) as exhibited in Table 9.
Step 10. The PDA and NDA of the five urban energy internet projects were calculated according to Eq. (13) and Eq. (14), respectively, as presented in Table 10.
Step 11. The weighted sum of PDA and NDA of five urban energy internet projects were computed according to Eq. (15) and Eq. (16), respectively, as presented in Table 11.
Step 12. The normalized values for the weighted sum of PDA and NDA of the five urban energy internet projects were computed according to Eq. (17) and Eq. (18), respectively, as presented in Table 12.
Step 13. The assessment score, AS_i for the five urban energy internet projects was computed by applying Eq. (19) as presented in Table 12. Finally, the five urban energy internet projects were ordered according to AS_i as presented in Table 12 and shown in Figure 4.

Table 7. Assessment matrix for five projects according to five sustainability dimensions.

Alternatives	Dimensions				
	D_1	D_2	D_3	D_4	D_5
A_1	MDM	MDM	LLO	MGH	ELH
A_2	MEM	ETL	LLO	HIH	MDM
A_3	ELH	HIH	MGH	ELH	MDM
$\mathbf{A_4}$	LLO	MEM	MDM	MDM	HIH
$\mathbf{A_5}$	MDM	MDM	ELH	MGH	HIH

Table 8. Assessment matrix for five projects according to five sustainability dimensions using T2NN.

Alt.	D_1	D_2
A_1	$\langle(0.40, 0.30, 0.35); (0.50, 0.45, 0.60); (0.45, 0.40, 0.60)\rangle$	$\langle(0.40, 0.30, 0.35); (0.50, 0.45, 0.60); (0.45, 0.40, 0.60)\rangle$
A_2	$\langle(0.50, 0.45, 0.50); (0.40, 0.35, 0.50); (0.35, 0.30, 0.45)\rangle$	$\langle(0.20, 0.20, 0.10); (0.65, 0.80, 0.85); (0.45, 0.80, 0.70)\rangle$
A_3	$\langle(0.95, 0.90, 0.95); (0.10, 0.10, 0.05); (0.05, 0.05, 0.05)\rangle$	$\langle(0.70, 0.75, 0.80); (0.15, 0.15, 0.25); (0.10, 0.15, 0.15)\rangle$
A_4	$\langle(0.35, 0.35, 0.10); (0.50, 0.75, 0.80); (0.50, 0.75, 0.65)\rangle$	$\langle(0.50, 0.45, 0.50); (0.40, 0.35, 0.50); (0.35, 0.30, 0.45)\rangle$
A_5	$\langle(0.40, 0.30, 0.35); (0.50, 0.45, 0.60); (0.45, 0.40, 0.60)\rangle$	$\langle(0.40, 0.30, 0.35); (0.50, 0.45, 0.60); (0.45, 0.40, 0.60)\rangle$
Alt.	D_3	D_4
A_1	$\langle(0.35, 0.35, 0.10); (0.50, 0.75, 0.80); (0.50, 0.75, 0.65)\rangle$	$\langle(0.60, 0.45, 0.50); (0.20, 0.15, 0.25); (0.10, 0.25, 0.15)\rangle$
A_2	$\langle(0.35, 0.35, 0.10); (0.50, 0.75, 0.80); (0.50, 0.75, 0.65)\rangle$	$\langle(0.70, 0.75, 0.80); (0.15, 0.15, 0.25); (0.10, 0.15, 0.15)\rangle$
A_3	$\langle(0.60, 0.45, 0.50); (0.20, 0.15, 0.25); (0.10, 0.25, 0.15)\rangle$	$\langle(0.95, 0.90, 0.95); (0.10, 0.10, 0.05); (0.05, 0.05, 0.05)\rangle$
A_4	$\langle(0.40, 0.30, 0.35); (0.50, 0.45, 0.60); (0.45, 0.40, 0.60)\rangle$	$\langle(0.40, 0.30, 0.35); (0.50, 0.45, 0.60); (0.45, 0.40, 0.60)\rangle$
A_5	$\langle(0.95, 0.90, 0.95); (0.10, 0.10, 0.05); (0.05, 0.05, 0.05)\rangle$	$\langle(0.60, 0.45, 0.50); (0.20, 0.15, 0.25); (0.10, 0.25, 0.15)\rangle$
Alt.	D_5	
A_1	$\langle(0.95, 0.90, 0.95); (0.10, 0.10, 0.05); (0.05, 0.05, 0.05)\rangle$	
A_2	$\langle(0.40, 0.30, 0.35); (0.50, 0.45, 0.60); (0.45, 0.40, 0.60)\rangle$	
A_3	$\langle(0.40, 0.30, 0.35); (0.50, 0.45, 0.60); (0.45, 0.40, 0.60)\rangle$	
A_4	$\langle(0.70, 0.75, 0.80); (0.15, 0.15, 0.25); (0.10, 0.15, 0.15)\rangle$	
A_5	$\langle(0.70, 0.75, 0.80); (0.15, 0.15, 0.25); (0.10, 0.15, 0.15)\rangle$	

Table 9. Decision matrix for five projects according to five sustainability dimensions.

Alt.	$\mathbf{D_1}$	$\mathbf{D_2}$	$\mathbf{D_3}$	$\mathbf{D_4}$	$\mathbf{D_5}$
$\mathbf{A_1}$	0.458	0.458	0.308	0.708	0.929
$\mathbf{A_2}$	0.575	0.238	0.308	0.813	0.458
$\mathbf{A_3}$	0.929	0.813	0.708	0.929	0.458
$\mathbf{A_4}$	0.308	0.575	0.458	0.458	0.813
$\mathbf{A_5}$	0.458	0.458	0.929	0.708	0.813
$\boldsymbol{AV_j}$	0.546	0.508	0.542	0.723	0.694

Table 10. Obtaining of the positive and negative distances from average.

Alt.	PDA					NDA				
	D_1	D_2	D_3	D_4	D_5	D_1	D_2	D_3	D_4	D_5
A_1	0.000	0.000	0.000	0.000	0.338	0.161	0.099	0.432	0.021	0.000
A_2	0.054	0.000	0.000	0.124	0.000	0.000	0.532	0.432	0.000	0.340
A_3	0.703	0.599	0.306	0.285	0.000	0.000	0.000	0.000	0.000	0.340
A_4	0.000	0.131	0.000	0.000	0.171	0.435	0.000	0.155	0.367	0.000
A_5	0.000	0.000	0.713	0.000	0.171	0.161	0.099	0.000	0.021	0.000

Table 11. Obtaining the weighted sum of the positive and negative distances from average.

Alt.	Weighted PDA					Weighted NDA				
	D_1	D_2	D_3	D_4	D_5	D_1	D_2	D_3	D_4	D_5
A_1	0.000	0.000	0.000	0.000	0.063	0.019	0.014	0.166	0.003	0.000
A_2	0.007	0.000	0.000	0.020	0.000	0.000	0.077	0.166	0.000	0.063
A_3	0.085	0.086	0.117	0.047	0.000	0.000	0.000	0.000	0.000	0.063
A_4	0.000	0.019	0.000	0.000	0.032	0.053	0.000	0.060	0.061	0.000
A_5	0.000	0.000	0.274	0.000	0.032	0.019	0.014	0.000	0.003	0.000

Table 12. Ranking of five urban energy internet projects by applying the EDAS method.

Alt.	$\mathbf{SP_i}$	$\mathbf{SN_i}$	$\mathbf{NSP_i}$	$\mathbf{NSN_i}$	$\mathbf{AS_i}$	**Rank**
$\mathbf{A_1}$	0.063	0.203	0.187	0.336	0.262	4
$\mathbf{A_2}$	0.027	0.306	0.080	0.000	0.040	5
$\mathbf{A_3}$	0.336	0.063	1.000	0.793	0.897	1
$\mathbf{A_4}$	0.051	0.173	0.151	0.435	0.293	3
$\mathbf{A_5}$	0.306	0.037	0.911	0.878	0.895	2

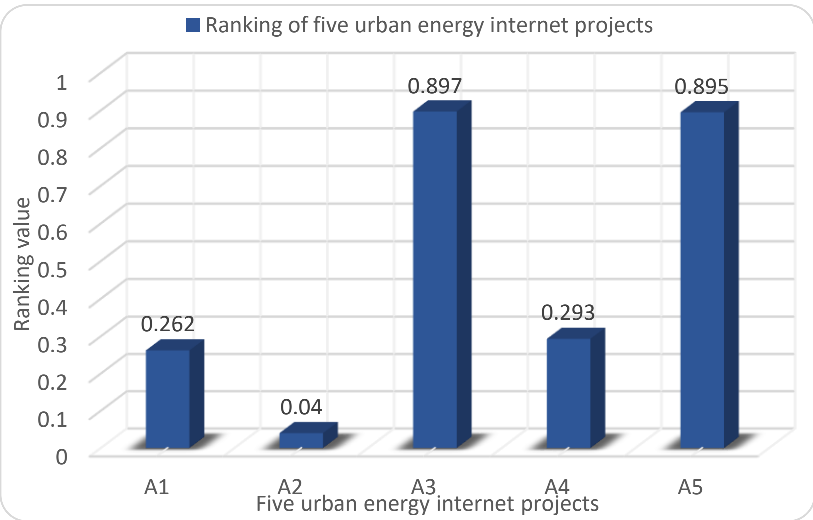

Figure 4. Final ranking of five urban energy internet projects using EDAS.

4.2 Findings and discussion

In this part, the results obtained from applying the T2NN-CRITIC-EDAS approach to evaluate five urban energy internet projects are discussed. Initially, the T2NN-CRITIC method was applied to evaluate five dimensions of urban energy internet sustainability. In this regard, the results indicate that the technical dimension is the dimension with the highest weight and most influence. Next, the T2NN-EDAS method was applied to rank five urban energy internet projects. The results indicate that the A_3 project is the highest in the ranking.

4.3 Sensitivity analysis

In this part, a sensitivity analysis model is presented by changing the weights for the technical dimension. The results of the sensitivity analysis in Figure 5 indicate that there are some slight changes in the order of the alternatives chosen in the study. The changes that occurred in the ranking of the alternatives are that the fifth alternative became the highest ranked when the weight of the technical dimension became equal to 0.5 until its weight became 1. Accordingly, the sensitivity analysis on the model used leads to some slight changes in the ranking of the selected alternatives, which means that changing the weights is important in the order of alternatives.

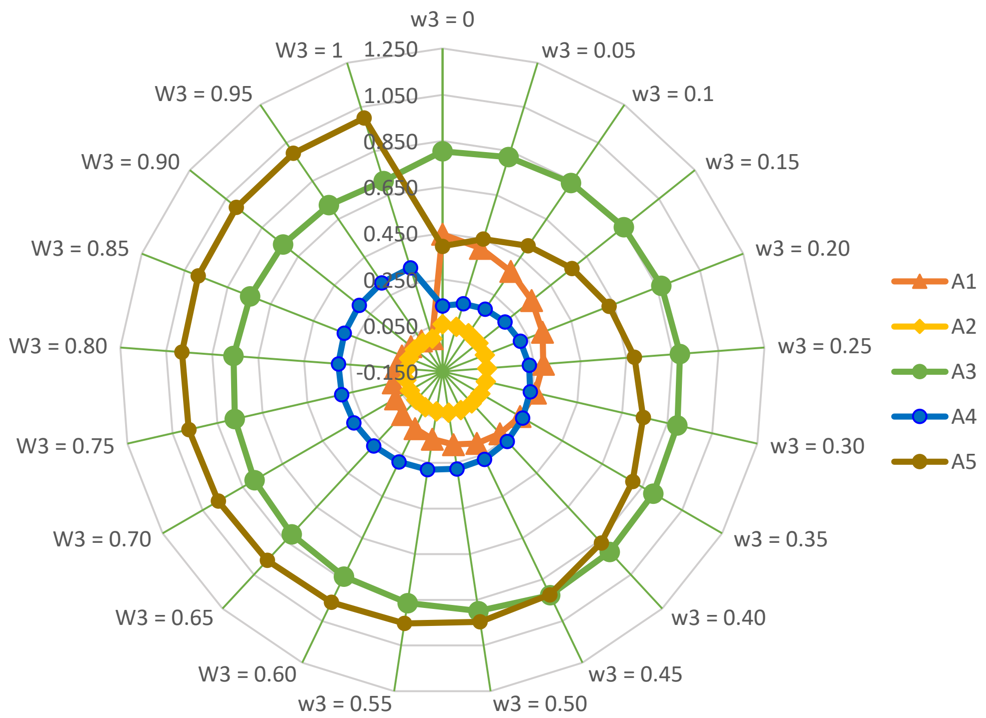

Figure 5. Influence of the w_3 on the ranking of urban energy internet projects.

5. Conclusions

The development and deployment of the UEI prioritize the achievement of sustainable energy supply, improved energy efficiency, and enhanced energy security. Nevertheless, the absence of research on the assessment of UEI projects has hindered the advancement of urban energy internet, despite the diligent endeavors of researchers and academics investigating its development and organization. In addition, scholars have acknowledged the need of addressing the evaluation problem by using neutrosophic set theory and its expansions, considering the inherent uncertainty in the actual world. This study presents an MCDM model to solve the problem of evaluating UEI projects in light of sustainability. The study was conducted under a neutrosophic environment and using T2NNs. The presented model relied entirely on the CRITIC and EDAS methods. Initially, the CRITIC method was used to evaluate five dimensions of sustainability and determine the most prioritized and weighted. In addition, the EDAS method was applied to rank five UEI projects selected for study. Also, a sensitivity analysis was conducted in order to show the importance of changing the weights on the results of the presented model. In future studies, the sustainability factors used in the evaluation process could be increased and the number of experts participating in the study could be increased. In addition, the study can be conducted under different environments to deal with uncertainty.

Acknowledgments

The author is grateful to the editorial and reviewers, as well as the correspondent author, who offered assistance in the form of advice, assessment, and checking during the study period.

Data availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare that there is no conflict of interest in the research.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

References

1. Hajduk, S.; Jelonek, D. A Decision-Making Approach Based on TOPSIS Method for Ranking Smart Cities in the Context of Urban Energy. Energies 2021, 14. https://doi.org/10.3390/en14092691.
2. Xuefeng, J.; Cunbin, L.; Ying, Z. Risk identification and influence analysis model for urban energy internet based on knowledge graph improved decision-making trial and evaluation laboratory. Expert Syst. Appl. 2023, 233, 120997, doi:https://doi.org/10.1016/j.eswa.2023.120997.
3. Heidary Dahooie, J.; Mohammadian, A.; Qorbani, A.R.; Daim, T. A portfolio selection of internet of things (IoTs) applications for the sustainable urban transportation: A novel hybrid multi criteria decision making approach. Technol. Soc. 2023, 75, 102366, doi:https://doi.org/10.1016/j.techsoc.2023.102366.
4. Wu, Y.; Zhang, T.; Yi, L. Regional energy internet project investment decision making framework through interval type-2 fuzzy number based Choquet integral fuzzy synthetic model. Appl. Soft Comput. 2021, 111, 107718, doi:https://doi.org/10.1016/j.asoc.2021.107718.
5. B., N.; Roy, J. A new hybrid MCDM framework for third-party logistics provider selection under sustainability perspectives. Expert Syst. Appl. 2023, 234, 121009, doi:https://doi.org/10.1016/j.eswa.2023.121009.
6. Abdelhafeez, A.; K.Mohamed, H.; A.Khalil, N. Rank and Analysis Several Solutions of Healthcare Waste to Achieve Cost Effectiveness and Sustainability Using Neutrosophic MCDM Model. Neutrosophic Syst. with Appl. 2023, 2, 25–37, doi:10.61356/j.nswa.2023.8.
7. Rani, P.; Mishra, A.R.; Krishankumar, R.; Ravichandran, K.S.; Kar, S. Multi-criteria food waste treatment method selection using single-valued neutrosophic-CRITIC-MULTIMOORA framework. Appl. Soft Comput. 2021, 111, 107657, doi:https://doi.org/10.1016/j.asoc.2021.107657.
8. Simić, V.; Milovanović, B.; Pantelić, S.; Pamučar, D.; Tirkolaee, E.B. Sustainable route selection of petroleum transportation using a type-2 neutrosophic number based ITARA-EDAS model. Inf. Sci. (Ny). 2023, 622, 732–754, doi:https://doi.org/10.1016/j.ins.2022.11.105.

9. Abdel-Basset, M.; Saleh, M.; Gamal, A.; Smarandache, F. An approach of TOPSIS technique for developing supplier selection with group decision making under type-2 neutrosophic number. Appl. Soft Comput. J. 2019, 77, 438–452, doi:10.1016/j.asoc.2019.01.035.

Received: 15 Sep 2023, **Revised:** 30 Oct 2023,
Accepted: 15 Nov 2023, **Available online:** 01 Dec 2023.