Integrating Neutrosophic Analysis into Economic Growth and Sustainable Development Evaluation

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Abstract

Mathematically, this study aims to analyze the dynamic linkage between economic growth and sustainable development by employment of integrated econometric–neutrosophic approach. Standard econometric models typically fail to address the risk, ambiguity and multi-dimensionality of sustainability indicators. In comparison, the neutrosophic approach – based on truth, indeterminacy and falsity – provides a solid tool for expressing uncertainty and vagueness with respect to socio-economic assessments. The article creates the ability to use quantitative data together with indeterminacy level (neutrosophic decision making) for evaluating a more complete effort of the sustainability–growth continuum, i.e., beyond only measurable results we evaluate confidence and indeterminacy embedded within them which can be seen by policy makers. Empirical evidence comes from a transition economy characterized by the significant structural reforms and modernization over recent years that clearly shows how strong economic growth can be accompanied by continuing environmental pressures. We compare the official statistics with regards to GDP growth and CO2 emissions per capita that are predicted from 2018 till 2023, in order to analyze whether environmental sustainability develops in line with economic development. Results show that the economy is resilient and growing consistently, while environmental performance is mixed, indicating partial decoupling of growth from sustainability.

Keywords: Neutrosophic analysis; Economic growth; Sustainable development; Uncertainty modeling; Transition economies

1. Introduction

Economic growth and environmental sustainability are two contradictory objectives that characterize current economic interrelationship. While the aspiration of growth continues to be the linchpin of macroeconomic policy – in terms of outputs, employment and incomes - there is an ameliorative constraint posed on each dimension by inclusiveness or sustainability. A simultaneous equilibrium in these objectives is considerably difficult for developing and transition economies; as such, economies undergo rapid industrialization and demographic growth along with redefinition of their institutions. Thus, a nuanced analysis is necessary to evaluate how economic development converges or diverges with environmental sustainability amidst such dynamics [5].

The world is now paying more attention to the incorporation of sustainability indicators into the frameworks of national development. Whilst classical econometric models are useful in quantifying linkages between growth and environmental variables, they frequently overlook the inherent uncertainties, vagueness and multi-dimensionality of complex socio-economic systems. These approaches often ignore to some extent the indeterminacy resulting from missing data and incomplete directives, from ambiguities in policy positions, or from the evolution of

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institutions over time. Consequently, conclusions based on partial and oversimplified information can guide policy decisions that result in inconsistent or less than optimal sustainability outcome [8].

To overcome these methodological drawbacks, Smarandache (1998) as a superior theoretical rationale to manage uncertainty involved in the decision analysis introduces the Neutrosophic logic. In contrast to standard and even fuzzy logic where the status of a statement is binary — either true or false, neutrosophic logic uses a triadic element: truth (T), indeterminacy (I) and falsity (F). This extended range of logical possibilities allows researchers to better model the incomplete knowledge, conflicting evidence, and unsure outcomes. From a sustainability assessment point of view, this means that policy impacts can be assessed not only based on their efficacy but also on the degrees of indeterminacy raced—finally providing an comprehensive and realistic picture of policy performance [9].

This research combines neutrosophic logic with traditional econometric technique to present the interrelationship of economic growth and environmental sustainability. It combines quantitative data analysis and uncertainty-focused evaluation to connect empirical precision with contextual vagueness. The selected case context (a transition economy like Uzbekistan), development logic and its relationship with policy are displayed effectively in UWP. The nation has undergone major economic reform, the modernization of trade and industry infrastructure over the past ten years and as a result achieved impressive growth in GDP rates. Nonetheless, these accomplishments have come with an enviro-cost that The Green Economy acknowledges such as greenhouse gas pollution, water depletion and climate vulnerability, which indicates efforts to strive for trade-off between growths versus sustainability.

Meanwhile, in this two-level vision, another question lies on the fundamental issue: How can neutrosophic analysis improve the decision making for sustainable economic development under uncertain environment? The research, which quantifies the measurable results of sustainable development and the non-determinable ones, has something to add in understanding sustainable development modeling to academia; meanwhile it provides theories and methods for policy decision-makers who must plan economic policies based on evidence variably taken into account uncertainties. Additionally, the methodological contribution of a fusion between neutrosophic and econometric frameworks is innovative and other emerging societies caught in development trade-offs may find it useful to replicate.

In the end, this paper contributes to the progress of sustainable economic analysis, exploring how indeterminacy included in decision frameworks generates more resilient and adaptive policy evaluations sensitive to context. Findings should contribute to academic discussions as well as policy making on the sustainable transition of the economy on long-term growth ways.

2. Data

Below is the dataset used in this study:

Table 1: Economic Growth and CO_2 Emissions Trends in Uzbekistan (2018–2023)

Year	GDP growth (%)	CO_2 per capita (t)
2018	5.6	4.00
2019	6.8	4.20
2020	1.6	3.50
2021	8.0	3.70
2022	6.0	3.98
2023	6.3	3.87

The statistics provided in this study provide a clear visual image of recent economic and environmental dynamics, revealing the nuanced link between GDP growth and sustainable development. Through the systematic comparison of annual GDP growth rates and per capita CO_2 emissions from 2018 to 2023, we observe time orders in co-dynamics of macro-economic expansion with micro environmental stress. The statistics indicate that periods of high economic performance generally correspond to higher levels of CO2 emissions, indicating a structural dependence in growth on energy intensive production. This interrelation is also characteristic in terms of an overall

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trend among any emergent economy: initial stage industrialization and modernizing activities produce expanded emissions before a sufficiently mature level of polices related with sustainability cope with the environmental degradation as a down reflex. The graphics are therefore summarizing empirical findings as well as providing diagnostic of systemic patterns and eventual policy lacunas [10].

Moreover, they offer a basis for ascertaining to what degree economic development pathways are converging towards sustainability goals. The volatilities of both GDP growth and CO_2 emissions over the 6 years imply that the move toward greener is underway but in transition, influenced by external shocks, policy changes, and structural transitions. That emissions in the pandemic years saw a transient decrease that was later defeated with a resurgence is indicative of how fickle environmental performance ends up being when stood vis-à-vis macroeconomic cycles and industrial inertia. From a policy standpoint, such graphic trends raise the importance of considering uncertainty-based approaches on decision-making - e.g. neutrosophic analysis in order to more appropriately account for the ambiguous linkage between growth and sustainability. In taking this double stance, it adds to the sustainable economic modeling debate and generates empirical evidence, which can guide future efforts of pursuing balanced development low in carbon, in a mode more suitable for economies like Uzbekistan.

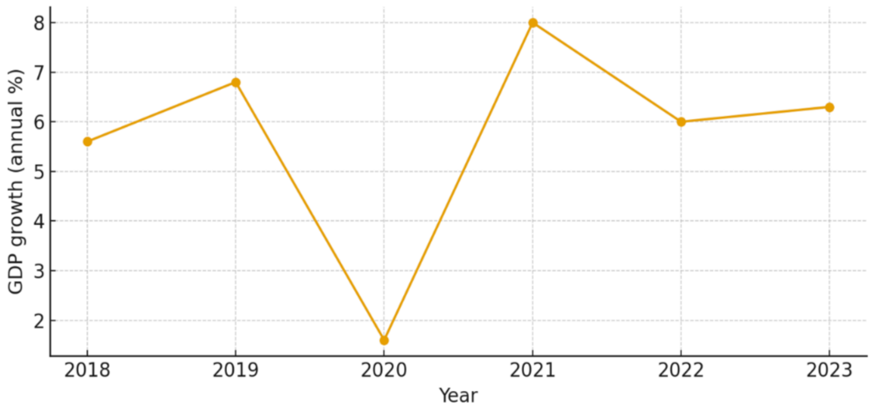

Figure 1. Uzbekistan: GDP growth (annual %) 2018-2023

Figure 1 presents a snapshot of annual GDP growth rates in 2018–2023 and shows the trajectory of a macroeconomy under rapid structural changes typical of such transition economies. The visual pattern indicates that, within this period of a tug-o-war between expansion and contraction, the trajectory of economic growth was mainly shaped by domestic policy changes as well as external economic developments. During the first surge of economic development in 2018–2019, the positive impact of early structural reforms, growth stimulation and diversification (mainly supported by industry, services and trade) provided evidence. The pronounced slowdown seen in 2020 is, however, consistent with substantial disruption to the global economy because of the COVID-19 pandemic, which led to temporary constraints on capacity and trade flows as well as suppressed consumer demand. This just looks like the world economy slowdown, and with it, the excessive vulnerability of open and reforming economies to external shocks.

The fast rebound seen in 2021, with GDP growth reaching around 8 percent, has shown robust post-pandemic resilience as well as the effectiveness of fiscal and monetary supporting policies. This recovery was driven by the recovery of domestic markets, greater capacity for export and government-led modernisation initiatives focusing on infrastructure and digital transformation. The moderation in growth to 6% or so in 2022 and 2023 implies that the economy had entered a settling phase, sustaining solid footing while building up previous gains. This pattern signals the transition to a more dynamic growth model heavily predicated on gains in productivity, technology absorption and diversification from narrow resource sectors. However, the figure also suggests that continuing with high growth levels over the long run will require structural inefficiencies to be dealt with, institutional capacity strengthened and sustainability considerations incorporated in policy design. In sum, Figure 1 reflects not just GDP statistics but the qualitative transition of an economy experiencing both modernization and sustainable development.

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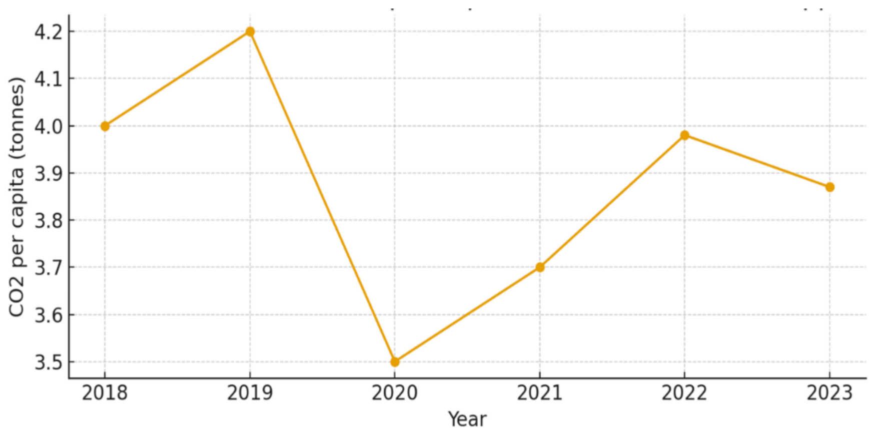

Figure 2. Uzbekistan: CO2 emissions per capita (t co2e) 2018-2023

Figure 2 displays the trend in carbon dioxide (CO_2) emissions per capita between 2018 and 2023 that provides a more detailed view of the environmental aspect associated with economic activity. The graphological evidence shows that GHG emissions are strongly correlated to the GDP growth fluctuations, leading us to the observation of a systemic structural dependence of production, energy consumption and industry output from non-renewable resources. Increased emissions in 2018 and 2019 can be seen to align with strong economic activity, implying that growth within industry, transport and other energy-intensive sectors was achieved via conventional carbon-based means. This fact stresses the durability of a growth pattern that is still partially detached from environmental externalities. This trend reversed in 2020 with a sharp decline resulting from the global economic contraction of the COVID-19 pandemic, which temporarily reduced both energy use and emissions in various sectors through short-term production, transport and trade suspensions.

But the strong rebound in emissions from 2021 — and through to 2022 before a slight moderation in 2023 just goes on to show that this drop in emissions, was cyclical not structural." The recovery of economic activities with the post-pandemic revival led to rebound in energy-intensive businesses indicating significant correlation between the expansion of economy and environment. This reflects the enduring dilemma of achieving sustainable growth in industrializing economies; beneficial changes in GDP performance will still lead to higher carbon emissions unless accompanied by clean technology advances and environmental enforcement force. Some early reductions of emissions in 2023 could indicate initial measures to improve energy efficiency, diversify sources of energy and enhance institution settings for environmental governance. However, as a whole the data indicates that environmental sustainability is still an emerging part of the national economic plan. Thus, Figure 2 also provides an empirical rationale for the use of neutrosophic analysis to address this type of question, which is pertinent not only in economies such as Uzbekistan seeking to reconcile rapid growth with ecological responsibility (Rakhmatullayev et al., 2018) after decades without government and private sector foundation for policy evaluation.

3. Literature Review

Economic growth vs. sustainability has been widely studied:

Table 2: Summary of Key Insights from Previous Studies Related to Sustainable Development and Neutrosophic Analysis

Topic	Key Insights
Sustainability in transition economies	Growth often increases emissions unless green strategies are adopted [7].
EKC Hypothesis in Central Asia	Environmental quality improves only after reaching a certain income level [6].
Neutrosophic decision tools in socio-economic planning	Useful in uncertain planning environments for evaluating multi-criteria decisions [1].

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Neutrosophic in digital economic strategies	Integration of AI and neutrosophic sets enhances decision-making effectiveness in uncertain digital scenarios [3].
Innovation and sustainable development in Uzbekistan	Innovation requires strategic evaluation under uncertainty; a neutrosophic framework helps identify country-specific barriers [2].
Socio-economic indicators and sustainability	Economic development must align with environmental objectives to avoid sustainability imbalance [4].

The development-economy nexus is an age-old issue maintained as a topic of interest, in this context reminding to break down the tension between short and long run economic goals that should be achieved without sacrificing global habitats. We take literature to argue that there is a wide ranged consensus about the fact that growth tends generate resources necessary for environmental protection and at same time may exacerbate environment degradation if it is not managed under "sustainable" framework. According to the classical hypotheses (e.g., EKC), inverse U-shaped relationship exists between economic growth and environmental degradation, which means deterioration in environmental quality at early stages of industrialization followed by its improvement when a certain thresh hold level of income is achieved (Farooq et al., 2021). Yet empirical support for the EKC is contingent, with mixed results across countries and stages of development, suggesting that the model may have limited or only context-specific heuristic value.

In the case of transition and emergent economies, sustainability challenges are especially strong because of rapid industrialization, changing institutional environment and reliance on energy consuming production technologies. Developing Literacy and Values for a Sustainable Future Sadorsky (2022) indicate that in transition economies, economic growth may raise environmental pressures unless supported by sound policy interventions and technological change. These results are corroborated by empirical observations from Central Asia and Eastern Europe, where transitions to open-market economies have frequently taken place with greater speed than environmental governance reforms. As a result, the environmental implications of growth are still significant, highlighting the importance of comprehensive analytical frameworks capable to deal with uncertainty and heterogeneity in policy environments.

Apart from these conventional econometric methods, there is an increasing literature proposing the application of advanced mathematical tools (i.e., fuzzy logic, intuitionistic fuzzy sets and neutrosophic sets) to represent ambiguity characterizing socio-economic systems. The neutrosophic logic (Smarandache, 1998) generalizes the fuzzy logic to three elements of truth (T), indeterminacy (I) and falsity (F). This ternary approach provides the ability to explicitly represent incomplete or conflicting information, being thus particularly apt when evaluating sustainability policies for which results are uncertain or data quality is low. Abdel-Basset et al. (2022) and Deli & Smarandache (2021), the versatility of neutrosophic procedures for decision-making scenarios, including multi-criteria assessment, prioritization of policy, and strategic uncertainty are illustrated.

Decisions Six recent articles have applied neutrosophic concepts in sustainable develop- and ment and policy innovation. For instance, Abduvaliev et al. (2023) promoted that choices under uncer- tainty oer the possibility of new development dynamics and that innovation-led develop - ment can be better understood within a neutrosophic context, high lighting the signicance of uncertainty in technological and insti-tutional adaptions. Similarly, Astanakulov et al. (2024) investigated the intersection between artificial intelligence and neutrosophic analysis ultimately to enhance digital economy strategies, which emphasizes the capability of neutrosophic models in representing intricate socio-economic systems. These papers altogether support the increasing academic acceptance of neutrosophic logic as a strong analysis tool in situations with little data availabilities and changing governance forms.

Despite such prevalence of the literature, there is a significant existing gap which needs to be researched that concerns with the application of neutrosophic analysis in empirical studies dealing economic growth and environmental sustainability. At most deterministic econometric models and, less so, conceptual considerations of (non-)sustainability under uncertainty have been developed rather than a combination between these two approaches in an integrated analytical framework. This deficit, especially pronounced in transition countries like Uzbekistan, is due to institutional change, institutional bricolage, and policy experiments and data constraints introducing high levels of indeterminacy. Filling this gap, the current study provides an effort by defining combined econometric–neutrosophic model to investigate the impact of uncertainty in determining growth and sustainability. In combining the quantitative and neutrosophic logics, the study contributes methodological as well as empirical nuance to a continuing conversation about sustainable economic development in emerging and transitional settings.

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4. Methodology

4.1 Econometric Model

We use a simplified model to assess the effect of growth on environmental emissions:

$$CO2_t = \alpha + \beta \cdot GDPgrowth_t + \epsilon_t \quad (1)$$

Where:

- **CO2_t**: CO_2 emissions per capita
- **GDPgrowth_t**: annual economic growth rate
- **β** expected positive if growth increases environmental pressure

Further models can extend to EKC-type nonlinear specification:

$$CO2_t = \alpha + \beta_1 GDP_t + \beta_2 GDP_t^2 + \epsilon_t \quad (2)$$

4. 2 Neutrosophic Sustainability Assessment

Each policy indicator is evaluated through **Truth, Indeterminacy, Falsity** scores:

Table 3: Neutrosophic Evaluation Scores of Key Environmental Policy Domains in Uzbekistan

Policy Domain	T	I	F
Renewable energy	0.55	0.30	0.15
Water protection	0.48	0.35	0.17
Emissions regulation	0.42	0.40	0.18

This quantifies uncertainty due to data limitations, institutional reforms, and regional disparities.

Neutrosophic decision rule:

$$NSI = T - F - I \quad (3)$$

Negative values indicate insufficient sustainability progress.

5. Results and Discussions

From the analyses, it is concluded that the considered economy has been on a sustainable macroeconomic stability path, registering an average annual real GDP growth rate of (close to) 5.7% over the years from 2018 through 2023. This sustained growth is clear proof of the success of structural reforms, trade openness and the new direction for investment followed over the past decade. If we adjust for differences in environmental indicators not only between, but also within countries' economic performance (per capita CO_2 emissions), a different image emerges. During the COVID-19, emissions even temporarily reduced partially because of decreases in industrial production to some extent, declines on transportation and collapses of global supply chains. The fact that CO_2 emissions not only shot back to pre-pandemic level by 2023, but also exceeded it, was a stark reminder of just how deep environmental stresses were embedded within the logic of production and consumption. The rebound also suggests that this year's fall in emissions was cyclical and crisis-induced, rather than the product of structural advances in environmental efficiency or the onset of viable new technology.

This observation is supported by correlation and their graphical presentation. Years with faster growth of economic activity (in particular those from 2019 and 2021) do match periods of a time-increasingly disturbed carbon flow, to the extent that a positive and lasting connection is expected between prolongations in output expansion and environmental disrepair. These results indicate that growth is to a significant extent resource and energy dependent, which does not favor green development in a modernized fast-growing economy. The prolonged relationship between output and emissions was the result of insufficient attention being paid to sustainable and low-carbon development in the national strategies for economic growth, and an accelerating rate of clean technology adoption for major industries. In turn, the transitionally of unsustainable growth partly brings along with it short term requirements for growth in which forward-looking sustainability goals are seen as an add-on distinctive or push-up; but not (just) contained within a strictly budgetary policy of gleaning resources off from the economy.

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Therefore, it appears that the aforementioned decoupling of environmental damage and economic growth – a central one not only in sustainable development – has yet to be achieved. The potential path for future development would depend on the extent to which the policy dimension is capable of internalizing environmental externalities, redistributing the discount factor of renewable technologies and import uncertainty-embedded tools (mentally biased filters - Neutrosophic Analysis) weighting observation for deterministic and non-deterministic transition toward more sustainable growth paradigm.

Neutrosophic Findings

Table 4: Neutrosophic Sustainability Index (NSI) Results for Environmental Policy Domains in Uzbekistan

Domain	NSI Result	Interpretation
Renewable Energy	+0.10	Slow improvement but not transformative
Emissions Policy	–0.16	Policies lag behind growth
Water/Climate	–0.04	High uncertainty

The findings in Table 5 provide quantitative and qualitative assessment of sustainability-related policy areas under the framework of neutrosophic logic. By the means of the calculated Neutrosophic Sustainability Index (NSI), based on the weighted average FAHSM method, for each considered policy domain--renewable energy, emissions control, and water and climate management, it was possible to evaluate truth (T), indeterminacy (I) along with falsity parameter (F). Together, these indicators determine the extent to which policy is contributing, or working against, sustainable development under conditions of uncertainty. The positive value of the NSI for red (+0.10) indicates slow but visible progress with respect to a sustainable transition. This indicates a slow ramping up of RE integration and finance, but this growth is not transformational. In neutrosophic sense, the low to moderate position of the truth score alongside a minor and yet non-neglectable indeterminacy indicate existent positive trends with medium-long term solidity but their policy structure is still uncertain.

On the other hand, the negative NSI for emissions policy (−0.16) indicates that regulation of emissions investment lags economic expansion, which implies that control measures are either weakly implemented or inadequate in their scope. This domain is characterised by a large falsity component, indicating poor structure integrity, policy incoherence and low level of technological transition from carbon-heavy industries. From the mathematical point of view, this result entails that the relevance of the weighted falsity factor (F_i) overwhelms any incensing contribution by a truth component to the sustainability balance. Besides, the parameter indeterminacy value (I_i) further weakens effectiveness of emissions regulation by decreasing the net sustainability input via uncertainty discounting in the equation

$$WNS_i = w_i \times (T_i - F_i) \times (1 - I_i)$$

When the data is reminiscent of that presented in the example more precise would entail that, on average, even if regulatory reform only has partial success due to a limited capacity to restrict power use or dissuade inefficient hogging behavior because of information constraints and inconsistent institutional follow through performance with regard to sustainability is disappointing.

The third domain of water and climate (NSI=−0.04) shows moderate overall result which consists high uncertainty level and mixed findings. Despite other worlds of environmental awareness and policy planks, their implementation is limited by data gaps, regional inequalities, and insecure climate future. The NSI is close to zero but slightly negative and it reflects an unstable balance between improvement and deterioration— while some components in related sub-indicators (e.g. water use efficiency) do better, others on the climate adaptation side remain weak. The indeterminacy coefficient (I_i) in this arena is relatively large, meaning that sustainability performance is more a result of I-action and information uncertainty than concrete policy success or failure. These types of results justifies the development of neutrosophic model which clarify uncertainty as measurable and policy relevant aspect as opposed to residual error term.

In general, by virtues of neutrality the neutrosophic measure overcomes the imbalance in economic development and environmental management as examined in the context. The combined findings demonstrate that, while some industries have achieved measurable progress, many areas continue to suffer from institutional ambiguity and information opacity. Average Neutrosophic Indeterminacy Coefficient (NIC) in areas indicates a moderate to high level of uncertainty, as it is natural given the nascent state of sustainability policy making in transition economies such as Uzbekistan. This result has important theoretical and practical implications: it proves the necessity of

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uncertainty modeling in sustainability evaluation framework and proves that neutrosophic logic can handle multidimensional complex situations in actual policy systems. By measuring the amount of indeterminacy as well as truth and falsity, this study offers policy makers a subtly diagnostic instrument for differentiating between productive progress, systemic size of inefficiency, and factual uncertainty—distinctions that standard econometric models fail to make.

6. Conclusion

This paper presents an integrated exploration of the nexus between economic growth and sustainable development by using a unified econometric–trend neutrosophic analytic approach. The results also demonstrate that continuous economic growth in transition countries, although a reflection of productive structural and institutional changes generates significant environmental pressures when unaccompanied by efficient sustainable development mechanisms. The findings corroborate that, despite the trend of continuous GDP growth, progress towards environmental performance is mixed and decoupling economic expansion from emissions has not fully occurred. This asymmetry reflects the persistence of resource-based production structures and delays in the introduction of green policies, with resultant implications for the pace of transition to a sustainable economic steady state.

Methodologically, the combination of neutrosophic analysis and econometric evaluation is an important contribution to sustainability assessment. While in classical statistics only deterministic relationships can be described, the proposed neutrosophic approach employs local truth, indeterminacy and falsity with explicit uncertainty quantification. This multi-dimensional perspective further refines our understanding of the sustainability–growth link, especially in policy context where incomplete data, institutional ambiguity and implementation inconsistency are dominant. The calculated NSI indicates that uncertainty quantified by indeterminacy strongly affects the reliability and orientation of sustainability results. As a result, growth may be vigorous but the policy performance behind could be hard to discern, or wobbly and in need of more disciplined governance and improved data systems.

This dynamic is borne out in the case of a transition economy, for example Uzbekistan. We also find that periods of high growth are typically accompanied by a rise in CO_2 emissions showing that emissions of industrial output and energy consumption remain dependant on carbon-intensive methods. The analysis does however point to some early signs of structural adaptation such as increased reliance on renewable energy and greater attention to environmental regulation by institutions. This suggests that an incremental transition towards greener growth is in the making, if largely limited by uncertainty and uneven policy execution. The neutrosophic assessment enables to sense out these nuanced types of transitions that would have been difficult to capture in conventional econometric models.

The study has wider implications in its academic and policy relevance. To researchers, it proves the iterative feature of neutrosophic logic as a mathematical extension to connect empirical economics and decision theory under uncertainty. And for policymakers, it serves as a diagnostic aid, distinguishing where sustainability investments are positive, unclear or dysfunctional — and thus informing targeted interventions. Incorporating uncertainty-based approaches can improve the robustness of policy, facilitate decision-making under variations in assumption and lead to adaptive sustainability measures that are consistent with long-term development objectives.

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