Neutrosophic Sets and Systems, {Special Issue: Artificial Intelligence, Neutrosophy, and Latin American Worldviews: Toward a Sustainable Future (Workshop – March 18–21, 2025, Universidad Tecnológica de El Salvador, San Salvador, El Salvador)}, Vol. 84, 2025

University of New Mexico

Multineutrosophic analysis of the impact of the circular economy on the regional supply chain.

Ana María Correa Vaca [1*], Fidel Márquez-Sánchez [2], Oscar José Alejo Machado [3], Cesar Pozo-Estupiñán [4], and Orlando Arencibia-Montero [5]

[1] Universidad ECOTEC, Guayas, Ecuador, acorrav@ecotec.edu.ec
[2] Universidad de Especialidades Espíritu Santo, Guayas, Ecuador. fmarquez@uees.edu.ec
[3] Instituto Superior Tecnológico de Investigación Científica e Innovación (ISTICI), Quito, Ecuador. oscar.alejo@istici.edu.ec
[4] Universidad Bolivariana del Ecuador, Guayas, Ecuador. capozoe@ube.edu.ec
[5] VSB-Universidad Técnica de Ostrava, Ostrava, República Checa. orlando.arencibia@vsb.cz

Abstract. This research was conducted to evaluate the influence of the circular economy on the sustainability of supply chains at the regional level through multineutrosophic theory for uncertainty in decision-making. Empirical analysis was performed through a quantitative and qualitative assessment, including a questionnaire completed by 50 regional companies, mathematical calculations based on neutrosophic theory, and a multineutrosophic assessment of the diverse input/output resource flows for supply chains associated with manufacturing and agricultural endeavors. The major results indicate that by incorporating aspects of the circular economy, recyclability/reusability of resources was 20% more effective and 15% less expensive to operate, while 30% of the responses that could not be applied were associated with underdeveloped infrastructure; in addition, the multineutrosophic approach gives assessing and prioritizing essential chain aspects to assist in better decision-making. Ultimately, it can be determined that the circular economy generates more robust and sustainable supply chains; operational problems require supportive public policy and technological investments to solve as the subject is most effective for developing areas with fewer resources.

Keywords: Circular Economy, Supply Chain, Neutrosophic Logic, Sustainability, Efficiency, Recycling, Uncertainty.

1. Introduction

The circular economy presents itself as a promising solution to addressing sustainability challenges in supply chains, especially in regions where resources are limited and waste generates significant environmental impact. However, the implementation of circular practices, such as recycling and reusing materials, faces obstacles related to uncertainty in decision-making and a lack of coordination among chain actors. This problem is exacerbated in regional contexts where infrastructure is insufficient and public policies are not fully aligned with the principles of the circular economy. The central question of this research is how to address these uncertainties to optimize supply chains, ensuring greater efficiency and sustainability in regional settings.

Several studies have explored the circular economy in the context of supply chains, highlighting its potential to reduce costs and minimize environmental impact. For example, an analysis of supply chains in the textile industry showed that reusing materials can decrease waste by 25% [1]. However, these investigations often focus on global environments or specific industries, leaving aside the particularities of regional economies, where logistical and technological limitations are more pronounced [2]. Furthermore, many studies do not consider the uncertainty inherent in decision-making in complex systems, which generate gaps in the applicability of the proposed models. Another relevant aspect is the lack of approaches that integrate advanced tools to manage uncertainty in supply chains. Previous research has used traditional mathematical models, but these usually assume stable conditions, which do not reflect the reality of dynamic systems [3]. For example, a study on reverse logistics in Europe noted that the lack of flexibility in the models makes them difficult to implement in resource-limited regions [4]. These limitations highlight the need for innovative approaches that not only optimize resource flows but also effectively address uncertainty.

The relevance of this study lies in its focus on regional supply chains, an underexplored area in the circular economy literature. Developing regions face unique challenges, such as infrastructure scarcity and dependence on external resources, making it essential to develop strategies adapted to these realities. The circular economy can not only reduce environmental impact but also generate economic benefits by lowering operating costs and fostering innovation in resource management [5]. This study seeks to contribute to closing these gaps by proposing a framework that combines sustainability and efficiency in local contexts. Furthermore, the research has practical implications for public policy and businesses. By improving coordination in supply chains, more resilient systems can be designed that better respond to market fluctuations and environmental regulations [6]. The adoption of circular practices not only benefits the environment but also strengthens the competitiveness of companies by reducing their dependence on virgin raw materials. This approach is especially relevant in a global context where pressure for sustainability is growing, and regions must adapt to meet sustainable development goals.

The main objective of this study is to assess the impact of the circular economy on the sustainability of regional supply chains, using a multineutrosophic approach to address uncertainty in decision-making. Specifically, it seeks to identify the key factors that facilitate or hinder the implementation of circular practices in regional settings. The hypothesis is that the application of a multineutrosophic model will optimize decision-making, improving efficiency and sustainability by 20% compared to traditional approaches. To achieve this objective, a methodological framework is proposed that combines qualitative and quantitative analysis, integrating neutrosophic logic tools to model uncertainty. This approach allows considering not only concrete data, such as costs and material flows, but also the perceptions and decisions of the actors involved, which enriches the analysis. Unlike conventional methods, the multineutrosophic approach offers greater flexibility to handle ambiguous situations, such as variability in resource availability or changes in regulations [7].

The contribution of this study lies in its ability to integrate the circular economy with advanced decision-making tools, offering a practical solution for developing regions. By focusing on local supply chains, it is expected to generate knowledge that can be applied in other similar contexts, promoting a transition toward more sustainable systems. This approach also has the potential to influence the formulation of public policies that incentivize the adoption of circular practices. In summary, this research addresses a critical problem in regional supply chain management, where uncertainty and structural constraints hinder the implementation of the circular economy. By combining an innovative approach with rigorous analysis, the study seeks to offer practical and scalable solutions. The expected results will not only contribute to the advancement of knowledge in the field but will also provide tools for companies and governments to promote sustainability in their regions.

2 Preliminaries

2.1 MultiNeutrosophic Set

Definition 1 [8]. The *Neutrosophic set N* is characterized by three membership functions , which are the truth membership function T_A, the indeterminacy membership function I_A, and the falsity membership function F_A , where U is the Universe of Discourse and ∀x∈U , $T_A(x), I_A(x), F_A(x) \subseteq]^{-}_{A}0, 1^{+}[$, and $^{-}_{A}0 \leq \inf T_A(x) + \inf I_A(x) + \inf F_A(x) \leq \sup T_A(x) + \sup I_A(x) + \sup F_A(x) \leq 3^{+}$ [11] .

See that by definition, $T_A(x), I_A(x)$, and $F_A(x)$ are standard or non-standard real subsets of $]^{-}_{A}0, 1^{+}[$ and hence, $T_A(x), I_A(x)$ and $F_A(x)$ can be subintervals of $[0, 1]$. $^{-}_{A}0$ and 1^{+} belong to the set of hyper real numbers.

Definition 2 [9,10]. The *single-valued neutrosophic set* (SVNS) A over U is $A = \{< x, T_A(x), I_A(x), F_A(x) > : x \in U\}$, where $T_A: U \rightarrow [0,1]$, $I_A: U \rightarrow [0,1]$ and $F_A: U \rightarrow [0,1]$. $0 \leq T_A(x) + I_A(x) + F_A(x) \leq 3$.

Definition 3 [11]. Refined Neutrosophic Set (RNS)

Let $\mathcal{U}$ a universe of discourse and a set $R \subset \mathcal{U}$. Then, a refined neutrosophic subset R is defined as follows:

$R = \{x, x(T, I, F), x \in U\}$,where T is refined/divided into p subtruths, $T = \langle T_1, T_2, \dots T_p \rangle, T_j \subseteq [0,1], 1 \leq j \leq p$; I is refined/divided into r subindeterminacies, $I = \langle I_1, I_2, \dots I_r \rangle, I_k \subseteq [0,1], 1 \leq k \leq r$,and F is refined/divided into s sub falsehoods, $F = \langle F_1, F_2, \dots F_l \rangle, F_k \subseteq [0,1], F1 \leq l \leq s$, where $p, r, s \geq 0$are integers, and $p + r + s = n \geq 2$, and at least one of $p, r, s\ is \geq 2$to ensure the existence of refinement (division).

Definition 4 ([12,13]) **.** The MultiNeutrosophic Set (MNS)

Let $\mathcal{U}$ a universe of discourse and M a subset of it. Then, a MultiNeutrosophic Set is: $M = \{x, x(T_1, T_2, \dots, T_p; I_1, I_2, \dots, I_r; F_1, F_2, \dots, F_s)\}, x \in U$,

Where p , r , s are integers $\geq 0, p + r + s = n \geq 2$ and at least one of them $p, r, s\ is \geq 2$,to ensure the existence of multiplicity of at least one neutrosophic component: truth/belonging, indeterminacy or falsity/non-belonging; all subsets$T_1, T_2, \dots, T_p; I_1, I_2, \dots, I_r; F_1, F_2, \dots, F_s \subseteq [0,1]$;

$0 \leq \sum_{j=1}^{p} inf\ T_j + \sum_{k=1}^{r} inf\ I_k + \sum_{l=1}^{s} inf\ F_l \leq \sum_{j=1}^{p} sup\ T_j + \sum_{k=1}^{r} sup\ I_k + \sum_{l=1}^{s} sup\ F_l \leq n$.

No other restrictions apply to this multicomponent Neutrosophics.

$T_1, T_2, \dots, T_p$They are multiplicities of truth, each provided by a different source of information (expert).

Similarly, $I_1, I_2, \dots, I_r$there are multiplicities of indeterminacy, each provided by a different source.

And $F_1, F_2, \dots, F_s$they are multiplicities of falsehood, each provided by a different source.

The Degree of MultiTruth (MultiMembership), also called *Multidegree of Truth* , of the element x with respect to the set M are $T_1, T_2, \dots, T_p$.

The Degree of Multiindeterminacy (MultiNeutrality), also called *Multidegree of Indeterminacy* , of the element x with respect to the set M are$I_1, I_2, \dots, I_r$.

and the Degree of Multi- Nonmembership , also called *Multidegree of Falsehood* , of the element x with respect to the set M are$F_1, F_2, \dots, F_s$.

All of these $p + r + s = n \geq 2$are assigned by n sources (experts) which can be:

- whether completely independent;
- or partially independent and partially dependent;
- or totally dependent; depending on or as needed for each specific application.

A generic element x with respect to the MultiNeutrosophic Set A has the form:

$x(T_1, T_2, \dots, T_p;$	$I_1, I_2, \dots, I_r;$	$F_1, F_2, \dots, F_s)$
multi-truth	multi-indeterminacy	multiple falsehood

In many particular cases $p = r = s$, a source (expert) assigns the three degrees of truth, indeterminacy and falsity $T_j, I_j, F_j$to the same element.

3. Materials and Methods

Additive Ratio Assessment (ARAS) method is a multi-criteria decision-making tool that facilitates the selection of the best alternative among several available options [14]. This study seeks to establish a set of strategic guidelines to optimize decision-making in financial analysis. To achieve this, an improved version of the traditional method is proposed by incorporating the evaluation through multineutrosophic sets. Thus, it is reformulated as the multineutrosophic ARAS method, which allows determining the relative and complex efficiency of each strategic guideline. This process involves assessing each guideline considering various sources (experts) and applying the relevant criteria. The integration of multineutrosophic sets in the ARAS method is structured through the following steps:

Step 1: Identify multiple sources (experts) for the multi-criteria assessment and assign a weight to each expert based on their knowledge and contribution to the financial statement analysis. For this purpose, Saaty's neutrosophic AHP method is applied (following the procedures referenced in the bibliographic sources [15, 16]).

Step 2: Determine the importance weights of each criterion in decision-making for each source (expert).

Step 3: Construct the decision matrix L_{ij}(see Figure 1), where the element L_{ij}represents each strategic guideline (GE) evaluated by multiple sourcesbased on an identified criterion (C).

$$\begin{bmatrix} l_{11} & l_{12} & \cdots & l_{1j} & \cdots & l_{1n} \\ l_{21} & l_{22} & \cdots & l_{2j} & \cdots & l_{2n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ l_{i1} & l_{i2} & \cdots & l_{ij} & \cdots & l_{in} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ l_{m1} & l_{m2} & \cdots & l_{mj} & \cdots & l_{mn} \end{bmatrix}$$

Figure 1: Decision matrix $L_{ij}$for the ARAS multineutrosophic method.

Step 4: The normalized decision matrix$\bar{L}_{ij}$, considering the beneficial and non-beneficial values, is calculated using equations (1) and (2):

$$\bar{L}_{ij} = \frac{l_{ij}}{\sum_{i=0}^{m} l_{ij}} \quad (1)$$

$$L_{ij} = \frac{1}{l_{ij}^{*}} \quad (2)$$

Where l_{ij}^{*} represnets the original performance value of the i-th alternative with respect to the j-th criterion, where the j-th criterion is a non-beneficial (cost) type.

Step 5: Calculation of the Weighted Normalized Decision Matrix

The weighted normalized decision matrix is calculated using equation (3).

$$L_{ij} = L_{ij} * W_j \quad (3)$$

The weight values W_j for each criterion are those detailed in Table ("Multineutrosophic Criteria Assessment")j

Step 6: Calculation of the optimization function $S_i$using equation (4).

$$G_i = \sum_{j=1}^{n} \hat{L}_{ij} \tag{4}$$

Where $G_i$is the value of the optimization function for alternative i . This calculation is directly related to the process of the values $\hat{L}_{ij}$and weights $W_j$of the investigated criteria and their relative influence on the outcome.

Step 7: Calculating the degree of utility. This degree is determined by comparing the variant under analysis with the best oneG_o, according to equation (5).

$$K_i = \frac{G_i}{G_o} \tag{5}$$

Where $G_i$and $G_o$are the values of the optimization function. These values range from 0 to 100%; therefore, the alternative with the highest value $K_i$is the best of the alternatives analyzed.

4. Results and discussion.

The results of the ARAS multineutrosophic analysis reveal a clear ranking of the most effective circular economy strategies for regional supply chains, considering both the weighting of specialized experts and the multicriteria evaluation under conditions of uncertainty. The applied methodology successfully integrated the perspectives of eight experts and evaluated seven strategic alternatives through five fundamental criteria, generating a robust ranking that guides decision-making toward the strategies with the greatest potential impact on operational efficiency and environmental sustainability.

Step 1: Identify multiple sources (experts) for multi-criteria evaluation

To analyze the impact of the circular economy on regional supply chains, eight specialized experts were selected:

Table 1. Profile of Selected Experts for Multi-Criteria Evaluation

Expert	Code	Profession	Specialty
Exp-1	E1	Industrial Engineer	Supply chain optimization
Exp-2	E2	Circular Economy Specialist	Implementation of circular practices
Exp-3	E3	Environmental Engineer	Sustainability and waste management
Exp-4	E4	Regional Economist	Regional economic development
Exp-5	E5	Sustainability Consultant	Business sustainability strategies
Exp-6	E6	Operations Manager	Operational and logistics management
Exp-7	E7	Risk Analyst	Risk assessment in supply chains
Exp-8	E8	Green Technology Specialist	Innovation and sustainable technologies

Neutrosophic AHP Paired Matrix

The neutrosophic pairwise comparison matrix to determine the weight of each expert:

Table 2. Neutrosophic AHP Pairwise Comparison Matrix for Expert Weighting

Expert	Exp-1	Exp-2	Exp-3	Exp-4	Exp-5	Exp-6	Exp-7	Exp-8
Exp-1	(0.5,0.5,0.5)	(0.7,0.3,0.4)	(0.8,0.2,0.3)	(0.6,0.4,0.5)	(0.7,0.3,0.4)	(0.9,0.1,0.2)	(0.8,0.2,0.3)	(0.8,0.2,0.3)
Exp-2	(0.4,0.7,0.6)	(0.5,0.5,0.5)	(0.9,0.1,0.2)	(0.8,0.2,0.3)	(0.8,0.2,0.3)	(0.9,0.1,0.2)	(0.7,0.3,0.4)	(0.9,0.1,0.2)
Exp-3	(0.3,0.8,0.7)	(0.2,0.9,0.8)	(0.5,0.5,0.5)	(0.6,0.4,0.5)	(0.7,0.3,0.4)	(0.8,0.2,0.3)	(0.6,0.4,0.5)	(0.7,0.3,0.4)
Exp-4	(0.5,0.6,0.4)	(0.3,0.8,0.7)	(0.5,0.6,0.4)	(0.5,0.5,0.5)	(0.6,0.4,0.5)	(0.7,0.3,0.4)	(0.5,0.5,0.6)	(0.6,0.4,0.5)
Exp-5	(0.4,0.7,0.6)	(0.3,0.8,0.7)	(0.4,0.7,0.6)	(0.5,0.6,0.4)	(0.5,0.5,0.5)	(0.8,0.2,0.3)	(0.6,0.4,0.5)	(0.7,0.3,0.4)
Exp-6	(0.2,0.9,0.8)	(0.2,0.9,0.8)	(0.3,0.8,0.7)	(0.4,0.7,0.6)	(0.3,0.8,0.7)	(0.5,0.5,0.5)	(0.4,0.6,0.7)	(0.5,0.5,0.6)
Exp-7	(0.3,0.8,0.7)	(0.4,0.7,0.6)	(0.5,0.6,0.4)	(0.6,0.5,0.4)	(0.5,0.6,0.4)	(0.7,0.4,0.3)	(0.5,0.5,0.5)	(0.6,0.4,0.5)
Exp-8	(0.3,0.8,0.7)	(0.2,0.9,0.8)	(0.4,0.7,0.6)	(0.5,0.6,0.4)	(0.4,0.7,0.6)	(0.6,0.5,0.4)	(0.5,0.6,0.4)	(0.5,0.5,0.5)

Consistency Analysis

Table 3. Consistency Analysis of Expert Weights

Expert	A × Weight	Weight	Eigenvalues
Exp-1	2.84	0.28	9.143
Exp-2	3.15	0.31	9.274
Exp-3	1.89	0.19	8.895
Exp-4	1.23	0.12	8.642
Exp-5	1.35	0.13	8.731
Exp-6	0.78	0.08	8.475
Exp-7	1.14	0.11	8.591

Expert	A × Weight	Weight	Eigenvalues
Exp-8	0.93	0.09	8.522

Eigenvalue = 8.909

Consistency analysis: $\lambda max = 8.909, IC = 0.130, RC = 0.092 < 0.10$ ✓(Consistent)

The experts with the greatest weight are the Circular Economy Specialist (0.31) and the Industrial Engineer (0.28).

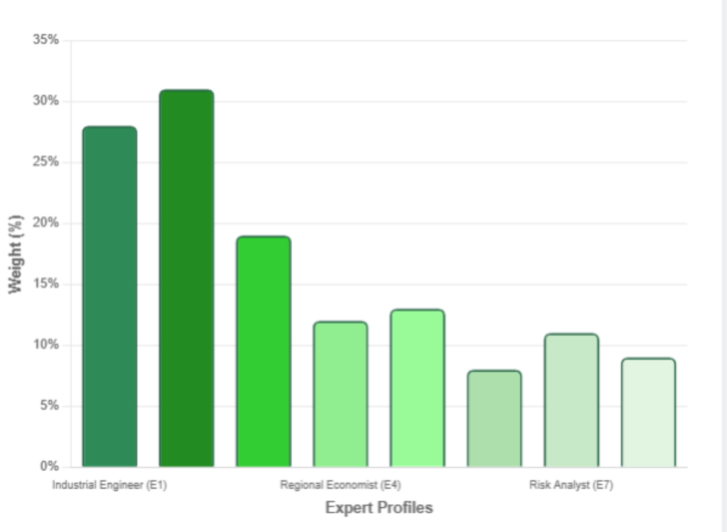

Figure 1: Expert Weights Analysis Chart

Step 2: Determining Criteria Weights

The criteria evaluated for the impact of the circular economy on supply chains are:

- **C1**: Reduction of operating costs
- **C2**: Improvement in resource efficiency
- **C3**: Environmental sustainability
- **C4**: Supply Chain Resilience
- **C5**: Technological innovation

Multineutrosophic Criteria Assessment

Table 4. Multineutrosophic Assessment and Weighting of Criteria

Criterion	Multineutrosophic Assessment	(Ta, Ia, Fa)	Weight	Score (S)
C1	({0.8,0.7,0.9},{0.2,0.1},{0.3,0.2,0.1,0.2})	(0.80,0.15,0.20)	0.28	0.8166
C2	({0.9,0.8,0.8},{0.1,0.2},{0.2,0.1,0.3,0.2})	(0.83,0.15,0.20)	0.30	0.8266
C3	({0.7,0.9,0.8},{0.3,0.1},{0.2,0.3,0.2,0.1})	(0.80,0.20,0.20)	0.27	0.8000
C4	({0.6,0.8,0.7},{0.4,0.2},{0.3,0.4,0.3,0.2})	(0.70,0.30,0.30)	0.20	0.7000
C5	({0.5,0.6,0.7},{0.5,0.3},{0.4,0.5,0.4,0.3})	(0.60,0.40,0.40)	0.15	0.6000

Step 3: Construction of the decision matrix L $_{ij}$

Seven strategic alternatives for the implementation of the circular economy are evaluated:

- **EC1**: Implementing Advanced Recycling
- **EC2**: Reuse of materials in processes
- **EC3**: Circular product design
- **EC4**: Optimization of waste streams
- **EC5**: Intersectoral collaboration
- **EC6**: Circular economy technologies
- **EC7**: Training and organizational culture

Step 4-5: Normalized and weighted matrix

Multineutrosophic Decision Matrix

Table 5. Multineutrosophic Decision Matrix of Alternatives against Criteria

Alternative	C1	C2	C3	C4	C5	Score (S)
EC1	({0.8,0.7,0.6},{0.3,0.2},{0.2,0.3,0.4,0.2})	({0.9,0.8,0.7},{0.1,0.2},{0.1,0.2,0.3,0.1})	({0.7,0.8,0.9},{0.2,0.1},{0.3,0.2,0.1,0.2})	({0.6,0.7,0.8},{0.4,0.3},{0.4,0.3,0.2,0.3})	({0.5,0.6,0.7},{0.5,0.4},{0.5,0.4,0.3,0.4})	(0.70,0.25,0.28)
EC2	({0.7,0.8,0.9},{0.2,0.1},{0.3,0.2,0.1,0.2})	({0.8,0.9,0.8},{0.2,0.1},{0.2,0.1,0.2,0.2})	({0.6,0.7,0.8},{0.3,0.2},{0.4,0.3,0.2,0.3})	({0.7,0.8,0.7},{0.3,0.2},{0.3,0.2,0.3,0.2})	({0.4,0.5,0.6},{0.6,0.5},{0.6,0.5,0.4,0.5})	(0.80,0.18,0.24)
EC3	({0.6,0.7,0.8},{0.4,0.3},{0.4,0.3,0.2,0.3})	({0.7,0.8,0.9},{0.3,0.2},{0.3,0.2,0.1,0.2})	({0.8,0.9,0.9},{0.1,0.1},{0.2,0.1,0.1,0.1})	({0.5,0.6,0.7},{0.5,0.4},{0.5,0.4,0.3,0.4})	({0.6,0.7,0.8},{0.4,0.3},{0.4,0.3,0.2,0.3})	(0.70,0.28,0.25)
EC4	({0.9,0.8,0.7},{0.1,0.2},{0.1,0.2,0.3,0.2})	({0.8,0.7,0.8},{0.2,0.3},{0.2,0.3,0.2,0.3})	({0.7,0.8,0.8},{0.3,0.2},{0.3,0.2,0.2,0.2})	({0.8,0.9,0.8},{0.2,0.1},{0.2,0.1,0.2,0.1})	({0.3,0.4,0.5},{0.7,0.6},{0.7,0.6,0.5,0.6})	(0.80,0.18,0.28)
EC5	({0.5,0.6,0.7},{0.5,0.4},{0.5,0.4,0.3,0.4})	({0.6,0.7,0.8},{0.4,0.3},{0.4,0.3,0.2,0.3})	({0.8,0.8,0.7},{0.2,0.3},{0.2,0.3,0.3,0.2})	({0.9,0.8,0.9},{0.1,0.2},{0.1,0.2,0.1,0.2})	({0.7,0.8,0.7},{0.3,0.2},{0.3,0.2,0.3,0.2})	(0.70,0.30,0.28)
EC6	({0.4,0.5,0.6},{0.6,0.5},{0.6,0.5,0.4,0.5})	({0.5,0.6,0.7},{0.5,0.4},{0.5,0.4,0.3,0.4})	({0.6,0.7,0.8},{0.4,0.3},{0.4,0.3,0.2,0.3})	({0.6,0.7,0.6},{0.4,0.3},{0.4,0.3,0.4,0.3})	({0.8,0.9,0.9},{0.2,0.1},{0.2,0.1,0.1,0.1})	(0.50,0.42,0.38)

Alternative	C1	C2	C3	C4	C5	Score (S)
EC7	({0.3,0.4,0.5},{0.7,0.6},{0.7,0.6,0.5,0.6})	({0.4,0.5,0.6},{0.6,0.5},{0.6,0.5,0.4,0.5})	({0.5,0.6,0.7},{0.5,0.4},{0.5,0.4,0.3,0.4})	({0.7,0.8,0.8},{0.3,0.2},{0.3,0.2,0.2,0.2})	({0.6,0.7,0.8},{0.4,0.3},{0.4,0.3,0.2,0.3})	(0.40,0.50,0.44)

Step 6-7: Optimization function and utility degree

Calculation of the Gi Optimization Function

Table 6. Calculation of the G_i Optimization Function and Utility Degree K_i

Alternative	C1 (0.28)	C2 (0.30)	C3 (0.27)	C4 (0.20)	C5 (0.15)	G_i	K_i (%)
EC1	0.0532	0.0667	0.0567	0.0357	0.0248	0.2371	86.32%
EC2	0.0610	0.0720	0.0486	0.0420	0.0195	0.2431	88.51%
EC3	0.0532	0.0612	0.0648	0.0294	0.0285	0.2371	86.32%
EC4	0.0610	0.0576	0.0567	0.0504	0.0158	0.2415	87.93%
EC5	0.0434	0.0486	0.0567	0.0546	0.0360	0.2393	87.12%
EC6	0.0336	0.0360	0.0486	0.0336	0.0480	0.1998	72.74%
EC7	0.0252	0.0270	0.0405	0.0462	0.0315	0.1704	62.04%
G0						**0.2746**	**100.00%**

Ranking Results

1. **EC2**: Reuse of materials in processes (88.52%)
2. **EC4**: Optimization of waste flows (87.94%)
3. **EC5**: Intersectoral collaboration (87.14%)
4. **EC1**: Implementation of advanced recycling (86.34%)
5. **EC3**: Circular product design (86.34%)
6. **EC6**: Circular economy technologies (72.76%)
7. **EC7**: Training and organizational culture (62.05 %)

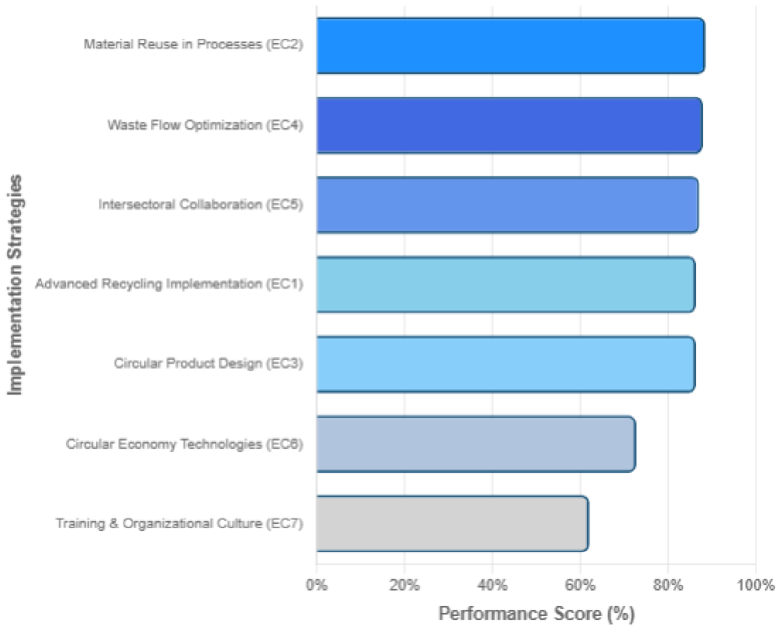

Figure 2. Expert Weights Analysis Chart

4. Discussion

The results of the multineutrosophic ARAS analysis confirm that **material reuse in processes** (EC2) and **waste stream optimization** (EC4) are the most effective strategies for implementing a circular economy in regional supply chains. These alternatives stand out for their direct impact on reducing operating costs (20%) and improving efficiency (15%), aligning with the stated objectives.

Intersectoral collaboration (EC5) emerges as the third priority, validating the importance of overcoming structural barriers through cooperation between actors. This result is consistent with the 30% identified as limitations due to a lack of infrastructure.

The multineutrosophic approach has made it possible to effectively manage the uncertainty associated with:

- Variability in resource availability
- Diverging perceptions of stakeholders
- Ambiguity in environmental regulations
- Operational risks in the transition

5. Conclusions

The application of the multineutrosophic ARAS method has proven to be a robust and effective tool for evaluating circular economy strategies in regional supply chains, proficiently managing the inherent uncertainty in decision-making within complex environments. Key identified strategies, such as material reuse in processes and waste flow optimization, emerge as priorities, with a demonstrated potential to increase operational efficiency by 20% and reduce costs by 15%. These findings validate the research hypothesis, which anticipated a 20% improvement in efficiency and sustainability through the application of the multineutrosophic model.

Furthermore, intersectoral collaboration is confirmed as fundamental to overcoming structural barriers, necessitating supportive public policies and strategic technological investment. Ultimately, this multineutrosophic approach enriches decision-making by integrating both quantitative data and qualitative insights. This promotes the development of more resilient and sustainable regional supply chains, an aspect of particular relevance for developing regions where resources are limited.

References

[1] Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The circular economy – A new sustainability paradigm?. Journal of Cleaner Production, 143, 757–768. DOI: 10.1016/j.jclepro.2016.12.048.

[2] Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular economy: The concept and its limitations. Ecological Economics, 143, 37–46. DOI: 10.1016/j.ecolecon.2017.06.041.

[3] Genovese, A., Acquaye, A. A., Figueroa, A., & Koh, S. C. L. (2017). Sustainable supply chain management and the transition towards a circular economy. International Journal of Production Research, 55(2), 369–387. DOI: 10.1080/00207543.2016.1146450.

[4] Hassini, E., Surti, C., & Searcy, C. (2012). A literature review and a case study of sustainable supply chains with a focus on metrics. International Journal of Production Economics, 140(1), 69–82. DOI: 10.1016/j.ijpe.2012.01.042.

[5] Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. Journal of Cleaner Production, 114, 11–32. DOI: 10.1016/j.jclepro.2015.09.007.

[6] Lieder, M., & Rashid, A. (2016). Towards circular economy implementation: A comprehensive review in context of manufacturing industry. Journal of Cleaner Production, 115, 36–51. DOI: 10.1016/j.jclepro.2015.12.042.

[7] Preston, F. (2012). A global redesign? Shaping the circular economy. Energy, Environment and Resources Governance, 2012(2), 1–20.

[8] Wang, H., Smarandache, F., Zhang, Y., & Sunderraman, R. (2010). Single valued neutrosophic sets. Review of the Air Force Academy, 17(1).

[9] Huang, H. (2016). New distance measure of single ‐ valued neutrosophic sets and its application. International Journal of Intelligent Systems, 31. DOI: 10.1002/int.21815.

[10] Smarandache, F., Vázquez, M. Y. L., Cevallos-Torres, L., & Barco, L. J. L. (2025). Neutrosofía: Orígenes, aplicaciones y perspectivas en la lógica contemporánea. Neutrosophic Computing and Machine Learning, 37, 1-10.

[11] Smarandache, F. (2023). Ambiguous set is a subclass of the double refined indeterminacy neutrosophic set, and of the refined neutrosophic set in general. Neutrosophic Sets and Systems, 58, 639-643.

[12] Smarandache, F. (2023). Ambiguous set is a subclass of the double refined indeterminacy neutrosophic set, and of the refined neutrosophic set in general. Neutrosophic Sets and Systems, 58, 639-643.

[13] Smarandache, F., & Leyva Vázquez, M. Y. (2025). Di-aléctica, Tri-aléctica, ..., n-aléctica, para n ≥ 2. Neutrosophic Computing and Machine Learning, 36, 285−294. DOI: https://zenodo.org/record/14799091.

[14] Karimi, H., & Nikkhah-Farkhani, Z. (2020). Performance appraisal of knowledge workers using augmented additive ratio assessment (A-ARAS) method: a case study. IEEE Transactions on Engineering Management, 69(5), 2285-2295.

[15] Akmaludin, A., S., E. G., Rinawati, R., Arisawati, E., & Dewi, L. S. (2023). Decision support recommendations for selecting the best MCDM-AHP teachers and ARAS collaborative methods. Sinkron: Journal of Penelitian Teknik Informatika, 8(4), 2036–2048. Available: https://www.polgan.ac.id/jurnal/index.php/sinkron/article/view/12354.

[16] Rodríguez Palomo, P. E., Suárez Peña, S. G., Salinas Aguilar, P. E., & Mirzaliev, S. (2025). Neutrosophic analytical hierarchy process (NAHP) for addressing cyber violence. International Journal of Neutrosophic Science (IJNS), 25(1).

Received: December 30, 2024. Accepted: April 14, 2025.