Analyzing the Perspective of Circular Economy and Sustainable Development in the Junín Region of Peru Using Neutrosophic Cognitive Maps

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Abstract

The Sustainable Development of a country is a relatively new concept, where the right of each country to achieve decent economic and social development is accepted, and where there is well-being for the population. At the same time, the environment is respected. On the other hand, the Circular Economy is another recent concept where the efficient and effective use of resources and products is proposed, where the fundamental principle is the reuse of waste as far as possible and its rational use, to reduce environmental pollution, and providing economic savings for the country. This paper aims to study the relationship between the concepts of Circular Economy and Sustainable Development contextualized in the Peruvian department of Junín. To examine this relationship and its future behavior, there are challenges such as the existence of indirect relationships between these two concepts, dependent on other concepts; and relationships between concepts that are unknown, at least partially. Taking all this into account, a group of three experts on the subject in Junín was asked for their opinion to determine the relationship between the selected concepts. This allowed the representation of knowledge with the help of a Neutrosophic Cognitive Map (NCM) and the study of the dynamic behavior of concepts with the help of the Method for Hidden Patterns.

Keywords: Circular Economy; Sustainable Development; Neutrosophic Cognitive Maps; Neutrosophic Number

1. Introduction

The Circular Economy refers to a model of production and reduction in the use of resources by implementing alternatives such as recycling waste or reusing certain components. The impacts of the Circular Economy are manifested in mitigating environmental damage, prolonging the useful life of resources, and generating new value in them. The Circular Economy offers alternatives to using existing products; that is, giving them a second chance to turn them into products with a new useful value.

Sustainable Development consists of the interrelation of natural resources, society, and economic development to achieve prosperity, thereby generating both individual and collective well-being, the latter related to economic and political growth, distribution of wealth, and the expansion of industrialization. From the above, Sustainable Development is defined as individual and collective well-being through the sustainable use of natural resources and good economic growth accompanied by a balanced distribution of wealth such as the expansion of industrial sectors.

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In an international context, first-world countries such as Sweden and Germany are linked to the Circular Economy, a new economic system that has allowed them to optimize the use of their resources sustainably. On the other hand, the countries that makeup Latin America and the Caribbean have great potential to adapt their economic systems to the principles of the Circular Economy. However, they must first overcome pending challenges such as the creation of a political framework that encourages society and the different social and economic actors to contribute to the creation of a Circular Economy and to better understand the need to move from a linear economic model to a circular one.

Similarly, Sustainable Development presents a significant drawback in Latin America, and this is mainly due to the high uncertainty in different scenarios; for example, the ability to achieve improvements in the different areas of sustainability, political instability in most countries in the region, and in the rest of the world, as well as difficulties in having the opportunity to access a greater and better number of financial resources.

In the Peruvian national reality, it is mentioned that the Circular Economy is applied in different areas, all focused on the efficient use of natural resources. In our country, various environmental policies support the adoption of the circular model, to promote a more responsible consumption of resources and their preservation. In companies, the Circular Economy generates income thanks to the reduction and reuse of waste, optimizing resources in a better way and turn taking care of the environment, complying with the requirements established in ISO 14001:2015, and achieving quality management.

On the other hand, despite existing state policies, the developments achieved are becoming less and less sustainable. The findings reveal that the Sustainable Development goals have not been fully met, especially in terms of reducing poverty, zero hunger, health and well-being, quality education, clean water and sanitation, decent work and economic growth, life below water, life on land and partnerships to achieve the goals. While the possibilities for Sustainable Development exist, greater government efforts are essential for the sustainable use of resources and meeting the needs to achieve human development.

Some of the possible reasons for which not much importance has been given to the Circular Economy and sustainable development are mainly due to the lack of interest in complying with environmental policies, lack of environmental commitment, few financial resources allocated to meet the Sustainable Development goals, absence of personnel trained in environmental issues and the lack of values that could be taught in higher education institutions.

The above-mentioned can have several consequences, mainly, indiscriminate use and exhaustion of environmental resources, unsustainable production processes, increased waste, increased global warming, increased social inequalities, and disparities in access to basic services, among others.

To avoid this, governments need to adopt a Circular Economy to achieve Sustainable Development in our society. The Circular Economy will allow us to establish the guidelines for the optimal use and conservation of resources, reduction of pollution, reduction of waste, sustainable economic growth, and improvement of people's quality of life. Likewise, investment is essential for the fulfillment of Sustainable Development goals to achieve a more prosperous society without inequalities.

The problem we are studying is to determine what relationship exists between the Circular Economy and Sustainable Development according to a group of experts surveyed from the Junín department in Peru, during the year 2024 and what their future perspective is.

The study we wish to carry out contains some difficulties, such as the complex relationship between these two concepts, which are linked to other additional concepts. We may also find imprecise relationships between two or more pairs of concepts. Therefore, we decided to use the Neutrosophic Cognitive Maps (NCM) for knowledge representation and the Method for Determining the Hidden Patterns for predicting the behavior of the concepts studied [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14].

In the study we are based on a model that exists in the neutrosophic literature, where this problem is addressed, [15]. NCMs consist of a directed graph whose nodes represent concepts and whose edges represent relationships between concepts to which weights are associated, especially for Simple Neutrosophic Cognitive Maps found within the set $\{-1, 0, 1, I\}$. The value -1 means that the relationship is inverse (the increase in the presence of a concept decreases the presence of the other and vice versa); 0 means that there is no relationship between the two of them; 1 means that the relationship is direct (the increase in the presence of a concept increases the presence of the other and vice versa); and what distinguishes the NCM from others is the use of the symbol I to represent indeterminacy in the relationship between concepts, which occurs when the relationship is not known, although this is intended to be expressed to maintain the accuracy of the phenomenon.

To carry out the study we divided this article according to the following structure, the Related Work section contains the basic notions about NCM, Neutrosophic Numbers, and the Model that appears in [15]. The section

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called The Study contains the elements used for the study and the results obtained. The last section is the Conclusion.

2. Related Work

This section is dedicated to providing a reminder of the basic notions of the theories that we will use to carry out the study.

A. Neutrosophic Cognitive Maps

Definition 1: ([1, 2, 3]) Let X be a universe of discourse. A *Neutrosophic Set* (NS) is characterized by three membership functions, $u_A(x), r_A(x), v_A(x) : X \to]^-0, 1^+[$, which satisfy the condition $^-0 \leq \inf u_A(x) + \inf r_A(x) + \inf v_A(x) \leq \sup u_A(x) + \sup r_A(x) + \sup v_A(x) \leq 3^+$ for all $x \in X$. $u_A(x), r_A(x)$ and $v_A(x)$ are the membership functions of truthfulness, indeterminacy, and falseness of x in A, respectively, and their images are standard or non-standard subsets of $]^-0, 1^+[$.

Definition 2: ([1, 2, 3]) Let X be a universe of discourse. A *Single-Valued Neutrosophic Set* (SVNS) A on X is a set of the form:

$$A = \{\langle x, u_A(x), r_A(x), v_A(x)\rangle : x \in X\} \qquad (1)$$

Where $u_A, r_A, v_A : X \to [0,1]$, satisfy the condition $0 \leq u_A(x) + r_A(x) + v_A(x) \leq 3$ for all $x \in X$. $u_A(x), r_A(x)$ and $v_A(x)$ denote the membership functions of truthfulness, indeterminate, and falseness of x in A, respectively. For convenience, a *Single-Valued Neutrosophic Number* (SVNN) will be expressed as $A = (a, b, c)$, where $a, b, c \in [0,1]$ and satisfy $0 \leq a + b + c \leq 3$.

Other important definitions are related to the graphs.

Definition 3: ([1, 2, 3, 16, 17]) A *neutrosophic graph* is a graph containing at least one indeterminate edge, which is represented by dotted lines.

Definition 4: ([1, 2, 3, 16, 17]) A *neutrosophic directed graph* is a directed graph containing at least one indeterminate edge, which is represented by dotted lines.

Definition 5: ([1, 2, 3]) A *Neutrosophic Cognitive Map* (NCM) is a neutrosophic directed graph, whose nodes represent concepts and whose edges represent causal relationships among the edges.

If $C_1, C_2, \dots, C_k$ are k nodes, each of the C_i $(i = 1, 2, \dots, k)$ can be represented by a vector $(x_1, x_2, \dots, x_k)$ where $x_i \in \{0, 1, I\}$. $x_i = 0$ means that the node C_i is in an activated state, $x_i = 1$ means that the node C_i is in a deactivated state and $x_i = I$ means that the node C_i is in an indeterminate state, in a specific time or a specific situation.

If C_m and C_n are two nodes of the NCM, an edge directed from C_m to C_n is called a connection and represents the causality from C_m to C_n. Each node in the NCM is associated with a weight within the set $\{-1, 0, 1, I\}$. If α_{mn} denotes the weight of the edge C_mC_n, $\alpha_{mn} \in \{-1, 0, 1, I\}$ then we have the following:

$\alpha_{mn} = 0$ if C_m does not affect C_n,

$\alpha_{mn} = 1$ if an increase (decrease) in C_m produces an increase (decrease) in C_n,

$\alpha_{mn} = -1$ if an increase (decrease) in C_m produces a decrease (increase) in C_n,

$\alpha_{mn} = I$ if the effect of C_m on C_n is indeterminate.

Definition 6: ([1, 2, 3]) An NCM having edges with weights in $\{-1, 0, 1, I\}$ is called a *Simple Neutrosophic Cognitive Map*.

Definition 7: ([1, 2, 3]) If $C_1, C_2, \dots, C_k$ are the nodes of an NCM. The neutrosophic matrix N(E) is defined as $N(E) = (\alpha_{mn})$, where α_{mn} denotes the weight of the directed edge C_mC_n, such that $\alpha_{mn} \in \{-1, 0, 1, I\}$. N(E) is called the *neutrosophic adjacency matrix* of the NCM.

Definition 8: ([1, 2, 3]) Let $C_1, C_2, \dots, C_k$ be the nodes of an NCM. Let $A = (a_1, a_2, \dots, a_k)$, where $a_m \in \{-1, 0, 1, I\}$. A is called *an instantaneous state neutrosophic vector* and means a position of the on-off-indeterminate state of the node in a given instant.

$a_m = 0$ if C_m is deactivated (has no effect),

$a_m = 1$ if C_m is activated (has an effect),

$a_m = I$ if C_m is indeterminate (its effect cannot be determined).

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Definition 9: ([1, 2, 3]) Let $C_1, C_2, \ldots, C_k$ be the nodes of an NCM. Let $\overrightarrow{C_1C_2}$, $\overrightarrow{C_2C_3}$, $\overrightarrow{C_3C_4}$,…, $\overrightarrow{C_mC_n}$ be the edges of the NCM, then the edges constitute a *directed cycle*.

The NCM is called *cyclic* if it has a directed cycle. It is said *acyclic* if it has not a directed cycle.

Definition 10: ([1, 2, 3]) An NCM containing cycles is said to have feedback. When there is feedback in the NCM, it is said that it is a *dynamic system*.

Definition 11: ([1, 2, 3]) Let $\overrightarrow{C_1C_2}$, $\overrightarrow{C_2C_3}$, $\overrightarrow{C_3C_4}$,…, $\overrightarrow{C_{k-1}C_k}$ be a cycle. When C_m is activated and its causality flows through the edges of the cycle and then it is the cause of C_m itself, then the dynamic system circulates. This is fulfilled for each node C_m with $m = 1, 2, \ldots, k$. The equilibrium state for this dynamic system is called the *hidden pattern*.

Definition 12: ([1, 2, 3]) If the equilibrium state of a dynamic system is a single state, then it is called a *fixed point*.

An example of a fixed point is when a dynamic system starts by being activated by C_l. If it is assumed that the NCM sits on C_l and C_k, i.e. the state remains as $(1, 0, \ldots, 0, 1)$, then this vector of the neutrosophic state is called a *fixed point*.

Definition 13: ([1, 2, 3]) If the NCM is established with a neutrosophic state-vector that repeats itself in the form:

$A_1 \to A_2 \to \cdots \to A_m \to A_1$, then the equilibrium is called a *limit cycle* of the NCM.

<u>Method for Determining the Hidden Patterns</u>

Let $C_1, C_2, \ldots, C_k$ be the nodes of the NCM with feedback. Assume that E is the associated adjacency matrix. A hidden pattern is found when C_l is activated and a vector input $A_1 = (1, 0, 0, \ldots, 0)$ is given. The data must pass through the neutrosophic matrix $N(E)$, which is obtained by multiplying A_1 by the matrix $N(E)$.

Let $A_1N(E) = (\alpha_1, \alpha_2, \ldots, \alpha_k)$ with the threshold operation of replacing α_m by 1 if $\alpha_m > p$ and α_m by 0 if $\alpha_m < p$ (p is a suitable positive integer) and α_m is replaced by I if this is not an integer. The resulting concept is updated; vector C_1 is included in the updated vector by transforming the first coordinate of the resulting vector into 1.

If $A_1N(E) \to A_2$ is assumed then $A_2N(E)$ is considered and the same procedure is repeated. This procedure is repeated until a limit cycle or fixed point is reached.

Definition 14: ([15]) A *neutrosophic number* N is defined as a number as follows:

$$N = d + I \quad (2)$$

Where d is called the determinate part and I is called the indeterminate part.

Given that $N_1 = a_1 + b_1I$ and $N_2 = a_2 + b_2I$ are two neutrosophic numbers, some operations between them are defined as follows:

$N_1 + N_2 = a_1 + a_1 + (b_1 + b_2)I$ (Addition);

$N_1 - N_2 = a_1 - a_1 + (b_1 - b_2)I$ (Difference),

$N_1 \times N_2 = a_1a_2 + (a_1b_2 + b_1a_2 + b_1b_2)I$ (Product),

$\frac{N_1}{N_2} = \frac{a_1+b_1I}{a_2+b_2I} = \frac{a_1}{a_2} + \frac{a_2b_1-a_1b_2}{a_2(a_2+b_2)}I$ (Division).

B. The model of NCM proposed in [15].

1. 14 specialists in Circular Economy were asked to give their opinion on a scale of -10 to 10, including 0, and they were also asked to use the symbol I as an indicator that they do not know about the possible relationship between each pair of the following variables:

V_1: Recycling rate.
V_2: Consumption of natural resources.
V_3: Added value per material.
V_4: Carbon footprint.
V_5: Municipal waste recycling index.
V_6: Number of companies adopting circular practices.
V_7: Quantity of repurposed products.
V_8: Investment in research and development in the Circular Economy.
This is justified because it is easier for specialists to evaluate on this scale than on a more restrictive one in the range of $\{-1,0,1,I\}$. -10 means a total inverse relationship, 10 means a total direct relationship, and 0 means that

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there is no relationship between the variables. Values between -9 and -1 or between 1 and 9 constitute intermediate opinions between the three previous values.

Each specialist was surveyed individually and independently from the rest to avoid influencing the responses.

That is, formally if we call $E = \{e_1, e_2, \cdots, e_{14}\}$ the set of the 14 experts. R_{ijk} symbolizes the relationship between the jth and kth criteria ($j, k \in \{1,2,\ldots,8\}$, $j \neq k$) according to the expert e_i($i = 1,2,\ldots,14$) such that $R_{ijk} \in \{-10, -9, \cdots, -1, 0, 1, \cdots, 9, 10, I\}$.

2. The numerical values are R_{ijk} calculate $\widehat{R}_{ijk} = \text{round}\left(\frac{R_{ijk}}{10}\right)$ and if $R_{ijk} = I$ maintain $\widehat{R}_{ijk} = I$.
3. For each fixed pair $j, k \in \{1,2,\ldots,8\}$, it is calculated $\overline{R}_{jk}$ as follows:

- If the mode of $\widehat{R}_{ijk}$ for $i = 1,2,\ldots,14$ is unimodal, $\overline{R}_{jk} = \text{mode}_i(\widehat{R}_{ijk})$ and it is taken $\overline{R}_{kj} = 0$.
- If the mode of $\widehat{R}_{ijk}$ for $i = 1,2,\ldots,14$ is not unimodal it is defined as follows:

➢ If $\widehat{R}_{ikj}$ for $i = 1,2,\ldots,14$ is unimodal, and $\overline{R}_{jk} = 0$ then it is taken $\overline{R}_{kj} = \text{mode}_i(\widehat{R}_{ikj})$.

➢ If $\widehat{R}_{ikj}$ $i = 1,2,\ldots,14$ is not unimodal, it is taken $\overline{R}_{jk} = \overline{R}_{kj} = I$.

4. In this way, the adjacency matrix is formed with the elements $\overline{R}_{jk}$ obtained from this algorithm.

3. The Study

In this section, we present the methods used for the study we carried out and also the results achieved. We begin by presenting the algorithm we designed, which is an adaptation of the algorithm presented in subsection B of the previous section, which, as we said, was the one applied in [15].

1. Three Peruvian specialists in Circular Economy were consulted and asked to give their opinion on a scale as indicated in Table 1:

Table 1: Relationship between linguistic and numerical values as measurement scales in the study carried out

Linguistic value	Numeric Value
Highly Correlated Directly	3
Directly Correlated	2
Little Correlated Directly	1
Not Correlated	0
Slightly Inversely Correlated	-1
Inversely Correlated	-2
Highly Inversely Correlated	-3
We don't know	I

Table 1 contains an adaptation made to the algorithm defined in [15]. This adaptation was made with the aim of helping decision-makers to qualitatively evaluate each of the aspects that must be taken into account. In this way, decision-makers only have to give an opinion according to the linguistic scale that appears in the table, and the calculations are carried out based on the numerical value that appears in the second column.

Another change about the previous algorithm is the definition of the concepts to be studied, which are the following:

V_1: Circular Economy.
V_2: Sustainable Development.
V_3: Resource Optimization.
V_4: Waste Reduction.
V_5: Economic Growth.
V_6: Social Needs.
V_7: Environment.
V_8: Natural Resources.

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Then, each specialist was surveyed individually and independently from the rest to avoid influencing the responses. That is, formally if we call $E = \{e_1, e_2, e_3\}$ the set of the 3 experts. R_{ijk} symbolizes the relationship between the jth and kth criteria ($j, k \in \{1,2, \ldots ,8\}$, $j \neq k$) according to the expert e_i($i = 1,2,3$) such that $R_{ijk} \in \{-3, -2, -1, 0, 1, 2, 3, I\}$.

2. The numerical values are R_{ijk} calculate $\widehat{R}_{ijk} = \text{round}\left(\frac{R_{ijk}}{3}\right)$ and if $R_{ijk} = I$ maintain $\widehat{R}_{ijk} = I$.
3. For each fixed pair $j, k \in \{1,2, \ldots ,8\}$, it is calculated $\overline{R}_{jk}$ as follows:

- If the mode of $\widehat{R}_{ijk}$ for $i = 1, 2, 3$ is unimodal, $\overline{R}_{jk} = \text{mode}_i\left(\widehat{R}_{ijk}\right)$ and it is taken $\overline{R}_{kj} = 0$.
- If the mode of $\widehat{R}_{ijk}$ for $i = 1, 2, 3$ is not unimodal it is defined as follows:
  - ➢ If $\widehat{R}_{ikj}$ for $i = 1,2, 3$ is unimodal and $\overline{R}_{jk} = 0$, it is taken $\overline{R}_{kj} = \text{mode}_i\left(\widehat{R}_{ikj}\right)$.
  - ➢ If $\widehat{R}_{ikj}$ for $i = 1,2, 3$ is not unimodal, it is taken $\overline{R}_{jk} = \overline{R}_{kj} = I$.

4. In this way, the adjacency matrix is formed with the elements $\overline{R}_{jk}$ obtained from this algorithm.

After the 3 specialists gave their opinions on the relationship between the concepts and once the previous algorithm was applied, we arrived at the adjacency matrix shown in the following table:

Table 2: N (E) adjacency matrix obtained from the study

Node	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8
V_1	0	2	3	3	1	I	3	2
V_2	0	0	0	0	0	I	0	0
V_3	0	3	0	2	0	0	0	-3
V_4	0	3	0	0	0	0	3	-3
V_5	0	0	0	0	0	3	-1	I
V_6	I	I	0	0	0	0	0	0
V_7	0	3	0	0	0	0	0	-2
V_8	0	3	0	0	I	0	0	0

Figure 1 contains the graphical representation of the NCM obtained.

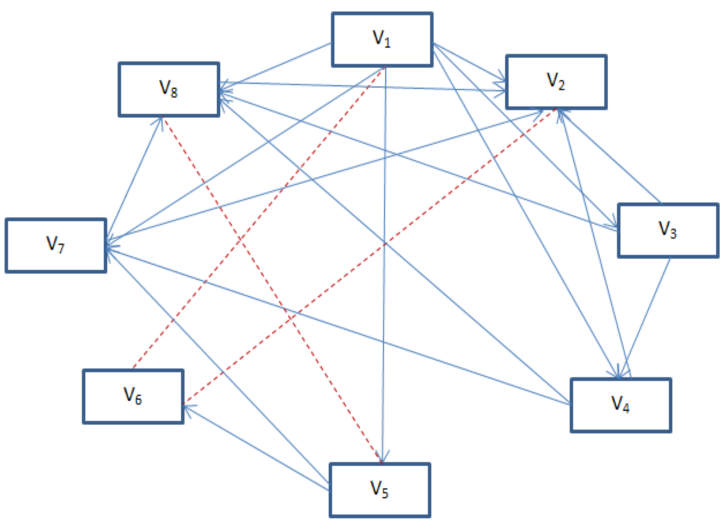

Figure 1. Graphical representation of the Neutrosophic Cognitive Map obtained

As done in [15] we obtained the results of the convergence of the algorithm for the $2^8 - 1 = 255$ possible initial states, excluding the degenerate case in which no node is active. This is summarized in Table 3.

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Table 3: Convergence results for all possible initial vectors except the degenerate case

	Convergence to the value		
Variable	0	1	I
V_1	0 (0)	128 (0.50196)	127 (0.49804)
V_2	0 (0)	128 (0.50196)	127 (0.49804)
V_3	63 (0.24706)	192 (0.75294)	0 (0)
V_4	31 (0.12157)	224 (0.87843)	0 (0)
V_5	0 (0)	128 (0.50196)	127 (0.49804)
V_6	0 (0)	128 (0.50196)	127 (0.49804)
V_7	31 (0.12157)	224 (0.87843)	0 (0)
V_8	0 (0)	128 (0.50196)	127 (0.49804)

As can be seen from Table 3, nodes V_4 and V_7 were activated more than 87% of the time concerning the initial values and never presented indeterminacy. V_3 was activated more than 75% of the time. For the other cases, it is observed that approximately half of the time, it is activated, and the other half is indeterminate [18-20].

4. Conclusion

This article focused on a study carried out in the department of Junín, Peru on the state of Sustainable Development and the Circular Economy in the region, both at present and its possible future behavior. To do so, we requested the opinion of three experts on the subject, who evaluated the causal relationship between eight concepts studied, including the two mentioned above. The other six were “Resource Optimization”, “Waste Reduction”, “Economic Growth”, “Social Needs”, “Environment” and “Natural Resources”. To carry out the study, we represented knowledge using a Neutrosophic Cognitive Map, which allowed including indeterminate causal relationships, which is not possible with Cognitive Maps or Fuzzy Cognitive Maps. The Method for Determining Hidden Patterns was used and an algorithm that appeared in [15] was adapted. When the results were run for all the initial activation vectors, it was seen that both the Circular Economy and Sustainable Development are either activated or remain undetermined in almost equal proportions, this means that for a favorable result, it is necessary to draw up policies that favor these concepts. Therefore, decision-makers are recommended to work in this direction intentionally. The same occurs with "Economic Growth", "Social Needs" and the exploitation of "Natural Resources". On the other hand, due to the causal dependence of the concepts "Resource Optimization", "Waste Reduction" and care for the "Environment" to the other concepts, a positive behavior of these would be expected because of the positive behavior of the others.

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