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Valuation of Internet of Energy (IoE) Platforms in Smart Cities: A Hybrid Multi-Criteria Decision Making Approach

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Abstract

A smart city is a place where people live using computing, sensing, and networking technology in a variety of ways, including smart buildings, smart homes, smart transportation, smart workplaces, smart offices, smart industries, and smart agriculture. These smart technologies need to connect so; we need to use the Internet of Things (IoT) that has applications in many areas of our smart lives. IoT has been used due to the growing usage of renewable energy sources and the challenges of network management. Internet of Energy (IoE) integrates the IoT and smart grid capabilities. The basic role of smart grids or IoE is an essential element in creating smart cities. In this work, we present some IoE platforms that represent the alternatives and their criteria. The proposed study treats the uncertainty of multi-criteria decision-making (MCDM) modified by single value triangular neutrosophic number (SVTrN) by choosing the optimal IoE platform based on the criteria importance through inter-criteria correlation (CRITIC) method and multi-attributive ideal-real comparative analysis (MAIRCA). The proposed model proved its effectiveness by applying it to an experimental case. The results show that the DCC (A3) platform is the best one.

Keywords: Smart Grids, Internet of Energy, MCDM, Smart City, IoT, Renewable Energy.

1 | Introduction

Nowadays, the Internet is an essential component of every aspect of life. With the world's population continuing to grow and challenges in utilizing renewable energy sources and reducing carbon emissions from fossil fuels, smart cities with communication and networking technologies have been used to manage energy. Improving energy systems for the use of renewable energy and carbon mitigation has become important to cities due to the growing interest in renewable energy and the need to minimize carbon emissions. The need for energy increases to keep up with civilization. The requirement for energy has been increasing throughout this time due to increased use in industries such as manufacturing, transportation, automation, health care, and home appliances. To meet future requirements for the development of smart cities, renewable energy development is necessary such as water, sun, wind, and geothermal energy, moving away from fossil fuels [1]. These challenges are not limited only to renewable energy source technologies but also depend on smart grids

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and energy storage systems, improving energy efficiency, increasing grid stability, reducing transmission losses, and enhancing energy security.

Internet of Things technologies is a technology in which the internet is used to connect data, people, processes, and things, and interact with the outside world or their interior states. This connection leads to improved information and analysis, which is used to control energy systems [2]. So, the IoT is important to increase and enable wireless communications in all fields [3].

Smart cities have smart technologies, smart energy, transportation, and healthcare are some of the various elements that make up smart cities [4]. Smart cities need to improve the efficiency of managing their infrastructure to keep up with population growth and create a sustainable living environment [5]. Since we need to reduce resource consumption, cities that continue to use fewer resources and generate less trash can be developed into smart cities. These cities used energy in various sectors, including residential buildings, transportation, industrial and commercial facilities, streets, sewage, water treatment, and electrical [6]. These systems improve and develop energy generation, distribution, and consumption through the use of modern technologies including data analytics like cloud computing, meters, and sensing services like sensors in Amsterdam's smart city which reduces traffic congestion, preserves energy, and enhances security [7].

The idea of the Internet of Energy (IoE) was born out of the combination of IoT and energy. To understand the concept of IoE, we must consider the revolution in the communications industry [8, 9]. In the past, the main source of voice communications was the public telephone network, a system that transmitted analog voice signals over copper wires that were routed to the calling party's telephone. This system was very reliable, but the high cost of transmitting information and the rapid development of technology made it difficult to provide affordable services to consumers [8]. With the development of the Internet in the communications industry, there has been a move toward a more efficient system of transmitting information, using digital technologies to exchange data between servers and clients and provide services such as email, web browsing, and voiceover. The overarching goal of the Energy Internet is to build an "Internet of Energy," a comprehensive energy system that delivers energy reliably and cost-effectively to consumers and businesses. The IoE will be able to monitor, manage, and control the transmission and use of energy more efficiently and sustainably using ICT, two-way control, automation, and computational intelligence in an amazing analog energy system [10]. The goal of using IoE in smart cities is to improve the decision-making process without human intervention, which will then improve the results of all actions as in Figure 1. Recently there are a lot of IoE platforms appeared to serve the energy in smart cities.

To select the best IoE platform there are several evaluation criteria such as water supply (C1), electricity consumption (C2), robust network (C3), and affordable housing (C4). So, we require a productive multi-criteria decision-making process to make a balance between all criteria. There exist also several platforms (alternatives) like ASTRI smart city (A1) [11], NTUITY (A2) [12], DCC (A3) [13], Iberdrola (A4) [14], next drive (A5) [15], and Electrex (A6) [16]. This study uses the CRITIC method and MAIRCA in the neutrosophic environment to select the optimal platform.

This study is organized into several sections; Section 1 is the introduction, motivation, and contribution. Section 2 is the previous related work. Section 3 is the methods that we used for evaluation. Section 4 is the case study and the last section introduces the conclusion and future directions.

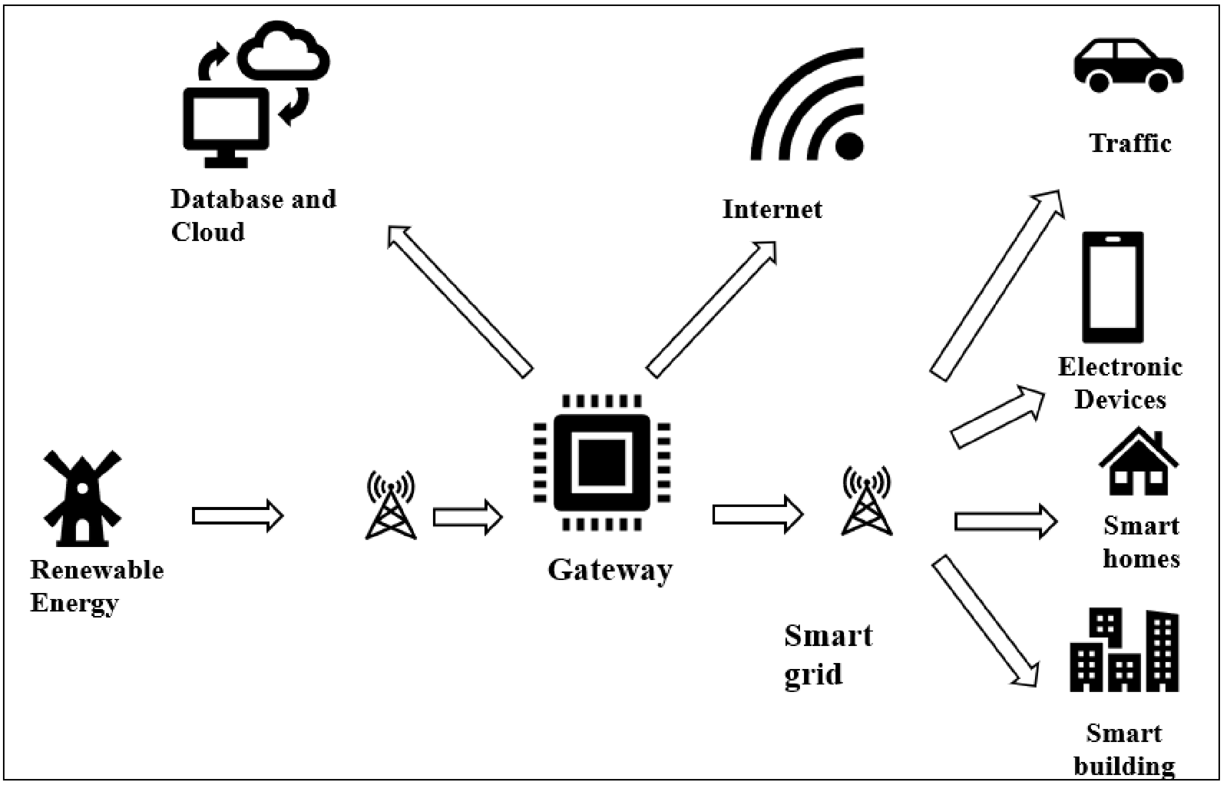

Figure 1. The IoE in smart cities [17].

2 | Literature Review

This section discusses several previous studies about the energy of the internet in smart cities and its applications. Many researchers have focused on the context of sustainable smart cities. This study sheds important light on how smart technologies affect household energy consumption [18]. Shokry et al. [19] evaluated smart grid applications, and information security risks for advanced metering infrastructure by evaluating criteria for energy metering systems with the ISRA method. Gerhard et al.[20] presented a study to discuss sensing in smart cities and increasing energy efficiency. Ali et al. [21] introduced an approach for improving the privacy and security of IoT in smart parking systems. Said et al. [22] suggested a way to use game theory and IoT to enhance the performance of intelligent parking systems according to the reservation system. Tanweer [23] presented a study to show IoT applications in smart cities. Also, this study [24] illustrated smart city technology and stakeholders in different fields. Mohamed [5] also evaluated IoT in smart city applications [5]. Sebastian et al. [25] developed an evaluation method that combines the modeling of protocol sequences and algorithms with actual wireless and radio settings which control to improve IoT nodes' energy efficiency in networks of smart cities. Li et al. [26] proposed a study to use RNN to provide the best possible dispatch of distributed energy generation in the smart grid, and forecasting by using data from smart meters. Ordouei et al. [27] used reinforcement learning to optimize and reduce smart city energy consumption and make the best possible balance between the confidence of its communications and its energy impression.

3 | Methodology

This section presents the mathematical decision-making methods in the neutrosophic environment as in Figure 2 for evaluating IoE platforms.

3.1 | Single-Valued Triangular Neutrosophic Sets (SVTrNS)

SVTrNS belongs to the Neutrosophic theory branch. Our study will use a neutrosophic linguistic scale by the model from this study [28] to evaluate our alternatives. The proposed methodology of MCDM problems based on Single Valued Triangular Neutrosophic numbers (SVTrN) of IoE platforms is shown in the following steps:

Step 1. Collect data and create decision matrices of experts and represent them by SVTrN numbers according to this scale [28].

Step 2. Aggregate decision matrices using the following equation,

$$x_{ij} = \frac{(\sum_{j=1}^{N} r_{ij})}{N} \tag{1}$$

Where $= 1,2,\ldots..,m\,, j = 1,2,\ldots\ldots.,n, N\ number\ of\ experts$, r_{ij} represents the value of criteria, m is the number of alternatives, n is the number of criteria.

Step 3. To obtain a crisp decision matrix, convert the SVTrN scale to a crisp value using the following equation,

$$\mathrm{S}(\mathrm{r_{ij}}) = \frac{(l_{ij}+\mathrm{m_{ij}}+\mathrm{u_{ij}})}{9} * (2 + \mathrm{T} - \mathrm{I} - \mathrm{F}) \tag{2}$$

Where l refers to the lower, m refers to the middle, and u refers to the upper values. T, I, F refers to true, indeterminacy, and false values.

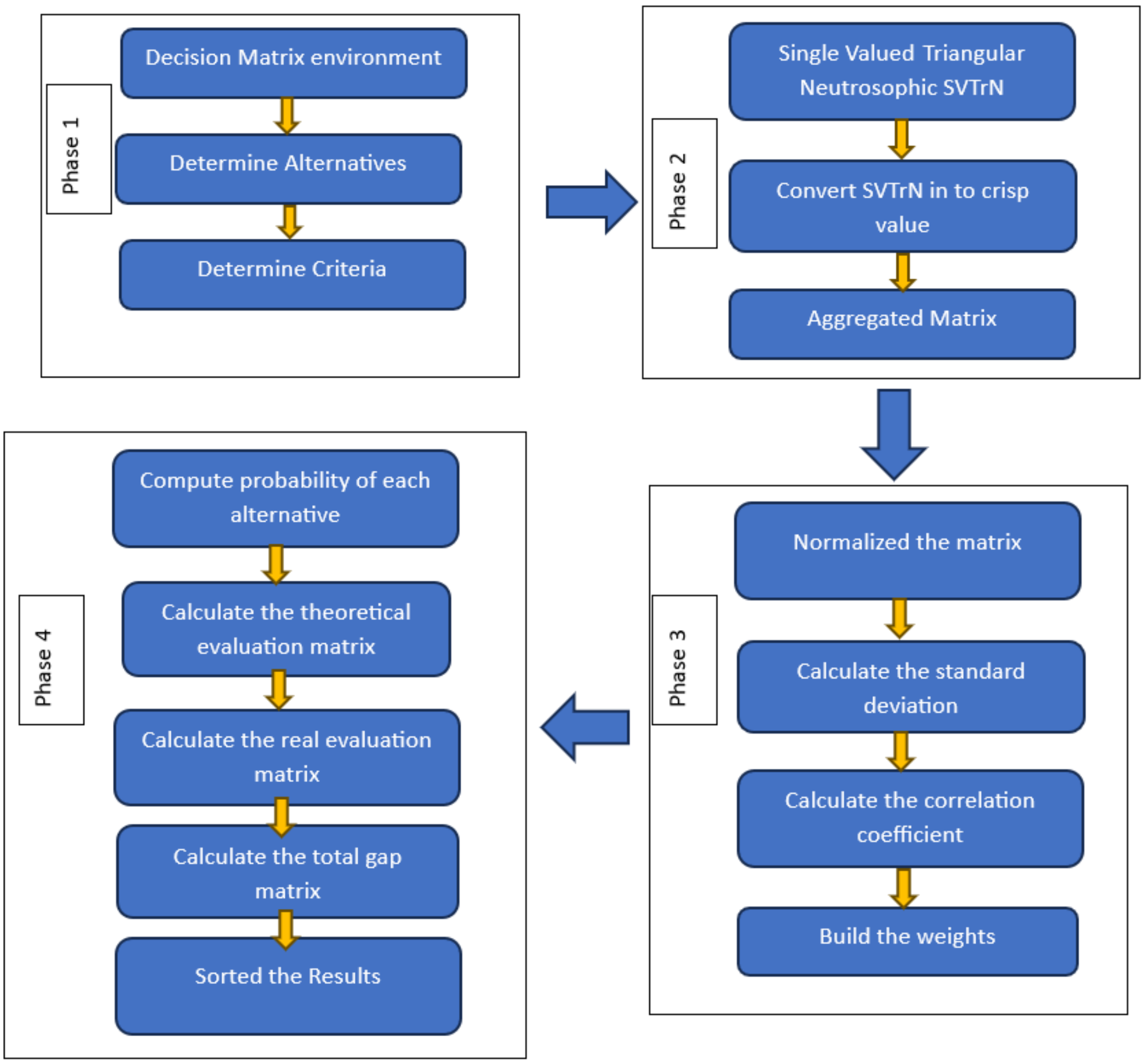

Figure 2. Framework of proposed methods.

3.2 | CRITIC Method

Proposed by Diakoulaki et al. [29]. This method is one of multi-criteria decision-making techniques for weighting criteria as follows:

Step 1. Use the decision matrix obtained before in step 3 as the decision matrix of CRITIC.

$$Max\ \{x_1(a), x_2(a), \dots\dots\dots x_m(a)/a \in A\} \tag{3}$$

Where x_n is the multi-criteria problem, A is a finite set.

Step 2. Normalizing the obtained matrix by Eq. (4),

$$x_{aj} = \frac{(x_j(a) - x_{j*})}{(x*_j - x_{j*})} \tag{4}$$

Where $x *_j$ is the best criterion value, and x_{j*} is the worst criterion value.

Step 3. Calculate the standard deviation for the normalized matrix,

$$x_j = \{x_j(1), x_j(2), \dots\dots\dots x_j(n)\} \tag{5}$$

Step 4. Calculate the linear correlation coefficient between the vectors of matrix $n * n$ criterion,

$$\sum_{k=1}^{m}(1 - r_{jk}) \tag{6}$$

Where r_{jk} is the linear correlation coefficient.

Step 5. Estimate the criterion by the following equation,

$$C_j = \sigma_j . \sum_{k=1}^{m}(1 - r_{jk}) \tag{7}$$

Where C_j is the amount of information.

Step 6. Measure the weight which is the conflict of criterion,

$$W_j = \frac{C_j}{\sum_{k=1}^{m} C_k} \tag{8}$$

3.3 | MAIRCA Method

MAIRCA is a relatively potent analysis technique proposed by Pamucar et al. [30]. The steps for ranking alternatives are as follows:

Step 1. Use the aggregated matrix which was calculated before using Eq. (2) in step 3 as the decision matrix of MARICA.

Step 2. Compute the probability of each m alternative by Eq. (9),

$$p_A = \frac{1}{m}; \qquad \sum_{i=1}^{m} p_A \tag{9}$$

Where m is the number of alternatives.

Step 3. Calculate the theoretical evaluation matrix (TP),

$$\begin{array}{cc} & \begin{array}{ccc} w_1 & \cdots & w_n \end{array} \\ \text{TP} = \begin{array}{c} P_{A_1} \\ \vdots \\ P_{A_m} \end{array} & \begin{bmatrix} t_{P_{11}} & \cdots & t_{P_{1n}} \\ \vdots & \ddots & \vdots \\ t_{P_{m1}} & \cdots & t_{P_{mn}} \end{bmatrix} \end{array} \tag{10}$$

$$\text{TP} = \begin{array}{c} P_{A_1} \\ \vdots \\ P_{A_m} \end{array} \begin{bmatrix} t_{P_{11}} w_1 & \cdots & t_{P_{1n}} w_n \\ \vdots & \ddots & \vdots \\ t_{P_{m1}} w_1 & \cdots & t_{P_{mn}} w_n \end{bmatrix}$$

Where w_n , is criteria weight coefficients.

Step 4. Calculate the real evaluation matrix (Tr),

For maximum $t_{r_{ij}} = t_{p_{ij}} = \left(\frac{x_{ij} - x_j^-}{x_j^+ - x_j^-}\right)$

For minimum $t_{r_{ij}} = t_{p_{ij}} = \left(\frac{x_{ij} - x_j^+}{x_j^- - x_j^+}\right)$ (11)

$x_j^+ = \text{Max}\ (x_1, x_2, \ldots\ldots, x_m)$

$x_j^- = \text{Min}\ (x_1, x_2, \ldots\ldots, x_m)$

Step 5. Calculate the total gap matrixg_{ij} ,

$$g_{ij} = t_{p_{ij}} - t_{r_{ij}} \quad (12)$$

Step 6. Calculate the function of the criteria (Q_i),

$$(Q_i) = \sum_{j=1}^{m} g_{ij} \quad (13)$$

4 | Case Study

In our study we introduce a new method for decision-making to select the best IoE platform in smart cities, there are several evaluation criteria such as water supply (C1), electricity consumption (C2), robust network (C3), and affordable housing (C4) which denoted as$\text{C} = \{\text{C1}, \text{C2}, \text{C3}, \text{C4}\}$. We supposed that six alternatives denoted as $\text{A} = \{\text{A1}, \text{A2}, \text{A3}, \text{A4}, \text{A5}, \text{A6}\}$.

Step 1. We supposed that there are four experts $\{expert1, expert2, xpert3\ , expert4\}$. They are all at the same level of skillfulness, based on their respective areas of expertise; the experts will evaluate the opinions and then make comparisons based on the criteria as in Table 1 and Table 2.

Step 2. Aggregate decision matrices by applying Eq. (1) as shown in Table 3.

Step 3. Calculate the crisp decision matrix by Eq. (2) as in Table 4.

Step 4. Calculate the best and worst values from the decision matrix.

Step 5. Normalize the decision matrix by Eq. (4) as appears in Table 5.

Table 1. Linguistic expert data.

	Water supply (C1)	**Electricity consumption(C2)**	**Robust Network (C3)**	**Affordable housing (C4)**
ASTRI Smart City (A1)	AH;AS	L;NS	M;ANS	VL;S
NTUITY (A2)	AL;ANS	VL;ANS	H;VSS	H;SLS
DCC (A3)	VH;STS	AH;S	M;SLS	M;MS
Iberdrola (A4)	VL;MS	M;SLS	L;ANS	H;AS
nextdrive (A5)	SVH;AS	VH;VSS	M;NS	VL;NS
Electrex (A6)	AH;STS	L;AS	AL;AS	M;AS

Table 2. The SVTrN values.

Expert1	C1	C2	C3	C4
A1	(7,8,9);(1,0,0)	(1,2,3);(0.2,0.8,0.8)	(2,3,4);(0,1,1)	(0,1,2);(0.7,0.4,0.4)
A2	(0,0,1);(0,1,1)	(0,1,2);(0,1,1)	(3,4,5);(0.9,0.1,0.1)	(3,4,5);(0.3,0.7,0.7)
A3	(4,5,6);(0.8,0.2,0.02)	(7,8,9);(0.7,0.4,0.4)	(2,3,4);(0.3,0.7,0.7)	(2,3,4);(0.5,0.5,0.5)
A4	(0,1,2);(0.5,0.5,0.5)	(2,3,4);(0.3,0.7,0.7)	(1,2,3);(0,1,1)	(3,4,5);(1,0,0)
A5	(5,6,7);(1,0,0)	(4,5,6);(0.9,0.1,0.1)	(2,3,4);(0.2,0.8,0.8)	(0,1,2);(0.2,0.8,0.8)
A6	(7,8,9);(0.8,0.2,0.02)	(1,2,3);(1,0,0)	(0,0,1);(1,0,0)	(2,3,4);(1,0,0)
Expert2	C1	C2	C3	C4
A1	(4,5,6);(1,0,0)	(3,4,5);(0,1,1)	(0,0,1);(0.3,0.7,0.7)	(0,1,2);(0.3,0.7,0.7)
A2	(2,3,4);(0.5,0.5,0.5)	(2,3,4);(0.5,0.5,0.5)	(7,8,9);(1,0,0)	(5,6,7);(0.9,0.1,0.1)
A3	(5,6,7);(0.3,0.7,0.7)	(0,0,1);(0.7,0.4,0.4)	(3,4,5);(0.9,0.1,0.1)	(2,3,4);(0.7,0.4,0.4)
A4	(1,2,3);(0,1,1)	(7,8,9);(0.3,0.7,0.7)	(0,1,2);(0.5,0.5,0.5)	(0,0,1);(0,1,1)
A5	(0,1,2);(0.9,0.1,0.1)	(0,0,1);(0.2,0.8,0.8)	(5,6,7);(0.7,0.4,0.4)	(1,2,3);(0.2,0.8,0.8)
A6	(1,2,3);(1,0,0)	(0,1,2);(0.9,0.1,0.1)	(2,3,4);(0,1,1)	(7,8,9);(0.5,0.5,0.5)
Expert3	C1	C2	C3	C4
A1	(0,1,2);(0.2,0.8,0.8)	(2,3,4);(0.3,0.7,0.7)	(1,2,3);(0.9,0.1,0.1)	(7,8,9);(0.9,0.1,0.1)
A2	(3,4,5);(0,1,1)	(0,0,1);(0.5,0.5,0.5)	(4,5,6);(0.2,0.8,0.8)	(2,3,4);(0.3,0.7,0.7)
A3	(1,2,3);(0.3,0.7,0.7)	(5,6,7);(0,1,1)	(0,0,1);(0.5,0.5,0.5)	(5,6,7);(0.7,0.4,0.4)
A4	(2,3,4);(0.9,0.1,0.1)	(0,1,2);(1,0,0)	(5,6,7);(1,0,0)	(3,4,5);(0,1,1)
A5	(5,6,7);(0.5,0.5,0.5)	(4,5,6);(0.9,0.1,0.1)	(0,0,1);(0.3,0.7,0.7)	(1,2,3);(1,0,0)
A6	(7,8,9);(1,0,0)	(3,4,5);(0.2,0.8,0.8)	(7,8,9);(0,1,1)	(0,1,2);(0.5,0.5,0.5)

Table 3. Aggregated matrix.

	C1	C2	C3	C4
A1	(3.67,4.67,5.67);(0.73,0.27,0.27)	(2,3,4);(0.17,0.83,0.83)	(1,1.67,2.67);(0.4,0.6,0.6)	(2.33,3.33,4.33);(0.63,0.4,0.4)
A2	(1.67,2.33,3.33);(0.17,0.83,0.83)	(0.67,1.33,2.33);(0.33,0.67,0.67)	(4.67,5.67,6.67);(0.7,0.3,0.3)	(3.33,4.33,5.33);(0.5,0.5,0.5)
A3	(3.33,4.33, 5.33);(0.47,0.53,0.53)	(4,4.67,5.67);(0.47,0.6,0.6)	(1.67,2.33,3.33);(0.57,0.43,0.43)	(3,4,5);(0.63,0.43,0.43)
A4	(1,2,3);(0.467,1.53,1.53)	(3,4,5);(0.53,0.47,0.47)	(2,3,4);(0.5,0.5,0.5)	(2,2.67,3.67);(0.33,0.67,0.67)
A5	(3.33,4.33,5.33);(0.8,0.2,0.2)	(2.67,3.33,4.33);(0.67,0.33,0.33)	(2.33,3,4);(0.4,0.63,0.63)	(0.67,1.67,2.67);(0.47,0.53,0.53)
A6	(5,6,7);(0.93,0.067,0.067)	(1.33,2.33,3.33);(0.7,0.3,0.3)	(3,3.67,4.67);(0.33,0.67,0.67)	(3,4,5);(0.67,0.33,0.33)

Table 4. Crisp decision matrix.

	C1	C2	C3	C4
A1	3.4091	0.51	0.712	2.0313
A2	0.415366667	0.4763	3.969	2.165
A3	2.0351	2.023533333	1.3927	2.36
A4	0.395333333	2.12	1.5	0.9174
A5	3.464	2.307033333	1.1818	0.7849
A6	5.592	1.631	1.2474	2.68
Best	5.592	2.307033	3.969	2.68
Worst	0.395333	0.4763	0.712	0.7849

Table 5. Normalized decision matrix.

	C1	C2	C3	C4
A1	0.579942	0.018408	0	0.657696
A2	0.003855	0	1	0.728247
A3	0.315542	0.845144	0.208996	0.831143
A4	0	0.897837	0.24194	0.069917
A5	0.590507	1	0.144243	0
A6	1	0.630731	0.164384	1

Step 6. Calculate the standard deviation as in Table 6.

Step 7. Calculate the linear correlation as in Table 7.

Step 8. Estimate criteria using Eq. (7).

Step 9: Calculate weights by using Eq. (8) as in Figure 3.

Table 6. Standard deviation.

Std	**0.387657**	**0.447391**	**0.356099**	**0.414213**

Table 7. The linear correlation.

	C1	C2	C3	C4
C1	0	0.89512	1.595187	0.64817
C2	0.89512	0	1.44314	1.48595
C3	1.595187	1.44314	0	0.838233
C4	0.64817	1.48595	0.838233	0

Table 8. Information criteria.

Cj
1.216653
1.710917
1.380439
1.231188

Table 9. Criteria weights.

	C1	C2	C3	C4
W	0.219644	0.308875	0.249213	0.222268

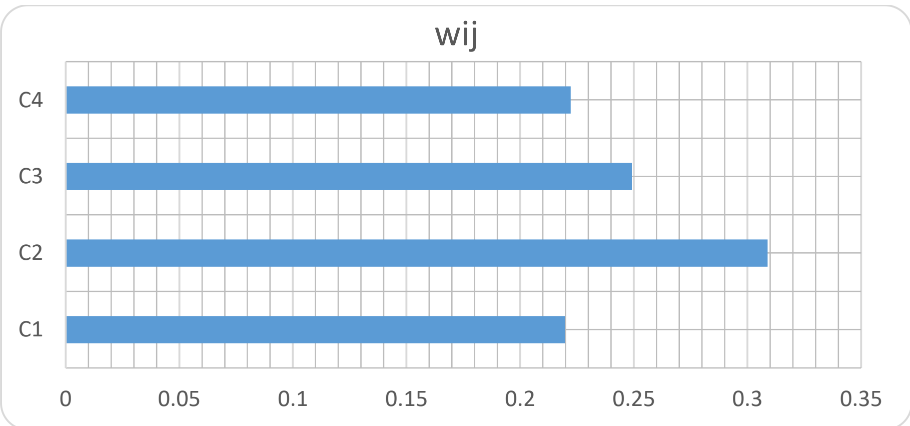

Figure 3. Weights of criteria.

Step 10: After calculating the weights of the criteria. Apply the MAIRCA method, in Table 4 and calculate the theoretical evaluation matrix **TP** using Eqs. (9) and (10).

Step 11. Calculate the real evolution matrix (Tr) using Eq. (11).

Step 12. Calculate the total gab matrix as in Table 12 by using Eq. (12).

Step 13. Calculate the criteria function using Eq. (13).

Step 14. Rank alternatives as in Figure 4.

Table 10. Theoretical evaluation matrix.

	C1	C2	C3	C4
	Max	Min	max	min
A1	0.036607	0.051479	0.041535	0.037045
A2	0.036607	0.051479	0.041535	0.037045
A3	0.036607	0.051479	0.041535	0.037045
A4	0.036607	0.051479	0.041535	0.037045
A5	0.036607	0.051479	0.041535	0.037045
A6	0.036607	0.051479	0.041535	0.037045

Table 11. Normalized matrix.

	C1	C2	C3	C4
	Max	**min**	**max**	**min**
A1	0.02123	0.050531	0	0.012681
A2	0.000141	0.051479	0.041535	0.010067
A3	0.011551	0.007972	0.008681	0.006255
A4	0	0.005259	0.010049	0.034455
A5	0.021617	0	0.005991	0.037045
A6	0.036607	0.01901	0.006828	0

Table 12. Total gab matrix.

	C1	C2	C3	C4
	Max	**Min**	**max**	**min**
A1	0.015377	0.000948	0.041535	0.024364
A2	0.036466	0	0	0.026978
A3	0.025056	0.043507	0.032855	0.030789
A4	0.036607	0.04622	0.031486	0.00259
A5	0.01499	0.051479	0.035544	0
A6	0	0.032469	0.034708	0.037045

Table 13. Criteria function.

Alternatives	Qi
ASTRI Smart City (A1)	0.082224
NTUITY (A2)	0.063444
DCC (A3)	0.132208
Iberdrola (A4)	0.116904
nextdrive (A5)	0.102014
Electrex (A6)	0.104222

Table 14. Rank of alternatives.

Alternatives	Rank
ASTRI Smart City (A1)	5
NTUITY (A2)	6
DCC (A3)	1
Iberdrola (A4)	2
nextdrive (A5)	4
Electrex (A6)	3

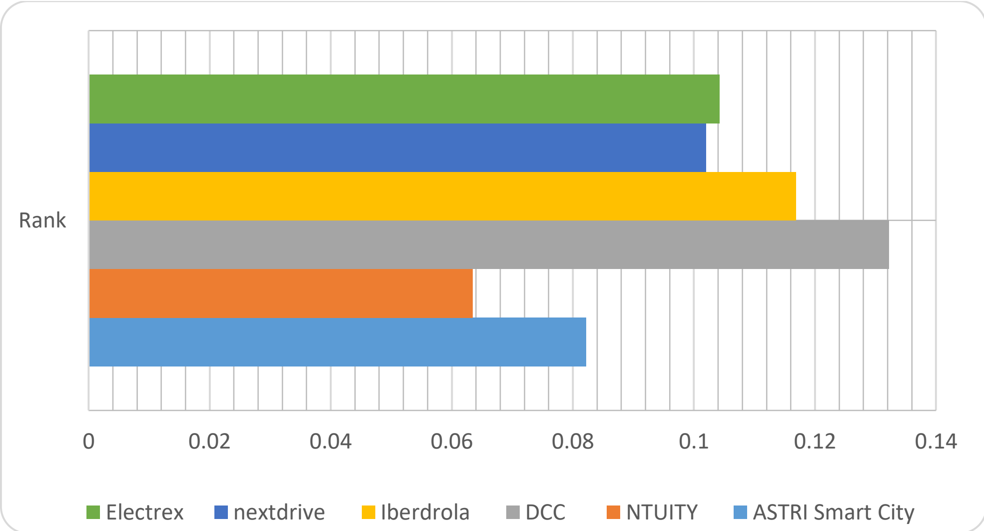

Figure 4. Rank of alternatives.

5 | Conclusion

The smart city makes use of information communication technologies including artificial intelligence, energy efficiency improvement, and sensing services to improve people's quality of life, and productivity. Analytical imperatives such as sustainability and energy efficiency drive the integration of renewable energy sources and optimization of energy usage in smart city layouts. This study aimed to improve the decision-making process by selecting the best platform. This is accomplished by applying CRITIC-MAIRCA methods in the neutrosophic environment to evaluate IoE platforms. Results showed that the best alternative is a Data Communication Company DCC.

In the future, we will use the suggested model in several MCDM problems. Also, we tend to use other methods such as ANP and TOPSIS to evaluate IoE platforms.

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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.

Conflicts 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.

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