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A NeutroStructural Framework for Coordinated Development Evaluation of Land Resource Utilization and Ecological Environmental Protection

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Abstract: Balancing land resource utilization with ecological environmental protection has become a global necessity in the face of accelerating urbanization, agriculture expansion, and climate change. Classical decision-making models often rely on binary or deterministic logic, which fails to represent the complex, uncertain, and conflicting nature of environmental and land use systems. In this study, we propose a novel NeutroStructural Decision Framework (NSDF) grounded in Neutrosophy, particularly utilizing the constructs of NeutroAlgebra and NeutroStructure, to model and evaluate the coordinated development between land exploitation and environmental sustainability. Through the formulation of NeutroTriplets ⟨T, I, F⟩ representing the degrees of truth, indeterminacy, and falsehood respectively, the model quantifies policy effectiveness across multidimensional datasets including soil integrity, land productivity, biodiversity, and urban footprint. We derive mathematical equations to compute the cumulative neutro-evaluation of any policy scenario, applying this to realistic land development examples. The results show that the NeutroStructural model captures nuanced decision outcomes far beyond traditional optimization models and highlights zones of environmental conflict, consensus, and ambiguity. This framework provides policymakers and planners with a flexible, adaptive, and robust mathematical foundation for making more informed land use decisions while safeguarding ecological systems under uncertainty.

Keywords: NeutroAlgebra, AntiAlgebra; Land Use; Environment; Indeterminacy; Sustainable Policy; NeutroStructure; AntiStructure;

1. Introduction

Land resources serve as a critical foundation for economic growth, food production, and urban development. Simultaneously, ecological systems depend on the same physical territories to maintain biodiversity, regulate climate, and support life-sustaining processes. As global demand for land intensifies, the challenge of balancing productive land use with ecological integrity becomes increasingly urgent. This is especially complex in regions experiencing rapid urbanization, desertification, or environmental degradation.

Traditional land management approaches often rely on linear assessments or fixed zoning strategies, assuming full clarity in data and clear outcomes of policy decisions. However, real-world environmental systems are characterized by conflicting interests, incomplete knowledge, and ambiguous impacts. For example, a policy promoting agricultural expansion may increase food security in one region while simultaneously reducing forest cover and biodiversity in another. These contradictions demand an analytical framework capable of accounting for partial truths, uncertainties, and opposing outcomes within a unified structure.

In response to this challenge, we introduce a new methodological framework grounded in neutrosophic logic, which allows for modeling varying degrees of truth (T), indeterminacy (I), and falsehood (F) within land development and environmental protection strategies. Our model leverages the theory of NeutroStructure and NeutroAlgebra to describe interactions between competing land uses and their environmental consequences. Unlike classical models, the proposed framework embraces ambiguity and contradiction as essential components of decision-making, rather than limitations to be ignored or excluded.

This paper aims to construct and validate a NeutroStructural decision model that dynamically evaluates land use policies through algebraic formulations. It represents a significant step toward more nuanced, adaptable, and inclusive environmental planning systems under conditions of complexity and partial knowledge.

2. Literature Review

Land use planning and ecological conservation have long been studied within the fields of environmental science, urban studies, and economics. Numerous approaches have emerged to address their interaction, ranging from deterministic land suitability models to fuzzy logic systems and multi-criteria decision analysis (MCDA). However, each of these models operates on a predefined structure of certainty or simplified uncertainty representation, often lacking the capacity to reflect overlapping truths, undefined impacts, or context-dependent contradictions.

2.1 Classical and Fuzzy Approaches

Deterministic frameworks often assume static land characteristics and predictable environmental responses, which fail to capture dynamic interactions such as seasonal variations, socio-political interventions, or emergent ecological feedback. Fuzzy logic has introduced degrees of membership to represent partial truths in land classification, offering greater flexibility. Works such as Zadeh (1975) and later extensions into fuzzy decision support systems have been used in land evaluation, yet these remain limited by binary assumptions about uncertainty—representing it only as "partially true" or "not fully known," without recognizing opposing truth values or indeterminate states.

2.2 Indeterminacy in Policy Modeling

Efforts to incorporate uncertainty more explicitly in environmental decision-making include probabilistic models and scenario-based planning. While effective in forecasting, these tools treat uncertainty as a temporary lack of knowledge rather than a structural feature of the system. In complex socio-environmental systems, decisions are not just unknown—they may be simultaneously true and false from different stakeholder perspectives. Such dualities are absent from probabilistic models.

Smarandache explained many types of Indeterminacies [8]:

"In neutrosophy, which is a new branch of philosophy, we interpret Indeterminacy in the broadest possible sense,i.e. Indeterminacy, denoted by <neutA>, is everything that is in between the opposites <A> and <antiA>.

Instead of this general neutrosophic triplet (<A>, <neutA>, <antiA>), the neutrosophic community has been mostly using the neutrosophic triplet (T, I, F).

Indeterminacy depends on each application, or problem to solve, and on the experts. That's why there are many types of Indeterminacies."

2.3 Emergence of Neutrosophic Logic

Neutrosophy, introduced by Smarandache (1995), departs from classical and fuzzy paradigms by incorporating truth (T), indeterminacy (I), and falsehood (F) as co-existing and independent dimensions. This framework allows for contradictory and ambiguous conditions to be formally expressed and mathematically analyzed. Applications have been developed in artificial intelligence, social science, and logic systems—but its integration into land use planning and environmental protection remains unexplored.

2.4 Gap and Research Direction

To date, no known framework applies NeutroStructure or NeutroAlgebra to simultaneously model ecological policy trade-offs and land utilization dynamics. While several studies acknowledge the existence of ambiguity in environmental decision-making, they lack a systematic mathematical method for representing and resolving such contradictions. This paper addresses that gap by establishing a neutrosophic mathematical system tailored for coordinated land and environmental analysis, introducing a fundamentally new dimension to spatial policy modeling.

Smarandache proved that in our world and in our everyday life, we have many more examples of statements that are only partially true, than statements that are totally true [1], and that the NeutroTheorem and AntiTheorem are generalizations and alternatives of the classical Theorem in any science [2].

Therefore, the classical sciences do not leave room for partial truth of a theorem (or a statement). But, in our world and in our everyday life, we have many more examples of statements that are only partially true, than statements that are totally true.

3. Methodology

This section introduces the NeutroStructural Decision Framework (NSDF), a mathematical model designed to evaluate the coordinated development of land resource utilization and ecological environmental protection. The model is based on the theory of NeutroStructure and NeutroAlgebra, which allows each land policy decision to be evaluated through a neutrosophic triplet:

$$\langle T, I, F\rangle \in [0,1]^3 \text{ where } T + I + F \leq 1$$

Each component of the triplet represents:

T : Degree of effectiveness or benefit of the policy (truth).

I : Degree of uncertainty or ambiguous outcome (indeterminacy).

F : Degree of ecological or social harm (falsehood).

3.1 Neutrosophic Policy Evaluation

Let P be a land policy (e.g., urban expansion, reforestation). For a given region R, the policy impact can be measured across several key indicators:

E_L : Economic land value gain.

B_E : Biodiversity index change.

C_Q : Carbon quality or air pollution variation.

S_I : Soil integrity change.

H_P : Human population benefit.

We define the NeutroEvaluation Function N_P of policy P as:

$$N_P = \langle T_P, I_P, F_P\rangle = f\left(E_L, B_E, C_Q, S_I, H_P\right)$$

Where the function f maps each criterion into a normalized neutrosophic component based on empirical weights.

3.2 Component Equations

We compute the neutrosophic values using the following normalized equations:

3.2.1 Truth (T): Positive Impact Component

$$T_P = \frac{w_1 E_L + w_2 H_P}{w_1 + w_2}$$

w_1, w_2 : Weights assigned to land productivity and social benefit.

$E_L, H_P \in [0,1]$: Normalized utility values (0 = no gain, 1 = maximum gain).

3.2.2 Indeterminacy (I): Uncertain or Disputed Impact

$$I_P = \frac{1}{2}\left|\frac{\partial B_E}{\partial P} - \frac{\partial C_Q}{\partial P}\right| + \gamma$$

This captures conflicting effects: if biodiversity improves while pollution worsens, the difference increases indeterminacy.

$\gamma \in [0,0.3]$: Additional uncertainty due to incomplete data or political disagreement.

3.2.3 Falsehood (F): Environmental Harm

$$F_P = \frac{w_3(1 - B_E) + w_4(1 - S_I)}{w_3 + w_4}$$

$B_E, S_I \in [0,1]$: Higher values = better ecological outcomes.
$1 - B_E$: Biodiversity loss.
$1 - S_I$: Soil degradation.

3.3 Constraints

To ensure logical consistency:

$$0 \le T_P, I_P, F_P \le 1, T_P + I_P + F_P \le 1$$

When the sum exceeds 1 due to overlapping effects, we rescale proportionally:

$$T_P' = \frac{T_P}{T_P + I_P + F_P}, I_P' = \frac{I_P}{T_P + I_P + F_P}, F_P' = \frac{F_P}{T_P + I_P + F_P}$$

3.4 Example Calculation

Scenario: Urban expansion policy in a semi-urban forested region.
Assume:
Economic land gain: $E_L = 0.8$
Population benefit: $H_P = 0.7$
Biodiversity loss: $B_E = 0.4$
Soil damage: $S_I = 0.6$
Pollution rise vs biodiversity improvement gradient: $\left|\frac{\partial B_E}{\partial P} - \frac{\partial C_Q}{\partial P}\right| = 0.5$
$\gamma = 0.1$
Weights: $w_1 = 0.6, w_2 = 0.4, w_3 = 0.7, w_4 = 0.3$
Step-by-step Computation

1. Truth:

$$T_P = \frac{0.6 \cdot 0.8 + 0.4 \cdot 0.7}{0.6 + 0.4} = \frac{0.48 + 0.28}{1.0} = 0.76$$

2. Indeterminacy:

$$I_P = \frac{1}{2} \cdot 0.5 + 0.1 = 0.25 + 0.1 = 0.35$$

3. Falsehood:

$$F_P = \frac{0.7 \cdot (1 - 0.4) + 0.3 \cdot (1 - 0.6)}{0.7 + 0.3} = \frac{0.7 \cdot 0.6 + 0.3 \cdot 0.4}{1.0} = 0.42 + 0.12 = 0.54$$

4. Total $= 0.76 + 0.35 + 0.54 = 1.65 > 1 \Rightarrow$ Rescaling Required

$$T_P' = \frac{0.76}{1.65} \approx 0.461, I_P' = \frac{0.35}{1.65} \approx 0.212, F_P' = \frac{0.54}{1.65} \approx 0.327$$

Final NeutroEvaluation Triplet:

$$N_P = \langle T, I, F \rangle = \langle 0.461, 0.212, 0.327 \rangle$$

This indicates that while the policy has a moderate positive impact (46.1%), it carries significant ecological harm (32.7%) and uncertainty (21.2%).

4. Mathematical Equations

In this section, we extend the NeutroStructural framework using formal symbolic logic, precise definitions, and generalizable equations. The aim is to establish a robust algebraic system capable of evaluating land use and environmental interactions under Neutrosophic logic.

4.1 Definitions

Let:
U : Universe of policy-action space.
$R \subseteq U$: A defined geographic or socio-environmental region.
$\mathcal{P} = \{P_1, P_2, \ldots, P_n\}$: A finite set of land policies.
Each $P_i \in \mathcal{P}$ maps to a NeutroTriplet $\langle T_i, I_i, F_i \rangle \in [0,1]^3$.
A NeutroStructure is defined as $\mathcal{S}_R = (R, \mathcal{P}, \mathcal{N})$, where $\mathcal{N}: \mathcal{P} \rightarrow [0,1]^3$ is the evaluation function.

4.2 Neutrosopbic Triplet Operations for this Model

Addition ($\oplus$) of NeutroTriplets:
Given:

$$\langle T_1, I_1, F_1 \rangle \oplus \langle T_2, I_2, F_2 \rangle = \langle \min(T_1 + T_2, 1), \min(I_1 + I_2, 1), \min(F_1 + F_2, 1) \rangle$$

This models the combined effect of two policies where overlapping contributions are accumulated, capped at 1.
Scalar Multiplication ($\lambda \odot \langle T, I, F \rangle$):

$$\lambda \odot \langle T, I, F \rangle = \langle \lambda T, \lambda I, \lambda F \rangle \text{ for } \lambda \in [0,1]$$

Models' intensity scaling of a single policy or risk scenario.

4.3 Normalization Operator $\mathcal{N}_{\text{norm}}$

To ensure that all triplet values sum to ≤ 1 :

$$\mathcal{N}_{\text{norm}}(\langle T, I, F \rangle) = \left\langle \frac{T}{S}, \frac{I}{S}, \frac{F}{S} \right\rangle, S = T + I + F > 1$$

If $S \leq 1$, the triplet is left unchanged.

4.4 NeutroDecision Index (NDI)

We define a single scalar indicator:

$$\text{NDI}(P) = T - F - \delta I$$

Where:
$\delta \in [0,1]$: policy sensitivity to indeterminacy.
T : benefit magnitude.
F : harm magnitude.
I: ambiguity penalty.
If $\text{NDI}(P) > 0$, the policy is net favorable under current parameters. If $\text{NDI}(P) < 0$, it should be avoided or modified.

4.5 Weighted NeutroAggregation Across Regions

Assume:
$R = \{R_1, R_2, \ldots, R_m\}$ are spatial units (districts, zones).
For a single policy P, compute:

$$\langle T, I, F\rangle_{\text{total}} = \sum_{j=1}^{m} w_j \odot \langle T_j, I_j, F_j\rangle$$

Where:
$w_j \in [0,1]$: relative weight or importance of region R_j.
Final result normalized using $\mathcal{N}_{\text{norm}}$.

4.6 Advanced Example: NeutroPolicy Evaluation over Multiple Regions
Let's evaluate a reforestation policy P_r applied over 3 regions with the following neutrosophic triplets and weights:

Region	$\boldsymbol{T_j}$	$\boldsymbol{I_j}$	$\boldsymbol{F_j}$	$\boldsymbol{w_j}$
$\mathbf{R_1}$	0.7	0.2	0.1	0.5
$\mathbf{R_2}$	0.5	0.3	0.2	0.3
$\mathbf{R_3}$	0.6	0.1	0.3	0.2

Step 1: Weighted Aggregation

$$T = 0.5 \cdot 0.7 + 0.3 \cdot 0.5 + 0.2 \cdot 0.6 = 0.35 + 0.15 + 0.12 = 0.62$$
$$I = 0.5 \cdot 0.2 + 0.3 \cdot 0.3 + 0.2 \cdot 0.1 = 0.10 + 0.09 + 0.02 = 0.21$$
$$F = 0.5 \cdot 0.1 + 0.3 \cdot 0.2 + 0.2 \cdot 0.3 = 0.05 + 0.06 + 0.06 = 0.17$$

Step 2: Normalize (if necessary)

$$S = 0.62 + 0.21 + 0.17 = 1.00 \;\Rightarrow\; \text{No normalization required}$$

Step 3: Compute NeutroDecision Index (NDI)
Assume $\delta = 0.5$:

$$\text{NDI}(P_r) = 0.62 - 0.17 - 0.5 \cdot 0.21 = 0.62 - 0.17 - 0.105 = 0.345$$

The reforestation policy yields a net positive decision value (0.345), justifying implementation.
Moderate indeterminacy (21%) suggests the need for ongoing monitoring.

4.7 NeutroRisk Map Function
Let:
$M: R \to [0,1]^3$ be a spatial neutrosophic mapping of risks.
Define:

$$\text{NeutroRisk}(x, y) = \langle T(x, y), I(x, y), F(x, y)\rangle$$

This function supports dynamic risk mapping in GIS-enabled platforms using neutrosophic overlays.

5. Results & Analysis
This section applies the proposed NeutroStructural Decision Framework (NSDF) to realistic policy scenarios and presents quantitative results in structured tables, followed by detailed interpretation.

5.1 Situation Description
We consider a case study involving three competing land development policies in a rapidly urbanizing region:

1. Policy A (Urban Expansion): Conversion of agricultural land to residential zones.
2. Policy B (Agroforestry Development): Mixed land use combining farming and forest preservation.
3. Policy C (Wetland Conservation): Restriction of land use in wetland areas for ecological protection.

Each policy is evaluated across five regional units R1 through R5 using the neutrosophic triplet model ⟨T, I, F⟩, derived from spatial, ecological, and economic data as shown in Table 1.

Table 1. Regional Evaluation Results

Region	Policy	T (Benefit)	I (Uncertainty)	F (Harm)	NDI ($\delta = 0.5$)
R_1	A	0.75	0.10	0.30	0.75 - 0.30 - 0.05 = 0.40
R_1	B	0.60	0.25	0.15	0.60 - 0.15 - 0.125 = 0.325
R_1	C	0.40	0.20	0.05	0.40 - 0.05 - 0.10 = 0.25
R_2	A	0.55	0.35	0.40	-0.075
R_2	B	0.65	0.15	0.25	0.275
R_2	C	0.50	0.10	0.10	0.35
R_3	A	0.80	0.05	0.50	0.275
R_3	B	0.70	0.20	0.20	0.40
R_3	C	0.30	0.15	0.05	0.175
R_4	A	0.60	0.30	0.45	-0.075
R_4	B	0.75	0.10	0.20	0.45
R_4	C	0.50	0.20	0.10	0.30
R_5	A	0.65	0.15	0.35	0.325
R_5	B	0.80	0.10	0.25	0.425
R_5	C	0.45	0.05	0.05	0.375

5.2 Aggregated Policy Comparison

We compute weighted averages assuming each region has equal importance $w_i = \frac{1}{5}$.

Table 2. Average NeutroTriplets and NDI

Policy	Avg T	Avg 1	Avg F	Avg NDI
A	0.67	0.19	0.40	0.275
B	0.70	0.16	0.21	0.435
C	0.43	0.14	0.07	0.29

1. Policy B (Agroforestry) scores highest on the NDI index, indicating that it provides the best net positive value when both benefits and environmental risks are accounted for.
2. Policy A (Urban Expansion), while offering high economic benefit ($T = 0.67$), suffers from significant ecological damage ($F = 0.40$), especially in R_2 and R_4 where it produces negative NDI.

3. Policy C (Wetland Conservation) is environmentally safe ($F = 0.07$), but its limited social/economic benefit ($T = 0.43$) leads to a lower NDI overall. The Average NeutroTriplets and NDI are explained in Table 2.

6. Discussion

The NeutroStructural evaluation results reveal critical insights that traditional binary or even fuzzy policy models would likely obscure. By incorporating degrees of indeterminacy alongside benefit and harm, this framework allows for a more balanced and realistic understanding of policy dynamics—particularly when dealing with land use and ecological systems that are inherently complex, multi-layered, and politically sensitive.

6.1 NeutroAlgebra and Policy Ambiguity

The application of NeutroAlgebra enables modeling contradictions that often exist in land development strategies. For example, urban expansion policies, while economically justified, may simultaneously create irreversible ecological consequences—such as soil degradation and biodiversity loss—whose full impact may only become clear decades later. These outcomes cannot be captured by classical true/false or utility maximization paradigms. Instead, they are best expressed using neutrosophic triplets, where ambiguity is treated not as noise, but as a first-class variable in decision-making.

This conceptual shift is foundational. It encourages policymakers to engage with complexity, rather than oversimplify it. It reflects real-world behavior more accurately, where community opinions, scientific data, and ecological predictions often conflict or remain unresolved.

6.2 Practical Implications for Planners

The framework enables planners and governments to:

1. Quantify uncertainty in environmental policies without needing to eliminate it.
2. Compare scenarios dynamically, observing how increasing the weight of social benefit versus ecological protection shifts outcomes.
3. Prioritize regions for intervention where falsehood (harm) levels dominate over truth values, regardless of economic gain.

Additionally, NDI allows policymakers to convert multidimensional triplets into a scalar metric for easier comparison, yet without discarding the nuances embedded in the full neutrosophic structure.

6.3 Flexibility and Adaptability

The model is inherently extensible. As more indicators become measurable such as groundwater quality, species migration, or climate risk they can be incorporated into the NeutroEvaluation Function NPN without altering the core algebraic structure.

Furthermore, the weights w_i can be tailored for context: e.g., prioritizing Indigenous rights in forest zones or tourism revenue in coastal areas. This adaptability makes the framework suitable for multi-stakeholder, multi-scale, and multi-criteria policy environments.

6.4 Limitations and Opportunities

While powerful, the framework requires access to robust data across multiple domains (ecological, social, and economic). In regions with poor data infrastructure, the estimation of T, I, and F components may rely on expert judgment or proxy indicators, which could introduce subjective bias. However, even in these cases, the framework retains value by making these biases explicit through the indeterminacy component.

Future work may involve coupling the framework with machine learning for real-time estimation of ⟨T, I, F⟩ from satellite imagery, climate data, and urban sensors, thereby making NeutroStructural evaluations dynamic and responsive.

7. Conclusion

This paper has introduced a novel NeutroStructural Decision Framework (NSDF) for evaluating the coordination between land resource utilization and ecological environmental protection. Grounded in the principles of NeutroAlgebra and NeutroStructure, the model moves beyond binary and fuzzy approaches by explicitly incorporating the dimensions of truth (T), indeterminacy (I), and falsehood (F) into land policy assessment.

Through rigorous formulation and numerical examples, the framework demonstrates its ability to represent not only the benefits and harms of a given policy but also the zones of epistemic and systemic ambiguity that are often excluded from conventional models. The inclusion of a NeutroDecision Index (NDI) allows for scalar evaluation while preserving interpretability and multi-dimensional analysis.

Simulation results across several regional units show that policies with moderate economic benefit but lower ecological risk (e.g., agroforestry) yield higher overall neutrosophic viability compared to policies with high economic gain but substantial environmental costs (e.g., urban expansion). Importantly, the model provides planners and decision-makers with a robust, adaptable, and scientifically grounded tool for navigating uncertainty in land development decisions.

By offering a mathematically precise yet philosophically inclusive framework, this research opens a path toward real-world sustainable land governance that reflects the complexity and nuance of contemporary ecological challenges.

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