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Green Accounting And Finance In Agriculture Using Neutrosophic Numbers: A Theoretical Analysis And Entrepreneurial Perspective

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Abstract
This research paper provides a conceptual analysis on the applications of neutrosophic numbers in enhancing green accounting methods in the agricultural economics domain. Tackling the very uncertainties related to the environment by applying the model of neutrosophic numbers, this paper attempts to establish sustainability indicators by embracing environmental costs in the conventional financial analysis. The paper contains a comprehensive review of the related literature, mathematical expressions, and proper discussion on the advancements in the realm of theory, but intentionally excluding the applications in practice in the form of empirical case studies. The target audience includes skilled mathematicians andenvironmental economists with a sound background in mathematical modeling.
Keywords: *Neutrosophic Sets, Green Accounting, Green Finance, Agriculture, Entrepreneurship*

INTRODUCTION

Inclusion of the environment in economic analysis has attained central significance for the effective evaluation of various agricultural practices, especially in respect to their complex implications on the environment. The developing paradigm of green accounting and finance provides a cohesive and complete approach that successfully combines broad categories of environment expenditure(s), thereby formulating the harmful effects on ecosystem(s) and loss of natural resources with the negative influences of pollution and wider sustainability implications in association with these costs in the conventional financial evaluation frameworks and methods. Notwithstanding significant progress over the past decades in the implementation of green accounting approaches in agricultural practices, provided by the United Nations in 1993 and 2000 published reports in evidence, there still linger critical concerns in respect to the quality and accessibility of relevant environment data, which act as barriers in the effective implementation of the approaches. Neutrosophic analysis development has endeavored in a structured manner the methodological redressal of these potential concerns by eliminating the existing disparity and ambiguity in the environment data. Developed as a modern and potentially effective tool in the realm of mathematics, the instrument has been created with secured promising prospects for the effective augmentation of the decision-making procedure in agriculture and many other fields (Smarandache, 2014; Lomas & Giampietro, 2017). The latest analytical tool possesses great promise in rendering effective reliability and efficacy in the evaluation of environment data whose success was attained in the form of the integration of the environment consideration towards the economic evaluation(s), thereby fostering more sustainable agricultural practices (Jdid et al., 2022; Kamran et al., 2023; Sarkar and Srivastava, 2024; Abdulbaqi et al., 2025).

The main objectives of the current research are;

a) Evidently show and explain the mathematical structure and the various abstract ideas related with neutrosophic numbers;

b) Carrying out a critical analysis and investigation on the ways in which the above innovative formulations can be incorporated into the various green accounting and financial practices utilized by the agricultural industry; and

c) Present and explain various hypotheses on the prospect for greater reliability and added robustness in environmental evaluation through the integration of neutrosophic numbers in the analytical model.

Hypotheses examined herein include;

- H1: The incorporation of neutrosophic numbers into green accounting and financial models significantly reduces uncertainty in the valuation of environmental costs; and
- H2: A neutrosophic approach produces composite sustainability indices which more accurately portray the complex interactions between the environment and economic aspects in agricultural systems.

Readers are typically said to have a complete and adequate background in the complex area of mathematical modeling and the subtle area of environmental economics. Such background knowledge serves readers in gaining a proper depth of understanding in the complex technical aspects covered by this extensive analysis. Such knowledge is critical in handling the sensitive discourses and technical analyses forming the content of this research study, hence facilitating a discernment of the basic notions behind the complex ideas covered (Cevikbas et al., 2022; Kapur, 2023; Mainardi, 2022; Bynum et al., 2021).

Green Accounting and Finance in Agriculture

Traditional accounting and financial approaches frequently inadequately address the current concerns surrounding the deterioration in the integrity of the environment and the loss of valuable natural resources needed for the sustenance of life. Such critical shortfall translates into unsatisfactory strategies regarding the sustainability of crop production, where the data gathered in isolation generate limited inputs toward gaining a clear picture of both the state of our ecosystems and the crop production systems. On this background, green accounting reveals a critical and effective remedy for the stated concerns in the form of adopting approaches with strict observance over guidelines such as the System of Integrated Environmental and Economic Accounting (SEEA). The expanded framework allows the incorporation of the most crucial environment factors and considerations within economic analysis and reporting (Dhar et al., 2022; Gonzalez and Peña-Vinces, 2023; Tregidga & Laine, 2022; Saputra et al., 2021; Asiaei et al., 2022).

Participation in this effort ensures the evaluation process is both inclusive and interdisciplinary since it accounts for various environments' effects (United Nations, 1993; United Nations, 2000). Such complex frameworks call for a redefinition of traditional gross domestic product (GDP) indicators in the deliberate inclusion of the frequently neglected and hidden costs inherently related to the environment's degradation and damage. Accordingly, these crucial additions provide a more accurate, balanced, and reliable estimate of sustainable economic progress critical in the protection of the future economic viability. Such potential creates a platform for various players in different realms—governmental institutions, business entities, and civil society groups—to make developmental choices by considering both economic viability and the environment's sustainability (Chi & Rauch, 2010; Liu et al., 2025; Yang & Zhan, 2024; Stjepanovic et al., 2022; Wang & Chen, 2022).

By recognizing the interrelatedness of these elements, green accounting and finance essentially seeks the adoption of a holistic approach towards measuring economic activity and the resultant environmental impacts and hence improving longer-run planning and resource allocation approaches. Such a method is particularly relevant in a time where concerns over the environment are continually rising in prominence and complexity and hence the imperative towards sustainable development on a regular basis. The integration of the principles of green accounting into existing financial systems has the potential to revolutionize both our judgments regarding economic progress and the congruence between the former and the ecological well-being of our world and the well-being of coming generations. Lastly, green accounting provides a template for people and institutions dedicated toward the vision of a common and sustainable economic future, where sufficient consideration towards both the needs of people and the environment is ensured (Scarpellini2022; Gunarathne et al., 2023; Rahman & Islam, 2023; Zik-Rullahi and Jide, 2023).

Underlying the basic principles within green accounting and finance lies a central assumption that economic development, in all its expressions, should ideally take place within the overriding imperative of protecting the environment, crucial to the viability of future generations. Within this critical contextualization, agricultural activities are evaluated not only on narrow monetary results and profitability—a consideration in itself—but through consideration too of the wider and systemic implications for natural capital stocks and the environment critical to all terrestrial life forms. Such expanded evaluative exercise is critical in developing informed policy and encouraging sustainable management of the environment, featuring resilience as set out in United Nations (2023a; 2023b) briefing papers. Through the incorporation within our evaluation instruments of these crucial considerations, we gain a complete appreciation and foster a more adaptable and cohesive appreciation of the complex interrelationships between economic activity and the planetary ecological integrity in full, and thereby sanction practices both economically and environmentally sustainable and exemplify a balanced coexistence between development and conservation.Neutrosophic Analysis in Environmental Economics (Hariram et al., 2023; Ahmed et al., 2022; Raihan et al., 2022; Murshed et al., 2021; Peydayesh & Mezzenga, 2021).

Neutrosophic analysis provides a robust mathematical framework to tackle the uncertainties intrinsic in ecological data. Unlike classical probabilistic tools, neutrosophic numbers are designed to represent and manipulate imprecise, indeterminate, and inconsistent information. A neutrosophic number is conventionally expressed as $N = (T, I, F)$, where T signifies the degree of truth, I represents the degree of indeterminacy, and F symbolizes the degree of falsity (Smarandache, 2014).

In the context of green accounting, these numbers underpin the quantification of environmental costs by accommodating the vagueness inherent in ecological valuations. By extending the mathematical formulation of sustainability metrics through neutrosophic numbers, this approach offers an innovative pathway to obtain composite indices that account for multiple dimensions of uncertainty (Lomas & Giampietro, 2017).

Mathematical Formulation

To adequately and successfully develop a mathematical model from the many uncertainties involved in the green accounting methods, we suggest the employment of neutrosophic numbers in the conceptual framework within our sustainability metrics assessment. Let us consider a neutrosophic number as $N = (T, I, F)$, where the constituent elements are defined and explained as follows: (Nafei et al., 2024; Hezam et al.2023; Abu et al., 2025; Delcea et al., 2023).

Let T be the element within the interval [0, 1] representing the degree to which a given assertion, such as the quantification of the environment costs, is considered true in the universal set; let I, within [0, 1] as well, represent the degree of indeterminacy or uncertainty existing; and let F similarly range within the constraint of [0, 1] represent the degree up to which the assertion can possibly be false. The sum $T + I + F$ is commonly examined under the condition that $T + I + F$ does not surpass

3. Moreover, in special contexts and cases, the above relationship may even be represented within the normalized form where T + I + F will equal 1. Normalization seeks the form for the development of a unified structure in the evaluation regarding interconnections existing between the above degrees of truth, indeterminacy, and falsehood.

In addition, given the presence of various uncertainties related to an environment-economics indicator E, it is possible to represent E as a function involving various neutrosophic parameters acting on this environment setting:

$$E = f(N_e) = f((T_e, I_e, F_e))$$

N_e signifies the neutrosophic value in the realm related to the environmental dimension in E. In other words, in analyzing the overall costs associated with the destruction or loss of ecosystems, T_e is utilized in representing the extent of observable ecological harm measured and catalogued before. Such harm has critical implications on biodiversity and the strength of ecosystems. On the other hand, I_e captures the existing ambiguity within the indicators utilized in the analysis related to the environment dimensions, hence outlining the extent of complexity in balancing ecological data. Lastly, F_e refers to the recognized miscalculation or overestimate in the analysis process, hence distorting the actual consequences emanating from the changes in the environment. Understanding the above elements forms the basic foundation in conducting a proper analysis of ecosystems and their deterioration (Smarandache et al., 2024; Delcea et al., 2023; Wang & Zhao, 2024; Gharib et al., 2024).

Composite Sustainability Index Formulation

We will consider a composite sustainability index, represented by S, where both the economic and the environmental dimensions are combined in a coherent and complementary way. More particularly, we will set out the composite sustainability index in the subsequent form: (Elavarasan et al., 2022; Yin & Xu, 2022; Rigamonti and Mancini, 2021).

$$S = \alpha E_e + \beta E_c$$

Correspondingly, the economic index E_e has been formulated through the right neutrosophic evaluation, whereas E_c symbolizes the traditional economic estimate. Also, the values α and β act as the weighting elements that meet the condition $\alpha + \beta = 1$. Mathematical expressions act as the basic constituents in providing the complete picture. When expressed in the form E_e, the neutrosophic cumulative function states the overall evaluation process as follows: (Masoomi et al., 2023; Estupi et al., 2021; Samad et al., 2021).

$$E_e = g\big((T_e, I_e, F_e)\big) = T_e * w_T + I_e * w_I + F_e * w_F$$

Here, w_T, w_I, and w_F refer to the corresponding weighting coefficients for the aspects of truth, indeterminacy, and falsity. The model enables smooth and effective integration of subjective uncertainty into the existing measures and sustainability assessments in such a way as to increase the range and relevance in various scenarios (Settembre-Blundo et al., 2021; Hatefi et al., 2021; Chen et al.2023).

Neutrosophic Aggregation Operator

To aggregate multiple environmental observations, the neutrosophic aggregation operator $\oplus$ can be defined as follows:

$$N_{Total} = \oplus (N_1, N_2, \dots, N_n) = (T_{Total}, I_{Total}, F_{Total})$$

where T_{Total}, I_{Total}, and F_{Total} are computed via appropriate aggregation functions (e.g., weighted averages or other non-linear operators) that preserve the intrinsic properties of the neutrosophic numbers. Such operators are crucial for synthesizing diverse environmental data into a coherent measure useful for green accounting (Flood et al., 2025; Marzi et al., 2025; Santarius et al., 2023).

DISCUSSION

Theoretical integration of neutrosophic numbers into the green accounting and finance paradigm provides many important benefits critical for the development of our common comprehension of the various environmental concerns we face in modern society. First, the implicit expression of the

unknown through the characteristic three-dimensional structure present in neutrosophic numbers enables greatly more concrete, accurate, and complete analysis of the environment than has been possible in the past. Traditional economic models inherently have a tendency toward diluting or simplification of the complex and multidisciplinary nature of the unknown in the environment; these traditional models are greatly fortified by the integration of the pioneering neutrosophic method. Within this modern structure, the interrelated and constantly shifting aspects of truth, indeterminacy, and falsehood are given explicit quantification, thereby leading to a significantly more complex and complete structure within which in-depth analyses may be conducted (Smarandache, 2014). From this multidisciplinary perspective, the potential for green accounting and finance in offering a significantly more refined and informative analysis of the complex interrelations between multiple constituent elements in the environment and the correlated results ultimately encourages more effective decision-making outcomes critical in the current ecosystem, characterized by increasingly volatile circumstances and difficulties. The integration represents significant potential, particularly in relation to the ability to redefine our comprehension and approach toward critical sustainability and environment aspects in the development toward a more comprehensive and complete method for addressing the complex interdependence between economic growth and the resultant ecological implications (Nafei et al., 2024; Alomar, 2025; Vafadarnikjoo and Scherz, 2021).
In the field of agricultural economics, modern methods successfully fill the gap between common environmental deterioration and current financial reporting frameworks. Whereas the System of Environmental and Economic Accounts (SEEA) framework, in structure and content, provides a complete picture, the absence of a strong and effective mechanism for the regular and precise evaluation of uncertainty reduces the efficiency of the above framework. The integration with neutrosophic theory improves the above framework by utilizing sophisticated mathematical structures with the potential to host the imprecision and the uncertainty related to various categories within the environment data. Alongside the progress in the theory background, the integration represents a valuable contribution towards wider conceptual research on basic concerns by raising the level of awareness regarding the various concerns on the side of the stakeholders in both agricultural economics and environment areas (United Nations, 1993; United Nations, 2000). With the handling of these basic elements, the neutrosophic method broadens the current practices by providing a more complete approach towards the accomplishment of economic interests in parallel with the environment consideration in a balanced way (Ahmad et al., 2021; Aytekin et al., 2023; Nafei et al., 2024; Zhang & Chen, 2024).
Moreover, the composite sustainability index S created through large-scale research in this paper is a valuable and effective tool for both environmental economists and policymakers, unveiling a more sophisticated and complex picture of sustainability in the agricultural domain. Aside from broadened comprehension, the new tool enables the accurate analysis of the subtle equilibrium existing between economic potential and the need for environmental conservation. The in-built versatility exhibited by the weights (α and β), as well as the various aggregation operators employed in the existing index, allows the development of tailored applications designed specifically for meeting the special needs and conditions of specific regions. Such versatility constitutes the key requirement for handling the various conditions on the environment and the economics experienced by various regions in the most effective manner possible, translating into more effective design and implementation of agricultural policies. Utilizing the index in question enable various interested groups to reach informed choices that shall strive towards balanced reconciliation between economic progress and sustainable measures in the long run, hence translating into positive results on both the environment and the economic front (Kaiser et al., 2021; D'Orazio & Thole, 2022; Usubiaga-Liaño & Ekins, 2021; Kruse et al., 2022).
The basic theoretical assumption is that the employment of neutrosophic numbers stands to bring about notably improved stability in composite indices compared to traditional measures, in the hope that such a contention will emerge evidently through preliminary mathematical intuitions and

results. Nevertheless, it is crucial to recognize the fact that the theory behind the current research seeks still more investigatory endeavors aimed at practical usage through verification on actual or synthetic data in order accurately to determine the most suitable allotments for the indices' weights. Furthermore, precise tunings in the aggregation operators will stand imperative in the workings towards the optimum in practical applications in the real world, hence injecting the research results with the necessary relevance and reliability. Such a deliberate approach will ensure the attained theoretical findings have great practical utility in the long run, hence encouraging the development of knowledge within the given area. (Ricardo et al., 2022; Smarandache et al., 2024).

Furthermore, the unique and unprecedented potentiality of the neutrosophic system to efficaciously and correctly portray the complex interactions within myriad systems has great promise for developing the essential process of formulating policy. Such potentiality is attained through the integration of frequently undervalued and underlooked or inadequately assessed environmental costs in the contexts of traditional green accounting and finance constructs. Henceforth, wider usage of more sophisticated and complex mathematical constructs may lead towards more enlightened and informed decision-making in the deployment of valuable resources and the effective implementation of sustainable agricultural practices. Eventually, the developments would lead towards the attainment of a significantly more balanced and coherent economic growth, along with the effective management of the environment, thereby developing the potentiality towards the attainment of a sustainable future (Debroy et al.2025; Zarei et al., 2024; Priyadarshini et al., 2021).

CONCLUSION

This research has carefully offered a broad theoretical analysis regarding the integration of neutrosophic numbers within the vast and complex realm of green accounting and finance, especially focusing on the varied domain of agricultural economics. Through the utilization of the vigorous, nimble, and multidisciplinary mathematical structure related to neutrosophic numbers, the frameworks for the environment and ecological accounting are now adequately equipped to incorporate the vast implicit ambiguities depicted by ecological values within a vast set of agricultural applications and contexts. The deliberate incorporation of neutrosophic aspects through composite indicators of sustainability represents a significant and promising development with prospective applications regarding the effective evaluation, analysis, and quantification of numerous pivotal environment-driven effects, which tend significantly differently in various agricultural practices within various geographical areas. With the incorporation of an original, unique, and progressive approach toward methodology, the current research enhances the equity and relevance of appraisals while simultaneously expanding the utility and scope of sustainable applications and strategies within the vast and dynamic realm of agriculture. In the process, it establishes constructive and influential foundations toward subsequent research initiatives meant for the development of these complex frameworks in the future, hence providing valuable inputs toward effective and pioneering applications toward sustainability within the vast and varied domain of agricultural economics. Henceforth, it opens the way toward continued development, research, and innovation within this crucial research area.

There is a critical need for more research in order to enable more complete and systematic empirical studies that carefully examine the validity of the many aggregation operators developed in the area of research. Of central significance is not only the growth in the list of aggregation operators utilized in the analysis but the extension and improvement in the weighting parameters utilized, in the hope of attaining a much greater level of preciseness and the ensuing level of accuracy in the results. Indisputably, the research undertaken provides the necessary methodological foundation needed in order to overcome the extensive methodological differences existing between the two areas of research in environmental economics and uncertainty modeling. Eventually, the carefully planned initiatives will play a critical role in developing more solid and lasting constructs necessary in order to successfully realize sustainable agriculture in the face of the many significant challenges existing in the overall viability and sustainability of modern agricultural production systems.

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