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Quadripartitioned Single-Valued Neutrosophic Properties and Their Application to Factors Affecting Energy Prices

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Abstract
The main idea of this study is the development of a quadripartitioned neutrosophic relations(properties)-based on decision-making method to recommend the most influential factor that affects energy prices in Colombia during pandemic. For supporting the results, we take some particular cities which are located in Colombia where prices of energy have been affecting before, during and after Covid-19 pandemic. The result provides evidence on the feasibility of the proposed method in recommending the influential factors that affect energy prices.

Keywords Neutrosophic logic · Quadripartitioned single valued · Decision-making

Introduction and Preliminaries

The notion of soft set theory which was introduced by Molodtsov (1999) has offered plenty of tools for dealing with uncertain, fuzzy, not clearly defined objects. Zhang (1994) presented the idea of bipolar fuzzy sets in which he proposed a new branch to study cognitive modelling and multi-agent decision analysis. Besides, bipolar fuzziness was studied as well as interval-based bipolar fuzzy logic was defined which generalizes a real-valued bipolar fuzzy logic by allowing interval-based linguistic variables. Shabir and Naz (2013) defined the notion of bipolarity of information in the soft sets. They defined bipolar soft sets and their basic operations of union, intersection and complementation for bipolar soft sets were studied. Riaz and Hashmi (2019) prevailed the concepts of intuitionistic fuzzy sets, Pythagorean fuzzy sets and q-rung orthopair fuzzy sets and these had numerous applications in several fields from real life. Unfortunately, these theories have their own limitations associated to the membership and non-membership grades. To eradicate these restrictions, they introduced the concept of linear Diophantine fuzzy set with the addition of reference parameters. This idea removed the restrictions of existing methodologies and the decision maker can freely choose the grades without any limitations. Ramot et al. (2002) introduced a new innovative concept which was called complex fuzzy set. This approach is absolutely different from other researchers, where Ramot et al. extended the range of membership function to unit disc in the complex plane, unlike the others who limited to [0, 1]. Hence, Ramot et al. added an additional term called the phase term to solve the enigma in translating some complex-valued functions on physical terms to human language and vice versa. After this, AL-Husban et al. (2020) presented a brief overview of the bipolar complex fuzzy sets which is an extension of bipolar fuzzy set theory. These new operations defined over the bipolar complex fuzzy sets some properties of these operations.

Inspired by these notions, the notion of neutrosophic sets which were introduced by Smarandache (1998) have given successful mathematical tools in solving uncertain and imprecise problems. These sets have further extended to complex neutrosophic sets by Ali and Smarandache (2015) where amplitude terms and phase terms were introduced. In 1995, starting from philosophy (when Smarandache fretted to distinguish between absolute truth and relative truth or between absolute falsehood and relative falsehood in logics, and respectively between absolute membership and relative membership or absolute non-membership and relative non-membership in set theory), he began to use the non-standard analysis. Also, inspired from the sport games (winning, defeating, or tie scores), from votes (pro, contra, null/black votes), from positive/negative/zero numbers, from yes/no/NA, from decision-making and control theory

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(making a decision, not making, or hesitating), from accepted/rejected/pending, etc. and guided by the fact that the law of excluded middle did not work any longer in the modern logics, he combined the non-standard analysis with a tricomponent logic/set/probability theory and with philosophy. From these notions, many neutrosophic studies have been done by many researchers in different fields of real, applied and pure sciences. For instance, Granados and Dhital (2021a) studied a new type of convergence in double sequences by using neutrosophic normed space; Granados (2021), Granados (2020), and Granados and Dhital (2021b) used the notion of neutrosophic topological space to define new idea of open set; Das et al. (2021) proposed a new concept on neutrosophic algebra by applying pentapartitioned neutrosophic Q-ideals of Q-algebra, Das et al. (2021) took the idea of quadripartitioned neutrosophic sets to introduced a new notion of topological space which was called topology quadripartitioned topological spaces, finally Granados (2021a) and Granados (2021b) used the notions of neutrosophic measure theory and neutrosophic probability theory to define new ideas on random variables. Additionally, researchers have investigated other notions such that neutrosophic queueing theory in Zeina (2020a) and Zeina (2020b) this is one branch of neutrosophic stochastic modelling. Furthermore, researchers have also studied neutrosophic time series prediction and modelling in many cases like neutrosophic moving averages, neutrosophic logarithmic models, and neutrosophic linear models (Alhabib and Salama 2020a; 2020b; Cruzaty et al. 2020). The quadripartitioned neutrosophic set (when n=4) is a particular case of the neutrosophic refined set (Smarandache 2013). Smarandache extended the neutrosophic set to refined [n-valued] neutrosophic set, and to refined neutrosophic logic, and to refined neutrosophic probability, i.e., the truth value T is refined/split into types of sub-truths such as T_1, T_2,..., similarly indeterminacy I is refined/split into types of sub-indeterminacies I_1, I_2,..., and the falsehood F is refined/split into sub-falsehood F_1, F_2,.... For more ideas, see Smarandache (2013).

The present paper is organized as follows. Next, we briefly remain some basic definitions of neutrosophic sets, quadripartitioned neutrosophic sets, quadripartitioned single-valued neutrosophic sets, complex quadripartitioned neutrosophic sets. In "Single-Valued Quadripartitioned Neutrosophic Properties for Decision-making", the computation procedures of quadripartitioned single-valued neutrosophic property for decision-making are presented. "Application" presents the application and implementation of the proposed method to factors that affect energy prices before, during and after (2019–2021) Covid-19 in a city in Colombia. Finally, the last section, some future research topics are provided. The model presented in this article is a better decision-making application than the decision-making approach presented by Chaw et al. (2020), given that it presents another degree of membership called contradiction and in this way allows a better visualization of the unknown in the study of these objects.

Next, we recall some well-known notions which were introduced by Chatterjee et al. (2016) and they are useful for the development of this paper.

Definition 1.1 (Chatterjee et al. 2016) Let X be a universe of discourse and $x \in X$, then a quadripartitioned set G in X is characterized by truth membership function T, contradiction membership function C, ignorance membership function I and falsity membership function F. The T, C, I and F are real standards or non-standards subsets of $]^{-}0, 1^{+}[$, and $T, C, I, F : X \rightarrow]^{-}0, 1^{+}[$. Hence, the neutrosophic set can be represented by

$$G = \{(x, T_G(x), C_G(x), I_G(x), F_G(x)) : x \in X\}.$$

Remark 1.2 There is no restriction on the sum of T, C, I, F, therefore $^{-}0 \leq T_G(x) + C_G(x) + I_G(x) + F_G(x) \leq 4^{+}$.

Definition 1.3 (Chatterjee et al. 2016) The form of a quadripartitioned single-valued neutrosophic set G over a universe of discourse X is given by

$$G = \{(x, T_G(x), C_G(x), I_G(x), F_G(x)) : x \in X\},$$

where $T_G(x), C_G(x), I_G(x), F_G(x) : X \rightarrow [0, 1]$ with $^{-}0 \leq T_G(x) + C_G(x) + I_G(x) + F_G(x) \leq 4^{+}$ for all $x \in X$. Quadripartitioned single-valued neutrosophic number is denoted by $G = (a, b, c, d)$, where $a, b, c, d \in [0, 1]$ and $a + b + c + d \leq 4$.

Definition 1.4 (Ali and Smarandache 2015) A complex neutrosophic set G, defined on a universe of discourse X, which is characterized by a complex-valued truth membership function $T_G(x)$ with a phase of periodicity, contradiction membership function $C_G(x)$ with a phase of periodicity, complex-valued ignorance membership function $I_G(x)$ with a phase of periodicity, and a complex-valued falsity membership function $F_G(x)$ with a phase of periodicity in G for any $x \in X$. The values of $T_G(x), C_G(x), I_G(x)$ and $F_G(x)$ and their sum may be all within the unit circle in the complex plane and so is given as

$$\begin{aligned}
T_G(x) &= p_G(x)e^{n\mu_G(x)} \\
C_G(x) &= s_G(x)e^{n\alpha_G(x)} \\
I_G(x) &= q_G(x)e^{n\nu_G(x)} \\
F_G(x) &= r_G(x)e^{n\omega_G(x)},
\end{aligned}$$

where $p_G(x), s_G(x), q_G(x)$ and $r_G(x) \in [0, 1]$ are amplitudes such that $^{-}0 \leq p_G(x) + s_G(x) + q_G(x) +$

$r_G(x) \leq 4^+$. The complex quadripartitioned neutrosophic set G can be expressed as follows

$$G = \{(x, T_G(x) = g_T, C_G(x) = g_C, I_G(x) = g_I, F_G(x) = g_F) : x \in X\},$$

where $T_G : X \to \{g_T : g_T \in G, |g_T| \leq 1\}$, $C_G : X \to \{g_C : g_C \in G, |g_C| \leq 1\}$, $I_G : X \to \{g_I : g_I \in G, |g_I| \leq 1\}$, $F_G : X \to \{g_F : g_F \in G, |g_F| \leq 1\}$ and $|T_G(x) + C_G(x) + I_G(x) + F_G(x)| \leq 4$.

Definition 1.5 (Ali and Smarandache 2015) Let G and H be two complex quadripartitioned neutrosophic sets over the universal sets X and Y, respectively. The Cartesian product of G and H which is denoted by $G \times H$, is given by

$$G \times H = \{\langle (x, y), T_{G\times H}(x, y), C_{G\times H}(x, y), I_{G\times H}(x, y), F_{G\times H}(x, y)\rangle : (x, y) \in X \times Y\},$$

where $T_{G\times H}(x, y)$ is a complex-valued truth membership function, $G_{G\times H}(x, y)$ is a complex-valued contradiction membership function, $I_{G\times H}(x, y)$ is a complex-valued ignorance membership function and $F_{G\times H}(x, y)$ is a complex-valued falsity membership function;

$$\begin{aligned}
T_{G\times H}(x, y) &= \min(p_G(x), p_H(y))e^{k \min(\mu_G(x), \mu_H(y))},\\
C_{G\times H}(x, y) &= \min(s_G(x), s_H(y))e^{k \min(\alpha_G(x), \alpha_H(y))},\\
I_{G\times H}(x, y) &= \max(q_G(x), q_H(y))e^{k \max(\nu_G(x), \nu_H(y))},\\
F_{G\times H}(x, y) &= \max(r_G(x), r_H(y))e^{k \max(\omega_G(x), \omega_H(y))}.
\end{aligned} \tag{1.1}$$

Definition 1.6 (Ali and Smarandache 2015) Let G and H be two complex quadripartitioned neutrosophic sets over the universal sets X and Y, respectively. A complex quadripartitioned relation (property) from G to H is a complex quadripartitioned neutrosophic subset of $G \times H$. Therefore, a complex quadripartitioned neutrosophic relation (property) from G to H is represented by $R(G, H)$, where $R(G, H) \subset G \times H$ is indicated as the set of orders sequence as follows

$$R(G, H) = \{\langle (x, y), T_R(x, y), C_R(x, y), I_R(x, y), F_R(x, y)\rangle : (x, y) \in X \times Y\},$$

where for all $x \in X$ and $y \in Y$, $T_R(x, y) = p_R(x, y) e^{j\mu_R(x,y)}$, $C_R(x, y) = s_R(x, y)e^{j\alpha_R(x,y)}$, $I_R(x, y) = q_R(x, y)e^{j\nu_R(x,y)}$ and $F_R(x, y) = r_R(x, y)e^{j\omega_R(x,y)}$. The values of $T_R(x, y)$,
$C_R(x, y), I_R(x, y)$ and $F_R(x, y)$ are within the unit circle in the complex plane. Besides, both the amplitude terms $p_R(x, y), s_R(x, y), q_R(x, y), r_R(x, y)$ and the periodicity terms $\mu_R(x, y), \alpha_R(x, y), \mu_R(x, y), \omega_R(x, y)$ are real-valued such that $p_R(x, y), s_R(x, y), q_R(x, y), r_R(x, y) \in [0, 1]$ and $0 \leq p_R(x, y) + s_R(x, y) + q_R(x, y) + r_R(x, y) \leq 3$.

Remark 1.7 The complex quadripartitioned neutrosophic properties consider four memberships of neutrosophic sets that reflect the relations between two quadripartitioned complex neutrosophic sets. Memberships of T, C, I, F of complex quadripartitioned neutrosophic sets are not only considered as a unit circle in the complex plane but also considered amplitude terms and periodicity terms in a unit circle. These properties could be applied to the MCDM problem that is germane with the characteristics of complex numbers. In the following section, we propose quadripartitioned single-valued neutrosophic properties that are purposely applied to decision-making.

Single-Valued Quadripartitioned Neutrosophic Properties for Decision-making

For the purpose of solving the MCDM problem, a computational procedure is proposed in this section. In this procedure, a complex quadripartitioned neutrosophic property is converted to a quadripartitioned single-valued neutrosophic property. The steps are proposed as follows:

Let X be a set of criteria and Y be a set of alternatives. Let G and H be the two quadripartitioned complex neutrosophic sets over X and Y, respectively.

Steps:

(1) Identify input data in complex quadripartitioned neutrosophic sets in which G and H are over X and Y, respectively.
(2) Compute the complex quadripartitioned neutrosophic properties, $R(G, H)$ of $G \times H$ where $\times$ indicates the Cartesian product of two complex quadripartitiones neutrosophic sets.
(3) Convert the complex quadripartitioned neutrosophic properties to quadripartitioned single-valued neutrosophic properties and calculate the membership values by applying the weighted aggregation values and phase terms. The conversion equations are given as

$$\begin{aligned}
T_R(x, y) &= w_1 p_R(x, y) + w_2(1/2\pi)\mu_R(x, y),\\
C_R(x, y) &= w_1 s_R(x, y) + w_2(1/2\pi)\alpha_R(x, y),\\
I_R(x, y) &= w_1 q_R(x, y) + w_2(1/2\pi)\nu_R(x, y),\\
F_R(x, y) &= w_1 r_R(x, y) + w_2(1/2\pi)\omega_R(x, y),
\end{aligned} \tag{2.1}$$

where $T_R(x, y)$ is a truth membership function, $C_R(x, y)$ is a contradiction membership function, $I_R(x, y)$ is a ignorance membership function and $F_R(x, y)$ is a falsity membership function in quadripartitioned single-valued neutrosophic property, $R(G, H)$, respectively. $p_R(x, y), s_R(x, y), q_R(x, y)$ and $r_R(x, y)$ are amplitude terms and $\mu_R(x,y)$, $\nu_R(x,y)$, $\omega_R(x,y)$ and $\alpha_R(x,y)$ are the phase terms in the quadripartitioned single-valued neutrosophic property $R'(G,H)$. w_1 and w_2 are the weighted aggregation values for amplitude terms and periodicity terms, respectively, where $w_1+w_2=1$ and $w_1, w_2 \in [0,1]$.

(4) Construct the quadripartitioned single-valued neutrosophic properties matrix for $x \in X$ and $y \in Y$ as follows:

$$R(x,y) = \begin{bmatrix} & y_1 & y_2 & \cdots & y_n \\ x_1 & (x_1,y_1) & (x_1,y_2) & \cdots & (x_1,y_n) \\ x_2 & (x_2,y_1) & (x_2,y_2) & \cdots & (x_2,y_n) \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ x_n & (x_n,y_1) & (x_n,y_2) & \cdots & (x_n,y_n) \end{bmatrix}$$

where the rows represent the independent variables and the columns represent the dependent variables.

(5) Construct the normalized quadripartitioned single-valued neutrosophic property matrix b using the following equation:

$$T + C + I - F.$$

Now, the normalized quadripartitioned single-valued neutrosophic properties matrix, R^* is obtained.

(6) Find the scores, S_i by taking the sum for each of the row, x_i of R^*.

(7) Determine the highest score, max S_i. The highest score indicates the most influential criteria.

The above computational procedures are then implemented in the following section in a case of energy prices before, during and after Covid-19 pandemic (2019–2021) in a city in Colombia.

Application

The energy demand in Colombia and in the world is increasing, as there is a large population and industrial growth, requiring energy consumption and bringing with it economic, social and environmental problems. Before the covid-19 pandemic, energy consumption in Colombian homes was not so high, in the quarantine the demand for it increased since everyone was in their homes due to confinement presented by the ONS and president of Colombia, it is from here that energy consumption and its price was affected by different factors. For more studies related to energy in Colombia and the world, we refer the reader to Blanco et al. (2020), Giraldo et al. (2018), Aikhuele et al. (2021), Sánchez-Zarco et al. (2019), and Ali et al. (2020).

Implementation

In this sub-section, we present the computational procedures used to obtain the most influential criteria that affect energy prices before, during and after covid-19 (2019–2021) in a city in Colombia. The implementation of the computational procedures is given as follows.

First, we define the set of criteria (fluctuations in energy prices before, during and after covid-19) (see 3.1) and set of alternatives (Others sort of energies) (see 3.2).

Symbols(X)	Criteria
a	Supply
b	Demand
c	Annual increase
d	Private companies
e	Colombia policity
f	Country economic rate

(3.1)

Symbols(Y)	Alternatives
g	Hydroelectric
h	Wind
i	Geothermal
j	Oil
k	Biomass
l	Solar

(3.2)

Step 1: Identify the input data given in complex quadripartitioned neutrosophic sets. X is the set of factors or criteria that contributed to fluctuations in energy prices before, during and after covid-19 and Y is the set of alternatives that measure energy prices in other cities in Colombia. Now, consider G and H are two complex quadripartitioned neutrosophic sets with four complex-valued membership functions, such as complex-valued truth membership function, complex-valued contradiction membership function, complex-valued ignorance membership function and complex-valued falsity membership function. The four membership functions represent “strong influence”, “weak influence”, “average influence” and “minimal influence”, respectively. In this property, the periodicity of input data is 36 months. The terms truth amplitude, contradiction amplitude, ignorance amplitude and false amplitude measure the membership degree of the impact of the criteria to alternative, respectively. The terms truth periodicity, ignorance periodicity, contradiction periodicity and false periodicity denote the phases in which the factors influence the energy prices’ alternatives. Periodicity is the period where it can determine the factors strongly influencing the alternatives or has average influence on the alternatives or the time in which the factors have minimal influence on alternatives. Since the periodicity terms in $R(G, H)$ represent periods and $R(G, H)$ represents the property between the factors affecting energy prices before, during and after covid-19 in a city in Colombia and the alternatives within the time frame of 36 months, then, in each complex quadripartitioned neutrosophic value, the range of each of the truth, contradiction, ignorance and false phase terms should be between 0 and 1. It is defined that complex quadripartitioned neutrosophic numbers with respect to factors for G and H are defined as follows:

$$G = \left\{ \frac{0.8e^{m2\pi(23/36)}, 0.3e^{m2\pi(8/36)}, 0.4e^{m2\pi(6/36)}, 0.3e^{m2\pi(17/36)}}{a}, \frac{0.4e^{m2\pi(3/36)}, 0.1e^{m2\pi(12/36)}, 0.9e^{m2\pi(15/36)}, 0.7e^{m2\pi(7/36)}}{b}, \frac{0.1e^{m2\pi(16/36)}, 0.5e^{m2\pi(11/36)}, 0.4e^{m2\pi(3/36)}, 0.1e^{m2\pi(5/36)}}{c}, \frac{1.0e^{m2\pi(32/36)}, 0.6e^{m2\pi(3/36)}, 0.7e^{m2\pi(7/36)}, 0.3e^{m2\pi(15/36)}}{d}, \frac{0.6e^{m2\pi(30/36)}, 0.2e^{m2\pi(22/36)}, 0.8e^{m2\pi(25/36)}, 1.0e^{m2\pi(22/36)}}{e}, \frac{0.1e^{m2\pi(35/36)}, 0.5e^{m2\pi(15/36)}, 0.2e^{m2\pi(1/36)}, 0.1e^{m2\pi(27/36)}}{f} \right\}$$

and

$$H = \left\{ \frac{0.1e^{m2\pi(13/36)}, 0.4e^{m2\pi(18/36)}, 0.3e^{m2\pi(16/36)}, 0.8e^{m2\pi(7/36)}}{g}, \frac{0.2e^{m2\pi(13/36)}, 0.4e^{m2\pi(2/36)}, 0.7e^{m2\pi(25/36)}, 0.3e^{m2\pi(17/36)}}{h}, \frac{0.4e^{m2\pi(26/36)}, 0.7e^{m2\pi(21/36)}, 0.7e^{m2\pi(30/36)}, 0.4e^{m2\pi(15/36)}}{i}, \frac{0.7e^{m2\pi(3/36)}, 0.4e^{m2\pi(35/36)}, 0.1e^{m2\pi(17/36)}, 0.4e^{m2\pi(5/36)}}{j}, \frac{0.3e^{m2\pi(33/36)}, 0.5e^{m2\pi(2/36)}, 0.8e^{m2\pi(24/36)}, 0.8e^{m2\pi(26/36)}}{k}, \frac{0.4e^{m2\pi(25/36)}, 0.1e^{m2\pi(25/36)}, 0.7e^{m2\pi(17/36)}, 0.4e^{m2\pi(17/36)}}{l} \right\}.$$

The complex quadripartitioned neutrosophic value for x_1 is $0.8e^{m2\pi(23/36)}$, $0.3e^{m2\pi(8/36)}$, $0.4e^{m2\pi(6/36)}$, $0.3e^{m2\pi(17/36)}$ and for y_1 is $0.1e^{m2\pi(13/36)}$, $0.4e^{m2\pi(18/36)}$, $0.3e^{m2\pi(16/36)}$, $0.8e^{m2\pi(7/36)}$. For the truth membership value between x_1 and y_1, the minimal amplitude terms and periodicity terms are degree 0.1 and 13 months, respectively. For the contradiction membership value, the minimal amplitude term and periodicity terms are degree 0.3 and 8 months. The maximal amplitude terms and periodicity terms in the ignorance membership value are degree 0.4 and 16 months. The maximal amplitude terms and periodicity terms in the falsity membership value are degree 0.8 and 17 months. Therefore, the properties between x_1 and y_1 are constructed. The other complex quadripartitioned neutrosophic properties are constructed similarly by applying (1.1).

Step 2: Compute the complex quadripartitioned neutrosophic properties, $R(G, H)$ of $G \times H$. The properties $R(G, H)$ are employed to investigate the affecting energy price alternatives. The property R is the Cartesian product of sets X and Y, and it is given by

$$R(G, H) = \left\{ \frac{0.1e^{m2\pi(13/36)}, 0.3e^{m2\pi(8/36)}, 0.3e^{m2\pi(16/36)}, 0.3e^{m2\pi(17/36)}}{(a, g)}, \frac{0.2e^{m2\pi(13/36)}, 0.3e^{m2\pi(2/36)}, 0.7e^{m2\pi(25/36)}, e^{m2\pi(17/36)}}{(a, h)}, \frac{0.4e^{m2\pi(26/36)}, 0.3e^{m2\pi(21/36)}, 0.4e^{m2\pi(30/36)}, 0.3e^{m2\pi(17/36)}}{(a, i)}, \frac{0.7e^{m2\pi(23/36)}, 0.3e^{m2\pi(35/36)}, 0.1e^{m2\pi(17/36)}, 0.3e^{m2\pi(17/36)}}{(a, j)}, \frac{0.3e^{m2\pi(23/36)}, 0.3e^{m2\pi(2/36)}, 0.8e^{m2\pi(24/36)}, 0.8e^{m2\pi(26/36)}}{(a, k)}, \frac{0.4e^{m2\pi(23/36)}, 0.1e^{m2\pi(8/36)}, 0.7e^{m2\pi(17/36)}, 0.4e^{m2\pi(17/36)}}{(a, l)}, \frac{0.1e^{m2\pi(3/36)}, 0.1e^{m2\pi(12/36)}, 0.9e^{m2\pi(16/36)}, 0.8e^{m2\pi(7/36)}}{(b, g)}, \frac{0.2e^{m2\pi(3/36)}, 0.1e^{m2\pi(2/36)}, 0.9e^{m2\pi(25/36)}, 0.7e^{m2\pi(17/36)}}{(b, h)}, \frac{0.4e^{m2\pi(3/36)}, 0.1e^{m2\pi(12/36)}, 0.9e^{m2\pi(30/36)}, 0.7e^{m2\pi(15/36)}}{(b, i)}, \frac{0.4e^{m2\pi(3/36)}, 0.1e^{m2\pi(12/36)}, 0.9e^{m2\pi(17/36)}, 0.7e^{m2\pi(7/36)}}{(b, j)}, \frac{0.3e^{m2\pi(3/36)}, 0.1e^{m2\pi(2/36)}, 0.9e^{m2\pi(24/36)}, 0.8e^{m2\pi(26/36)}}{(b, k)}, \frac{0.4e^{m2\pi(3/36)}, 0.1e^{m2\pi(12/36)}, 0.9e^{m2\pi(17/36)}, 0.7e^{m2\pi(17/36)}}{(b, l)}, \frac{0.1e^{m2\pi(13/36)}, 0.4e^{m2\pi(11/36)}, 0.4e^{m2\pi(16/36)}, 0.8e^{m2\pi(7/36)}}{(c, g)}, \frac{0.1e^{m2\pi(13/36)}, 0.4e^{m2\pi(2/36)}, 0.7e^{m2\pi(25/36)}, 0.3e^{m2\pi(17/36)}}{(c, h)}, \frac{0.1e^{m2\pi(16/36)}, 0.5e^{m2\pi(11/36)}, 0.7e^{m2\pi(30/36)}, 0.4e^{m2\pi(15/36)}}{(c, i)}, \frac{0.1e^{m2\pi(3/36)}, 0.4e^{m2\pi(11/36)}, 0.4e^{m2\pi(17/36)}, 0.4e^{m2\pi(5/36)}}{(c, j)}, \frac{0.1e^{m2\pi(16/36)}, 0.5e^{m2\pi(2/36)}, 0.8e^{m2\pi(24/36)}, 0.8e^{m2\pi(26/36)}}{(c, k)}, \frac{0.1e^{m2\pi(16/36)}, 0.1e^{m2\pi(11/36)}, 0.7e^{m2\pi(17/36)}, 0.4e^{m2\pi(17/36)}}{(c, l)}, \frac{0.1e^{m2\pi(13/36)}, 0.4e^{m2\pi(3/36)}, 0.7e^{m2\pi(16/36)}, 0.8e^{m2\pi(15/36)}}{(d, g)}, \frac{0.2e^{m2\pi(13/36)}, 0.4e^{m2\pi(2/36)}, 0.7e^{m2\pi(25/36)}, 0.3e^{m2\pi(17/36)}}{(d, h)}, \frac{0.4e^{m2\pi(26/36)}, 0.6e^{m2\pi(3/36)}, 0.7e^{m2\pi(30/36)}, 0.4e^{m2\pi(15/36)}}{(d, i)}, \frac{0.7e^{m2\pi(3/36)}, 0.4e^{m2\pi(3/36)}, 0.7e^{m2\pi(17/36)}, 0.4e^{m2\pi(15/36)}}{(d, j)},$$

$$\frac{0.3e^{m2\pi(32/36)}, 0.5e^{m2\pi(2/36)}, 0.8e^{m2\pi(24/36)}, 0.8e^{m2\pi(26/36)}}{(d,k)},$$
$$\frac{0.4e^{m2\pi(25/36)}, 0.1e^{m2\pi(3/36)}, 0.7e^{m2\pi(17/36)}, 0.4e^{m2\pi(17/36)}}{(d,l)},$$
$$\frac{0.1e^{m2\pi(13/36)}, 0.2e^{m2\pi(18/36)}, 0.8e^{m2\pi(25/36)}, 1.0e^{m2\pi(22/36)}}{(e,g)},$$
$$\frac{0.2e^{m2\pi(13/36)}, 0.2e^{m2\pi(2/36)}, 0.8e^{m2\pi(25/36)}, 1.0e^{m2\pi(22/36)}}{(e,h)},$$
$$\frac{0.4e^{m2\pi(26/36)}, 0.2e^{m2\pi(21/36)}, 0.8e^{m2\pi(30/36)}, 1.0e^{m2\pi(22/36)}}{(e,i)},$$
$$\frac{0.6e^{m2\pi(3/36)}, 0.2e^{m2\pi(22/36)}, 0.8e^{m2\pi(25/36)}, 1.0e^{m2\pi(22/36)}}{(e,j)},$$
$$\frac{0.3e^{m2\pi(30/36)}, 0.2e^{m2\pi(2/36)}, 0.8e^{m2\pi(25/36)}, 1.0e^{m2\pi(26/36)}}{(e,k)},$$
$$\frac{0.4e^{m2\pi(25/36)}, 0.1e^{m2\pi(22/36)}, 0.8e^{m2\pi(25/36)}, 1.0e^{m2\pi(22/36)}}{(e,l)},$$
$$\frac{0.1e^{m2\pi(13/36)}, 0.4e^{m2\pi(15/36)}, 0.3e^{m2\pi(16/36)}, 0.8e^{m2\pi(27/36)}}{(f,g)},$$
$$\frac{0.1e^{m2\pi(13/36)}, 0.4e^{m2\pi(2/36)}, 0.7e^{m2\pi(25/36)}, 0.3e^{m2\pi(27/36)}}{(f,h)},$$
$$\frac{0.1e^{m2\pi(/36)}, 0.7e^{m2\pi(21/36)}, 0.7e^{m2\pi(30/36)}, 0.4e^{m2\pi(27/36)}}{(f,i)},$$
$$\frac{0.1e^{m2\pi(/36)}, 0.4e^{m2\pi(15/36)}, 0.2e^{m2\pi(17/36)}, 0.4e^{m2\pi(27/36)}}{(f,j)},$$
$$\frac{0.1e^{m2\pi(/36)}, 0.5e^{m2\pi(15/36)}, 0.8e^{m2\pi(24/36)}, 0.8e^{m2\pi(26/36)}}{(f,k)},$$
$$\frac{0.1e^{m2\pi(/36)}, 0.1e^{m2\pi(15/36)}, 0.7e^{m2\pi(17/36)}, 0.4e^{m2\pi(27/36)}}{(f,l)}\}.$$

This means the complex quadripartitioned neutrosophic value which is given by

$$\frac{0.1e^{m2\pi(13/36)}, 0.3e^{m2\pi(8/36)}, 0.3e^{m2\pi(16/36)}, 0.3e^{m2\pi(17/36)}}{(a,g)},$$

it can be interpreted that the energy supply does not strongly influences the hydroelectric alternative energy before, during and after Covid-19. The complex-valued truth membership function $0.1e^{m2\pi(13/36)}$ represents that there is a low influence with degree 0.1 and this influence span of 13 months is considered a middle-point time of influence, complex-valued contradiction membership function $0.3e^{m2\pi(8/36)}$ represents that there is a low affectation in using of this energy with degree 0.3 and this influence span of 8 months is considered a very short time of influence, the complex-valued ignorance membership function $0.3e^{m2\pi(16/36)}$ indicates that it is unable to determine if there is an influence of the supply on the hydroelectric or not with a degree of 0.3, and this influence is not evident for 16 months. For the complex-valued falsity membership function, $0.3e^{m2\pi(17/36)}$ indicates the low influence with degree 0.3 and the influence period is 17 months.

Step 3: Convert the complex quadripartitioned neutrosophic properties to quadripartitioned single-valued neutrosophic properties. To estimate the objective weights of each criterion: $w_i = \frac{C_i}{\sum_{i=1}^{m} C_i}$. After some calculations, consider that the weighted aggregation value for amplitude term is $w_1 = 0.8$ and for periodicity terms is $w_2 = 0.2$, then convert the complex quadripartitioned neutrosophic property $R(G,H)$ to quadripartitioned single-valued neutrosophic properties $R'(G,H)$ using (2.1). Then, by the complex quadripartitioned neutrosophic value

$$\frac{0.1e^{m2\pi(13/36)}, 0.3e^{m2\pi(8/36)}, 0.3e^{m2\pi(16/36)}, 0.3e^{m2\pi(17/36)}}{(a,g)},$$

we have

$$\begin{aligned} T_R(a,g) &= w_1 p_R(x,y) + w_2(1/2\pi)\mu_R(x,y) \\ &= 0.8(0.1) + (0.2)(1/2\pi)(2\pi)(13/36) \\ &= 0.152 \end{aligned}$$

$$\begin{aligned} C_R(a,g) &= w_1 s_R(x,y) + w_2(1/2\pi)\alpha_R(x,y) \\ &= (0.8)(0.3) + (0.2)(1/2\pi)(2\pi)(8/36) \\ &= 0.284 \end{aligned}$$

$$\begin{aligned} I_R(a,g) &= w_1 q_R(x,y) + w_2(1/2\pi)\nu_R(x,y) \\ &= (0.8)(0.3) + (0.2)(1/2\pi)(2\pi)(16/36) \\ &= 0.328 \end{aligned}$$

$$\begin{aligned} F_R(a,g) &= w_1 r_R(x,y) + w_2(1/2\pi)\omega_R(x,y) \\ &= (0.8)(0.3) + (0.2)(1/2\pi)(2\pi)(17/36) \\ &= 0.334 \end{aligned}$$

Step 4: Construct the quadripartitioned single-valued neutrosophic properties matrix for $x \in X$ and $y \in Y$. The quadripartitioned single-valued neutrosophic properties matrix is obtained by converting all the membership values of complex quadripartitioned neutrosophic properties using a weighted equation. So,

$$\begin{aligned} &(T_R(a,g), C_R(a,g), I_R(a,g), F_R(a,g)) \\ &\quad = (0.152, 0.284, 0.328, 0.334). \end{aligned}$$

Step 5: Construct the normalized quadripartitioned single-valued neutrosophic property matrix. The quadripartitioned single-valued neutrosophic property matrix is as follows,

$$R(x,y)=\begin{array}{c}\\ a\\ b\\ c\\ d\\ e\\ f\end{array}\begin{array}{cccccc} g & h & i & j & k & l\\ \end{array}\begin{bmatrix} (0.15, 0.28, 0.32, 0.33) & (0.35, 0.28, 0.45, 0.17) & (\cdots) & (\cdots) & (\cdots) & (0.26, 0.38, 0.10, 0.15)\\ (0.25, 0.18, 0.32, 0.24) & (0.1, 0.01, 0.13, 0.22) & (\cdots) & (\cdots) & (\cdots) & (0.13, 0.25, 0.42, 0.18)\\ (0.10, 0.28, 0.42, 0.14) & (0.15, 0.38, 0.03, 0.02) & (\cdots) & (\cdots) & (\cdots) & (0.11, 0.15, 0.22, 0.14)\\ (0.05, 0.1, 0.2, 0.2) & (0.25, 0.26, 0.32, 0.34) & (\cdots) & (\cdots) & (\cdots) & (0.14, 0.32, 0.23, 0.13)\\ (0.2, 0.22, 0.16, 0.04) & (0.17, 0.27, 0.44, 0.29) & (\cdots) & (\cdots) & (\cdots) & (0.02, 0.28, 0.12, 0.24)\\ (0.15, 0.23, 0.06, 0.44) & (0.19, 0.22, 0.43, 0.16) & (\cdots) & (\cdots) & (\cdots) & (0.36, 0.21, 0.25, 0.41) \end{bmatrix}$$

and normalized quadripartitioned single-valued neutrosophic property matrix is given by

R*	g	h	i	j	k	l
a	0.42	0.91	0.44	0.12	0.15	0.59
b	0.51	0.02	0.45	0.22	0.30	0.62
c	0.66	0.54	0.32	0.45	0.12	0.34
d	0.15	0.49	0.25	0.16	0.34	0.56
e	0.54	0.59	0.60	0.12	0.21	0.18
f	0.02	0.68	0.67	0.36	0.45	0.41

(3.3)

Step 6: Find the scores, Si by taking the sum for each of the row x_i of R^*, we have

Row	Score
a	2.63
b	2.12
c	2.43
d	1.95
e	2.24
f	2.59

(3.4)

Step 7: Determine the highest score, max S_i. It can be seen that the highest score, is 2.63 which is corresponding to supply. Hence, the "Supply" is the most influential factor that affects the prices of energy in a city in Colombia before, during and after Covid-19. Besides, in (3.4), we can see that another factor that affects the prices of energy in a city in Colombia before, during and after Covid-19 is "Country economic rate", which means that "Supply" and "Country economic rate" are the most influential factors which affect the prices of energy in Colombia during pandemic of Covid-19.

Remark 3.1 To understand in a simple way the use of decision-making by using neutrosophic sets, true membership function can be understood as the people who energy prices did not get affected, but those people who energy prices were affected for any factor, can be considered as false membership function. Nonetheless, there was an indeterminacy which was divided into ignorance and contradiction. Contradiction can be used for prices which were reported as Colombian's energy control and the prices which were received by some customer. Ignorance can be employed as the discount that some people had to receive, but did not know that they had this discount, and they ended up paying high prices.

Next, we present comparison of our proposed model with some present models.

Type of Neutrosophic Set	Uncertainty	Falsity	Indeterminancy	Indeterminancy is Bifurcated
NS (Smarandache 1998)	✓	✓	✓	x
NFS (Das et al. 2020)	✓	✓	✓	x
INS (Bhowmik and Pal 2009)	✓	✓	✓	x
NSS (Kumar 2013)	✓	✓	✓	x
SVNS (Smarandache 1998)	✓	✓	✓	x
QSVNS (proposed)	✓	✓	✓	✓

Notations:

- NS: Neutrosophic Set
- NFS: Neutrosophic Fuzzy Set
- INS: Intuitionistic Neutrosophic Set
- NSS: Neutrosophic Soft Set
- SVNS: Single-Valued Neutrosophic Set
- QSVNS: Quadripartitioned Single-Valued Neutrosophic Set

Remark 3.2 As you can see, the advantage of this method is that indeterminacy can be bifurcated and restricted to some membership function depending of the problem. For instance, indeterminacy could be divided into unknown and contradiction, or another sort of indeterminacy that the problem comes up with.

Conclusion

This study provides several significant contributions to the fundamental knowledge of relations (properties) in neutrosophic sets theory and also its application. In this paper, we considered a case where prices of energy were affected by covid-19 before, during and after this happened. The quadripartitioned single-valued neutrosophic property which was proposed in this study deals with several opportunities to be explored in future research. The proposed property could be applied to plenty of fields of study in solving real-world issues such as pattern recognition, big data, and stochastic process. For future studies, we propose to extend this method to n-refined single valued and to compare that new method with the method defined in this paper. Also, this method can be improved and applied in new real situations.

Data Availability This manuscript has no associated data.

Declarations

Conflict of Interest The authors declare no competing interests.

References

Aikhuele DO, Akinosi OA, Turan FB (2021) A hybrid fuzzy model for the performance evaluation of biomethane gas as a renewable energy source. Process Integr Optim Sustain 5:993–1002

Ali M, Smarandache F (2015) Complex neutrosophic set. Neural Comput Appl 28:1817–1834

Ali T, Ma H, Nahian AJ (2020) A multi-criteria decision-making approach to determine the optimal hybrid energy system in coastal off-grid areas: a case study of Bangladesh. Process Integr Optim Sustain 4:265–277

Alhabib R, Salama A (2020) The neutrosophic time series-study its models (linear-logarithmic) and test the coefficients significance of its linear model. Neutrosophic Sets and Systems 33:105–115

Alhabib R, Salama A (2020) Using moving averages to pave the neutrosophic time series. International Journal of Neutrosophic Science 3(1):14–20

AL-Husban A, Amourah A, Jaber J (2020) Bipolar complex fuzzy sets and their properties. Italian Journal of Pure and Applied Mathematics 43:754–761

Bhowmik M, Pal M (2009) Intuitionistic neutrosophic set. Journal of Information and Computing Science 4(2):142–152

Blanco D, Henriquez S, Fajardo E, Romero H (2020) Consumption of Energy, Economic Growth, and Carbon Dioxide Emissions in Colombia. Revista Fuentes: El Reventón Energético 18(1):41–50

Chatterjee R, Majumdar P, Samanta SK (2016) On some similarity measures and entropy on quadripartitioned single valued neutrosophic sets. Journal of Intelligent & Fuzzy Systems 30:2475–2485

Chaw Y, Abdullah L, Othman M (2020) Single-valued neutrosophic relations and their application to factors affecting oil prices. CAAI Transactions on Intelligence Technology 5(2):115–120

Cruzaty L, Reyes M, Castillo C (2020) A Neutrosophic Statistic Method to Predict Tax Time Series in Ecuador. Neutrosophic Sets and Systems 34:33–39

Das S, Das R, Granados C, Mukherjee A (2021) Pentapartitioned neutrosophic Q-ideals of Q-algebra. Neutrosophic Sets and Systems 41:53–63

Das S, Das R, Granados C (2021) Topology on quadripartitioned neutrosophic sets. Neutrosophic Sets and Systems 45:54–61

Das S, Roy BK, Kar MB (2020) Neutrosophic fuzzy set and its application in decision making. J Ambient Intell Human Comput 11:5017–5029

Giraldo M, Vacca R, Urrego A (2018) Las energias alternativas, una oportunidad para Colombia? Punto de Vista 9(13):1–13

Granados C (2021) New results on neutrosophic random variables. Neutrosophic Sets and Systems 47:286–297

Granados C (2021) Sanabria, J., On independence neutrosophic random variables. Neutrosophic Sets and Systems 47:541–557

Granados C, Dhital A (2021) Statistical Convergence of Double Sequences in Neutrosophic Normed Spaces. Neutrosophic Sets and Systems 42:333–344

Granados C, Dhital A (2021) New results on Pythagorean neutrosophic open sets in Pythagorean neutrosophic topological spaces. Neutrosophic Sets and Systems 43:12–23

Granados C (2021) Una nueva noción de conjuntos neutrosóficos a través de los conjuntos $^*b$-abiertos en espacios topológicos neutrosóficos. Eco Matemá,tico 12(2):1–12

Granados C (2020) Un nuevo estudio de los conjuntos supra neutrosophic crisp. Revista Facultad de Ciencias Básicas 16(2):65–75

Kumar P (2013) Neutrosophic soft set. Annals of Fuzzy Mathematics and Informatics 5(1):157–168

Molodtsov D (1999) Soft set theory-first results. Computers and Mathematics with Applications 37(4-5):19–31

Ramot D, Milo R, Friedman M, Kandel A (2002) Complex fuzzy sets. IEEE Transactions on Fuzzy Systems 10:171–186

Riaz M, Hashmi M (2019) Linear Diophantine fuzzy set and its applications towards multi-attribute decision-making problemas. 37:5417–5439

Sánchez-Zarco XG, Cansino-Loeza B, Ponce-Ortega JM (2019) A Multi-Objective Optimization Approach for Water–Energy–Food Grids in Isolated Communities. Process Integr Optim Sustain 3:471–485

Shabir M, Naz M (2013) On Bipolar Soft Sets

Smarandache F (1998) Neutrosophy: neutrosophic probability, set, and logic. ProQuest information & learning

Smarandache F (2013) n-Valued refined neutrosophic logic and its applications in physics. Progress in Physics 4:143–146

Zeina M (2020) Neutrosophic Event-Based Queueing Model. International Journal of Neutrosophic Science 6(1):48–55

Zeina M (2020) Erlang Service Queueing Model with Neutrosophic Parameters. International Journal of Neutrosophic Science 6(2):106–112

Zhang W (1994) Bipolar fuzzy sets and relations: a computational framework for cognitive modeling and multiagent decision analysis, Proceedings of the First International Joint Conference of The North American Fuzzy Information Processing Society Biannual Conference. The Industrial Fuzzy Control and Intellige 1:305–309