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Study of the Circular Economy Model as a Strategy for the Development of Peru Based on Neutrosophic Cognitive Maps

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Abstract. The circular economy has become a crucial approach to address the environmental and economic challenges associated with sustainable production and consumption. Instead of the traditional linear model of "take, make, use, and dispose of", the circular economy seeks to close material and resource cycles, minimize waste and maximize added value throughout the supply chain. In this context, the different strata of the Peruvian economy play an important role in the transition toward a circular economy. However, several indicators have been identified that show poor performance in this form of development. The purpose of this study is to identify the opportunities for the implementation of the circular economy model in the Peruvian economy. The investigation results provide a comprehensive vision of the pitfalls and congruences for implementing this strategy. Neutrosophic cognitive maps were selected as a study tool, which represents relationships between concepts; in this case, indeterminacy is also included to represent unknown, neutral, imprecise relationships, etc. between concepts. To design the dynamic neutrosophic cognitive map, 14 circular economy specialists were surveyed, based on their individual and independent criteria and so the model was obtained. Then, from the run of all the possible cases according to the algorithm of seeking the hidden patterns, the absolute and relative frequencies for the convergence to each one of the possible values were obtained.

Keywords: Circular Economy, Sustainable Development, Neutrosophic Cognitive Maps, Neutrosophic Number.

1 Introduction

The circular economy is a strategy that aims to reduce both the input of materials and the production of virgin waste, closing the "loops" or economic and ecological flows of resources. It encompasses much more than the production and consumption of goods and services, as it includes, among other aspects, the switch from fossil fuels to the use of renewable energy, and diversification as a means of achieving resilience. As part of the debate, it should also include a deep discussion on the role and use of money and finance, and some of its pioneers have also called for renewing the tools for measuring economic performance.

Peru has not developed coordinated actions for the establishment of circular economy processes, so it is necessary to use international indicators that are utilized to measure the scope and optimal use of this form of management. The authors, based on the thematic analysis of twenty authors, set as references the following:

a) Recycling rate: It is the percentage of materials recycled of the total materials generated. Measures the effectiveness of the material recycling and reuse system.
b) Consumption of natural resources: A measure of the total consumption of natural resources, such as water, minerals, wood, and energy, compared to the country's economic output.
c) Added value per material: This indicator shows how much economic value is generated per unit of material used. Greater efficiency in the use of materials may indicate a more circular economy.

d) Carbon footprint: It is the total amount of greenhouse gas emissions produced by a specific nation, company, or activity. The circular economy seeks to reduce these emissions throughout the life cycle of products.
e) Municipal Waste Recycling Rate: Measures the percentage of recycled waste instead of being sent to landfills or incinerated.
f) Number of companies adopting circular practices: Counts the number of companies that have implemented circular economy strategies, such as design for recycling, use of recycled materials, and service-based business models.
g) Number of Refurbished Products: Measures the number of products that are repaired or refurbished rather than scrapped and replaced.
h) Investment in research and development in the circular economy: Measures the level of investment in research and development of technologies and practices related to the circular economy.

Neutrosophic Cognitive Maps are used as a study tool [1]. These are defined as directed graphs, where the nodes represent concepts and the edges represent causal relationships between the concepts. In the theory of Cognitive Maps, each edge is associated with a numerical value in the set $\{-1, 0, 1\}$, where -1 represents that the cause-effect relationship is negative (if the value of one concept increases, the value of the other decreases and vice versa), 0 represents the absence of a relationship between the concepts, while 1 represents a positive relationship (when the presence of one concept increases, the other also increases and vice versa) [2]. In the case of the Dynamic Neutrosophic Cognitive Maps, the symbol "I" also appear to indicate that the relationship between the concepts is not exactly known. This tool has been applied in many problems [1, 3-8].

The difficult with designing a circular economy is that it is a complex phenomenon, where there are non-linear relationships between variables, in addition to the fact that some of the relationships may be conflicting or contradictory, for example, a successful economy in the short or medium term can be more efficient if it ignores the care of the environment, however in the long term it will fail. For all this, this work is also in tune with the theory of Neutrosophic Systems and Neutrosophic Dynamic Systems introduced by F. Smarandache in [9].

Dynamic Systems is a methodology for analyzing and modeling temporal behavior in complex environments. It is based on the identification of feedback loops between elements, and also on information and material delays within the system. What makes this approach different from others used to study complex systems is the analysis of the effects of loops or feedback loops, in terms of flows and adjacent deposits. In this way, the dynamics of the behavior of these systems can be structured through mathematical models. The simulation of these models can currently be performed with the help of specific computer programs.

To obtain the elements of the cognitive map, 14 Peruvian specialists in Circular Economy were surveyed, who gave their opinion on the subject, each one individually. In this way, by simulating all possible cases, the absolute frequency was calculated for the system to converge to one of the three possible values, that is, for the system to converge to an activated (1), deactivated (0), and indeterminate value (I), for each of the possible states. This problem is treated as a non-linear system, within the framework of Neutrosophy

This study aims to determine the elements of the circular economy that are opportunities and those that are challenges, for the current economy of Peru.

This paper is divided into sections, the next one is called Materials and Methods, where the fundamental concepts of Dynamic Neutrosophic Cognitive Maps are explained. The Results section contains the elements used for the study and the results obtained. Last section is dedicated to give the conclusions.

2 Materials and Methods

Neutrosophic Cognitive Maps will be used in this study, so we explain them in the following.

2.1 Neutrosophic Cognitive Maps

Definition 1: ([10, 11]) Let X be a universe of discourse. A *Neutrosophic Set* (NS) is characterized by three membership functions, $u_A(x), r_A(x), v_A(x) : X \rightarrow]^-0, 1^+[$, 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: ([12, 13]) Let X be a universe of discourse. A *Single-Valued Neutrosophic Set* (SVNS) A on X is a set of the form:

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

Where $u_A, r_A, v_A : X \rightarrow [0,1]$, 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 $v_A(x)$ are 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: ([12, 14]) A *Neutrosophic graph* contains at least one indeterminate edge, represented by dotted lines.

Definition 4: ([12, 14]) A *Neutrosophic directed graph* is a directed graph containing at least one indeterminate edge, which is represented by dotted lines.

Definition 5: ([5, 7]) A *Neutrosophic Cognitive Map* (NCM) is a neutrosophic directed graph, whose nodes represent concepts and whose edges represent causal relationships among the edges.

Let $C_1, C_2, \dots, C_k$ be 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 $x_i \in \{0, 1, I\}$. $x_i = 1$ means that the node C_i is in an activated state, $x_i = 0$ 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 [15].

If C_m and C_n are two nodes of the NCM, a directed edge 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} denote 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: ([5, 7]) A NCM having edges with weights in $\{-1, 0, 1, I\}$ is called *Simple Neutrosophic Cognitive Map*.

Definition 7: ([5, 7]) 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: ([5, 7]) 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 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),

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

Definition 9: ([5, 7]) Let $C_1, C_2, \dots, C_k$ 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: ([5, 7]) A 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: ([5, 7]) 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 $m = 1, 2, \dots, k$. The equilibrium state for this dynamic system is called the *hidden pattern*.

Definition 12: ([5, 7]) 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 for 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 $(1, 0, \dots, 0, 1)$, then this vector of the neutrosophic state is called a *fixed point*.

Definition 13: ([5, 7]) 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 $C_1, C_2, \dots, C_k$ 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 $A_1 = (1, 0, 0, \dots, 0)$ 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; the vector C_1 is included in the updated vector by transforming the first coordinate of the resulting vector into 1.

If $A_1N(E) \rightarrow A_2$ 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: ([16]) A *neutrosophic number* N is defined as a number as follows:

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

Where d is called the *determined part* and I is called the *indeterminate part.*

Given $N_1 = a_1 + b_1I$ and $N_2 = a_2 + b_2I$ 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).

3 Results

To reach the expected results, the following procedure was followed:

1. 14 Circular Economy specialists were asked to give their opinion on a scale from -10 to 10, including 0, in addition to being 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:
   V1: Recycling rate.
   V2: Consumption of natural resources.
   V3: Added value by material.
   V4: Carbon footprint.
   V5: Municipal waste recycling rate.
   V6: Number of companies adopting circular practices.
   V7: Number of retrofitted products.
   V8: Investment in research and development in 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 complete inverse relationship, 10 means a complete direct relationship, and 0 means that there is no relationship between the variables. Values between -9 and -1 or between 1 and 9 represent intermediate opinions between the three previous values.
   Each specialist was surveyed individually and independently from the rest to avoid influencing the answers.

In other words, formally if we call $E = \{e_1, e_2, \cdots, e_{14}\}$ to the set of 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 of R_{ijk} are calculated $\hat{R}_{ijk} = round\left(\frac{R_{ijk}}{10}\right)$ and $R_{ijk} = I$ if $\hat{R}_{ijk} = I$.

   It approximates -0.5 to -1 and 0.5 to 1.
3. For each fixed pair $j, k \in \{1,2, \ldots, 8\}$, it is calculated $\bar{R}_{jk}$ as follows:
   - If the mode of $\hat{R}_{ijk}$ for $i = 1,2, \ldots, 14$ is unimodal, take $\bar{R}_{jk} = mode_i(\hat{R}_{ijk})$ and $\bar{R}_{kj} = 0$.
   - If the mode of $\hat{R}_{ijk}$ for $i = 1,2, \ldots, 14$ is not unimodal, it is defined as follows:
     - If $\hat{R}_{ikj}$ for $i = 1,2, \ldots, 14$ is unimodal, take $\bar{R}_{kj} = mode_i(\hat{R}_{ikj})$ and $\bar{R}_{jk} = 0$.
     - If $\hat{R}_{ikj}$ for $i = 1,2, \ldots, 14$ is not unimodal, take $\bar{R}_{jk} = \bar{R}_{kj} = I$.
4. In this way, the adjacency matrix is formed with the elements $\bar{R}_{jk}$ obtained from this algorithm.

After applying the surveys to the 14 specialists and processing the data obtained with the help of the previous algorithm, we arrive at the following adjacency matrix:

$$N(E) = \begin{pmatrix} 0 & -1 & 1 & -1 & 0 & 1 & 1 & I \\ 0 & 0 & I & 1 & 0 & 0 & 0 & I \\ 0 & I & 0 & -1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & -1 & 0 & 1 & 1 & 0 \\ 0 & -1 & 1 & -1 & 0 & 0 & 1 & 0 \\ 0 & -1 & 1 & -1 & 0 & 0 & 0 & 0 \\ I & I & 1 & -1 & 1 & 1 & 1 & 0 \end{pmatrix}$$

Figure 1 contains the graphical representation of the graph obtained from the previous adjacency matrix.

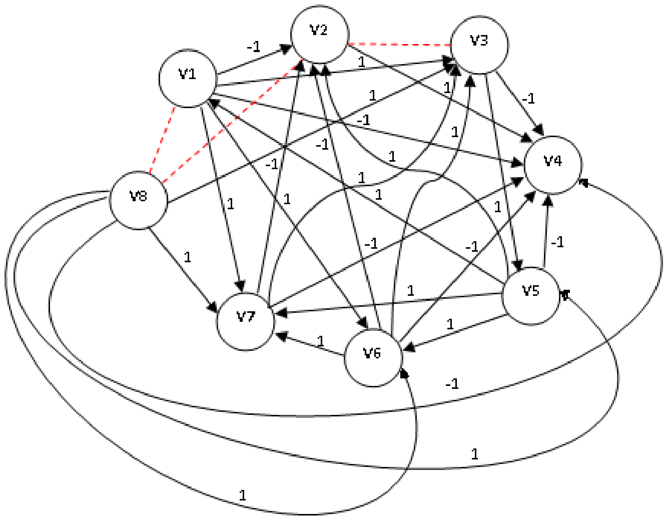

Figure 1: neutrosophic cognitive Map obtained from the experts.

We ran the system for every possible value of the initial state with the help of the Hidden Patterns algorithm. This is a quantity of $2^8 - 1 = 255$, excluding the case where no node is activated. The absolute frequency of convergence of each variable to each of the possible values within the set $\{0, 1, I\}$ was calculated, in addition to the relative frequencies. The results are shown in Table 1.

	Convergence to the value		
Variable	0	1	I
V1	1 (0.0039216)	252 (0.98824)	2 (0.0078431)
V2	1 (0.0039216)	254 (0.99608)	0 (0)
V3	1 (0.0039216)	252 (0.98824)	2 (0.0078431)
V4	0 (0)	255 (1)	0 (0)
V5	1 (0.0039216)	252 (0.98824)	2 (0.0078431)
V6	1 (0.0039216)	252 (0.98824)	2 (0.0078431)
V7	1 (0.0039216)	252 (0.98824)	2 (0.0078431)
V8	1 (0.0039216)	128 (0.50196)	126 (0.49412)

Table 1: Absolute frequency of convergence of the system to each of the possible values $\{0, 1, I\}$. The relative frequencies appear into parentheses.

All variables are activated most of the time. At least 252 times, excluding the variable V8 which is activated 128 times. 128 is the number of times that a variable appears activated as an initial value, not as a consequence of the activation of the rest of the variables. That is why V8 is activated only if there is the political will to invest in Research and Development on circular economy, it will never be activated as a consequence of the activation of any other variable. The rest of the variables are activated at least 124 times as a consequence of the activation of the other variables. On the other hand, the V4 carbon footprint variable is always activated, even as activation of the rest, this is because it is a variable that is a consequence of the others. There are few cases in which a variable remains inactive, which is due to the great interrelation that exists between the elements of the system. On the other hand, there is rarely indetermination, excluding V4, which remains indeterminate 126 times.

Below we delve into the results obtained from the surveys and the experts' assessments of the status of each of the concepts. The experts were asked to give a rating between 0 and 10 on the status of each of the variables in Peru today and the results were as follows:

V1 (Recycling rate): 3 expresses that the recycling rate is poor, which represents the insufficient quantity of materials that are recycled.

V2 (Consumption of natural resources): 7 Value that means that the available natural resources are being over-exploited.

V3 (Added Value): 2 Value that formulates that insufficient economic value is being generated from the efficient use of materials and resources.

V4 (Carbon Footprint): 8 Amount from which it can be inferred that the carbon footprint is very high, which is interpreted as high greenhouse gas emissions related to economic and production activities.

V5 (Recycling Index): 3 which indicates that the use of municipal waste is insufficient, a difference that is sent to landfills or incinerated.

V6 (Number of Companies with Circular Economy practices): 2 indicates that a low number of companies have adopted circular economy practices, which shows little importance given by companies to this activity.

V7 (Quantity of refurbished product): 4 that expresses an insufficient culture and practice of refurbishing or reusing products.

V8 (Investment in Research in Recycling): 2 A value that indicates that there is inadequate investment in R&D investment processes in research and development of technologies for recycling as a means of obtaining raw materials.

The obtained values were divided by 10 and the initial vector was obtained $S = (0.3, 0.7, 0.2, 0.8, 0.3, 0.2, 0.4, 0.2)$. The algorithm for seeking Hidden Patterns is designed for initial values of 0 (inactivated) or 1 (activated), therefore we converted S into an initial vector closer to the integer values 0 or 1, leaving $X_0 = (0, 1,0,1,0,0,0,0)$, the result obtained from applying the algorithm of seeking Hidden Patterns was: $(I, 1,0,1, I, I, I, I)$, that is, there are not encouraging results, in this case, significant added values will never be obtained and the rest of the variables remain undetermined. Although the negative results of high consumption of natural resources and high carbon footprint remain active.

We can carry out simulations with the model to determine which strategies to follow, for example, suppose that we considerably reduce the high consumption of natural resources and the carbon footprint so that they are practically inactive, and at the same time we activate the recycling rate, that is, we start from the initial vector $X_0 = (1, 0,0,0,0,0,0,0)$, the result is $(1, 1,1,1,1,1,1, I)$. In other words, all the variables are activated except the investment in R&D, this means that by activating only recycling the results are encouraging. We checked that V2 and V4 were activated in a negative sense, i.e. they were reduced. See below, the complete run of the algorithm:

$X_0 = (1, 0,0,0,0,0,0,0) \hookrightarrow X_0M = (0, -1,1, -1, 0, 1,1, I)$

$X_1 = (1, 1,1,1,0,1,1,0) \hookrightarrow X_1M = (I, -2 + 2I, 2 + 2I, -2 - I,\ 1 + I, I,\ 1 + I,\ I)$

$X_2 = (1,1, 1,1,1, I, 1, I) \hookrightarrow X_2M = (1 + I,\ -2,\ 1 + 4I,\ -2 - 3I,\ 1 + I,\ 1 + 2I, 1 + 3I, 2I)$

$X_3 = (1,1, 1,1,1, 1,1, I) \hookrightarrow X_3M = (1 + I,\ -4 + 2I,\ 3 + 2I,\ -4 - I,\ 1 + I,\ 2 + I,\ 3 + I, 2I)$

$X_4 = X_3 = (1,1, 1,1,1, 1,1, I)$.

Now suppose that investment in R&D is also activated with $X_0 = (1, 0,0,0,0,0,0,1)$ the result is $(1, 1,1,1,1,1,1,1)$.

Suppose that only investment in R&D is activated, with the negative values of high consumption of natural resources and high carbon footprint, that is, in $X_0 = (0, 1,0,1,0,0,0,1)$ this case we have the final result $(1, 1,1,1,1,1,1,1)$, that is, investment in technologies is essential to obtain an effective circular economy.

Conclusion

In this article, the possibility of obtaining an effective circular economy in Peru was studied. This is a theme that responds to the theory of nonlinear systems, which is why dynamic cognitive maps were used to process the results, specifically, we rely on neutrosophic cognitive maps because we include the possibility that there is not enough knowledge about the relationship between two concepts, which is natural in any system with non-linear dynamics. We resorted to the opinion of 14 Peruvian experts on the subject, from which the NCM was designed, concerning 8 variables determined by bibliographic research, where we reached the following conclusions:

1. Starting from the current state of the variables, the results in the future are unknown. In other words, it is necessary to make economic policy changes to improve the current situation of the circular economy in Peru. The experts assessed the current situation as inadequate.

2. Encouraging results will only be achieved by considerably increasing the recycling rate.
3. Investment in R&D on circular economy is not activated alone from the other variables, a State and government will is needed to achieve this. Once this is substantially achieved the rest of the indicators will be activated.

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