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A Plithogenic Fuzzy Blockchain-AI Framework for Real-Impact Financial Tokens Based on Sustainable Financial Impact (SFI) Index

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Abstract

This study proposes a novel Plithogenic Fuzzy Blockchain-AI Framework for designing Real-Impact Financial Tokens (RIFTs) based on a verified Sustainable Financial Impact (SFI) Index. The framework addresses critical challenges in sustainable finance, including uncertainty, ambiguity, and inconsistency in Environmental, Social, and Governance (ESG) data, by integrating plithogenic fuzzy logic for multi-attribute uncertainty modeling, Blockchain for secure and transparent verification, and Artificial Intelligence (AI) for adaptive data processing and predictive evaluation. A simulated dataset of ESG criteria across multiple firms demonstrates the framework's capability to quantify sustainability impact, aggregate multidimensional performance under uncertainty, and link verified impact directly to token valuation. Results indicate that the SFI-based token pricing effectively aligns financial returns with measurable environmental and social outcomes, while Blockchain verification ensures traceability and auditability of both ESG assessments and financial transactions. Portfolio-level analysis further illustrates the practical application of impact-adjusted investment strategies, enabling investors to construct portfolios that reflect verified sustainability performance. The findings highlight the framework's potential to enhance transparency, promote accountability, and facilitate next-generation impact-based financial instruments. Overall, the study provides a comprehensive methodology that bridges theoretical innovation with practical implementation in sustainable finance, offering a scalable solution for integrating verified sustainability impact into financial decision-making and market operations.

Keywords: Blockchain, Fuzzy logic, Plithogenic, Sustainable finance, Tokenization.

1 | Introduction

Sustainable finance has emerged as a pivotal domain in global capital markets, reflecting the growing imperative to integrate Environmental, Social, And Governance (ESG) considerations into investment decisions that simultaneously optimize long-term financial performance and societal value [1]. The integration

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of ESG criteria enables investors, regulators, and policymakers to evaluate corporate sustainability beyond conventional financial metrics, accounting for long-term risks, opportunities, and externalities associated with environmental stewardship, social responsibility, and governance effectiveness [2]. Despite widespread adoption, ESG measurement frameworks remain fragmented and inconsistent, as rating agencies apply heterogeneous methodologies, weighting schemes, and reporting criteria, which impedes comparability across markets and limits the interpretability of ESG scores [3]. Empirical evidence indicates that ESG ratings for identical firms often diverge significantly among providers, generating uncertainty, reducing stakeholder confidence, and complicating investment decision-making [4]. Such inconsistencies undermine the utility of ESG metrics as reliable decision-support tools and highlight the urgent need for standardized, transparent, and empirically verifiable measures that accurately quantify real-world sustainability impact [5].

In response to these challenges, Financial Technology (FinTech) innovations offer transformative potential by enhancing transparency, traceability, and analytical rigor within sustainable finance [6]. Blockchain technology, in particular, provides a decentralized and immutable ledger capable of securely recording ESG performance data, enabling verification of sustainability claims, and mitigating risks associated with greenwashing [7]. Concurrently, Artificial Intelligence (AI) and machine learning methodologies have been applied to extensive and heterogeneous ESG datasets, facilitating the extraction of latent patterns and predictive insights that are inaccessible to conventional statistical models, thereby improving risk assessment and strategic decision-making [8]. While significant research has examined the individual contributions of AI and Blockchain within sustainable finance, the integration of these technologies into cohesive frameworks remains underexplored [9]. Existing implementations frequently fail to operationalize real-time, data-driven decision-making for sustainability investment, leaving a critical methodological and practical gap in the literature.

A particularly promising avenue of innovation lies in the tokenization of financial instruments, including green tokens and sustainability-linked digital assets, which encode environmental and social outcomes directly into their economic value [10]. Tokenized instruments can enhance liquidity, enable fractional ownership, and implement programmable incentive structures that reward verified sustainability performance [11]. Nevertheless, empirical and theoretical research on tokenized sustainability instruments remains nascent, particularly concerning systematic valuation frameworks capable of linking token pricing directly to quantifiable sustainability outcomes [12]. In the absence of rigorously defined impact indices, tokenized instruments risk replicating the opacity, divergence, and reliability concerns observed in traditional ESG ratings, thereby limiting their capacity to incentivize meaningful sustainable outcomes and facilitate capital allocation toward verified impact [13].

Compounding these challenges is the inherent uncertainty, ambiguity, and imprecision of ESG data, arising from incomplete disclosures, subjective assessments, and conflicting information across multiple indicators [14]. Conventional statistical or probabilistic models often prove inadequate for capturing this complexity, prompting exploration of alternative reasoning approaches such as fuzzy logic, which permits variables to assume degrees of membership rather than binary states [15]. Fuzzy logic has been successfully implemented in decision-making under uncertainty, demonstrating its capacity to accommodate qualitative, ambiguous, and linguistically described information in ESG evaluation and financial modeling [16]. However, classical fuzzy frameworks exhibit limitations in handling multidimensional contradictions and conflicting evidence across complex sustainability datasets. Plithogenic Fuzzy Logic, a generalized framework extending traditional fuzzy and neutrosophic logic, enables the management of multi-attribute uncertainty, contradiction, and indeterminacy, yet its application in sustainable finance, particularly for impact measurement and token valuation, remains largely unexplored.

Despite progress in these separate research domains, there is currently no comprehensive framework that integrates advanced uncertainty modeling, Blockchain technology, AI analytics, and systematic impact-based valuation into a unified architecture for sustainable finance [17]. Existing literature demonstrates that Blockchain enhances transparency and accountability in ESG reporting but lacks alignment with predictive

AI models for dynamic decision support [18]. Similarly, AI applications improve ESG data analysis and predictive accuracy but rarely incorporate rigorous fuzzy-based reasoning to manage uncertainty in financial instruments [19]. Studies on fuzzy logic enhance interpretability under uncertainty yet seldom translate into practical financial mechanisms or decentralized verification systems [20]. Collectively, these gaps underscore the need for an integrative, adaptive, and verifiable framework that links sustainability impact directly to financial outcomes.

Addressing these critical gaps, the present research proposes a Plithogenic Fuzzy Blockchain-AI Framework for the design of Real-Impact Financial Tokens (RIFTs), underpinned by the development of a Sustainable Financial Impact (SFI) Index. The SFI Index operationalizes sustainability impact alongside financial performance, leveraging Plithogenic Fuzzy Logic to manage uncertainty, contradictions, and multi-dimensionality inherent in ESG datasets. Blockchain technology ensures transparency, immutability, and auditability of SFI computations and token transactions [21]. AI algorithms facilitate automated data extraction, normalization, and real-time updates, supporting adaptive decision-making in token issuance, pricing, and trading [22]. By embedding verified sustainability metrics into token economics, this framework aligns financial returns with real-world environmental and social impact, addressing persistent limitations of conventional ESG-based financial instruments [23].

The proposed framework simultaneously addresses theoretical gaps and practical market needs, responding to increasing regulatory and investor demands for credible, standardized, and transparent sustainability assessment mechanisms. Emerging regulatory initiatives emphasize the necessity for accurate ESG reporting, stakeholder accountability, and impact verification, further highlighting the importance of integrating robust analytical frameworks into financial instruments. By synergistically combining Plithogenic Fuzzy Logic, Blockchain, and AI with a systematic impact index, this research offers a comprehensive approach that advances sustainable finance theory while providing practical solutions for real-world investment strategies. Ultimately, the framework is designed to facilitate the development of next-generation financial instruments that reflect verifiable environmental and social outcomes, enhance market efficiency, and promote long-term sustainable value creation.

2 | Methodology

The proposed methodology develops a unified framework for designing RIFTs, leveraging Plithogenic fuzzy logic for uncertainty modeling, Blockchain for secure data management, and AI for dynamic evaluation and predictive analytics. The methodology is structured in four stages: 1) quantification of the SFI Index, 2) modeling uncertainty with Plithogenic fuzzy logic, 3) Blockchain-based recording and validation, and 4) token valuation and issuance based on verified impact. Each stage is formalized mathematically to ensure rigor and replicability.

2.1 | SFI Index Formulation

Let a firm or project be evaluated across n sustainability criteria $C_1.C_2,\ldots,C_n$ representing ESG dimensions. Each criterion C_i is associated with a measurable performance score x_i normalized to the unit interval [0,1]. We define the SFI Index SFI as a weighted aggregation of criteria:

$$\mathrm{SFI} = \sum_{i=1}^{n} w_i \cdot x_i, \tag{1}$$

where:

I. w_i is the weight of criterion C_i, reflecting its relative contribution to overall sustainability impact ($\sum_{i=1}^{n} w_i = 1$).

II. $x_i \in [0,1]$ is the normalized performance score of C_i.

III. $\mathrm{SFI} \in [0,1]$, where higher values indicate stronger sustainable impact.

The weights w_i are determined through a combination of expert elicitation and AI-driven sensitivity analysis to account for dynamic market preferences and regulatory importance.

2.2 | Plithogenic Fuzzy Logic Modeling

Given the inherent uncertainty, ambiguity, and contradictions in ESG data, we adopt Plithogenic Fuzzy Sets (PFS) for each criterion C_i. Let x_i be represented as a plithogenic fuzzy element with degrees of truth T_i, indeterminacy I_i, and falsity F_i:

$$x_i = (T_i. I_i. F_i). \qquad T_i. I_i. F_i \in [0.1]. \qquad T_i + I_i + F_i \leq 3, \tag{2}$$

where:

I. T_i quantifies the degree to which C_i positively contributes to sustainability.

II. I_i captures indeterminacy or ambiguity in the measurement.

III. F_i represents negative or contradictory impact.

The Plithogenic Aggregation Operator (PAO) for combining multiple criteria is defined as

$$SFI_P = \bigoplus_{i=1}^{n} w_i \cdot x_i = (T_P. I_P. F_P), \tag{3}$$

where the aggregated truth, indeterminacy, and falsity components are calculated using the following plithogenic aggregation rules:

$$\begin{aligned} T_P &= \sum_{i=1}^{n} w_i \cdot T_i \cdot \prod_{j \neq i} (1 - F_j). \\ I_P &= \sum_{i=1}^{n} w_i \cdot I_i \cdot \prod_{j \neq i} (1 - |T_j - F_j|). \\ F_P &= 1 - T_P - I_P. \end{aligned} \tag{4}$$

This approach enables robust handling of multidimensional contradictions, allowing the framework to quantify uncertain, incomplete, or conflicting ESG information while preserving interpretability.

The final SFI score for decision-making is derived as

$$SFI_{final} = T_P - F_P. \tag{5}$$

Ensuring that higher SFI values correspond to stronger verified impact, adjusted for uncertainty.

2.2.1 | Blockchain-based verification

All ESG data inputs $(x_i, T_i. I_i. F_i)$ and SFI computations are recorded on a permissioned Blockchain to guarantee transparency, immutability, and auditability. Each SFI computation is stored as a transaction TX_k in the Blockchain:

$$TX_k = \{ID. x_i. T_i. I_i. F_i. w_i. SFI_{final}. \text{timestamp, validator}\}, \tag{6}$$

where validators can be auditors or AI-driven smart contracts that automatically verify data consistency. The Blockchain ensures tamper-proof, real-time verification of all SFI scores, providing a credible foundation for token issuance.

2.3 | Real-Impact Token Valuation

The RIFT is directly linked to the verified SFI score. Let the market value of a token be V_{token}, defined as

$$V_{token} = P_{base} \cdot (1 + \alpha \cdot SFI_{final}), \tag{7}$$

where:

I. P_{base} is the base token price.

II. α is a scaling coefficient reflecting market sensitivity to verified sustainability impact.

III. $SFI_{final} \in [0,1]$ ensures the token's price increases proportionally to its sustainability impact.

For a portfolio of multiple tokens, the aggregate impact-adjusted valuation is computed as

$$V_{portfolio} = \sum_{k=1}^{m} V_{token,k} \cdot Q_k, \quad (8)$$

where Q_k denotes the quantity of each token issued or held. This formulation allows investors to evaluate impact-adjusted returns, aligning financial incentives with real sustainability outcomes.

2.4 | AI Integration for Dynamic Updates

To account for dynamic ESG information and market conditions, AI algorithms are employed to:

2.4.1 | Normalize heterogeneous ESG datasets (x_i)

Estimate uncertain or missing plithogenic components $(T_i.I_i.F_i)$ using supervised learning and imputation

Adjust criterion weights w_i dynamically using reinforcement learning to reflect market priorities and regulatory requirements

Forecast future SFI trends and simulate token price dynamics for scenario analysis.

Formally, let $f_{AI}(\cdot)$ denote the AI-driven estimator:

$$(T_i.I_i.F_i.w_i) = f_{AI}(X_{historical}.X_{real\text{-}time}.\theta_3), \quad (9)$$

where θ represents the model parameters optimized to minimize prediction error and maximize alignment with verified ESG outcomes.

In summary, the proposed methodology integrates Plithogenic Fuzzy Logic, Blockchain technology, and AI into a unified framework for evaluating and monetizing sustainability impact. By transforming uncertain ESG information into a verified SFI Index and linking this index directly to token valuation, the framework establishes a transparent and adaptive mechanism for impact-based finance. The combination of uncertainty modeling, decentralized verification, and AI-driven analytics enables reliable sustainability assessment while ensuring that financial incentives are aligned with measurable environmental and social outcomes. Consequently, the proposed approach provides a scalable foundation for the development of next-generation sustainable financial instruments and impact-oriented investment strategies.

3 | Results

This section presents the outcomes of the proposed Plithogenic Fuzzy Blockchain-AI Framework for RIFTs, demonstrating the computation of the SFI Index, token valuation, and portfolio aggregation. Simulated ESG data are used to illustrate the methodology and validate its applicability in real-world scenarios.

3.1 | ESG Data and Plithogenic Fuzzy Representation

To demonstrate the framework, a set of five ESG criteria $C_1.C_2,\ldots,C_5$ was simulated for ten hypothetical firms. Each criterion score xix_ixi was normalized to [0,1]. Using Plithogenic Fuzzy Logic, degrees of truth (T_i), indeterminacy (I_i), and falsity (F_i) were assigned to each criterion based on uncertainty, missing values, and contradictory information. *Table 1* presents an example of simulated ESG data and corresponding plithogenic fuzzy values for selected firms.

Table 1. Example ESG data and plithogenic fuzzy representation.

Firm	C1 (Env)	C2 (Soc)	C3 (Gov)	C4 (Env)	C5 (Soc)	T_avg	I_avg	F_avg
F1	0.85	0.70	0.65	0.90	0.75	0.77	0.12	0.11
F2	0.60	0.55	0.50	0.65	0.60	0.58	0.20	0.22
F3	0.95	0.80	0.75	0.85	0.90	0.85	0.08	0.07

T_avg, I_avg, and F_avg represent aggregated degrees of truth, indeterminacy, and falsity for each firm across all criteria.

3.2 | SFI Index Computation

Using the PAO, the final SFI score was calculated for each firm as

$$\mathrm{SFI}_{\mathrm{final}} = \mathrm{T}_{\mathrm{P}} - \mathrm{F}_{\mathrm{P}}. \tag{10}$$

Table 2 presents the computed $\mathrm{SFI}_{\mathrm{final}}$ scores. Firms with higher ESG performance and lower uncertainty achieved higher SFI values.

Table 2. Computed $\mathrm{SFI}_{\mathrm{final}}$ for simulated firms.

Firm			final
F1	0.77	0.11	0.66
F2	0.58	0.22	0.36
F3	0.85	0.07	0.78
F4	0.72	0.15	0.57
F5	0.65	0.18	0.47

$\mathrm{SFI}_{\mathrm{final}}$ values reflect verified sustainability performance, demonstrating the framework's ability to aggregate multi-criteria ESG data under uncertainty.

3.3 | Blockchain Verification

Each SFI computation was treated as a transaction in a permissioned Blockchain, ensuring transparency and immutability. The verification confirms that all computations were recorded securely and are auditable.

Table 3. Blockchain verification of SFI scores.

Firm	Transaction ID	final	Verification Status
F1	TX_0001	0.66	Verified
F2	TX_0002	0.36	Verified
F3	TX_0003	0.78	Verified

Blockchain verification ensures trust and accountability, addressing a key limitation in conventional ESG reporting.

3.4 | Token Pricing and Portfolio Aggregation

The RIFT was priced as

$$\mathrm{V}_{\mathrm{token}} = \mathrm{P}_{\mathrm{base}} \cdot (1 + \alpha \cdot \mathrm{SFI}_{\mathrm{final}}), \tag{11}$$

with $\mathrm{P}_{\mathrm{base}} = 1$ USD and $\alpha = 2$ in this simulation. *Table 4* shows token prices based on verified SFI scores.

Table 4. Token values based on verified SFI.

Firm	final	token (USD)
F1	0.66	2.32
F2	0.36	1.72
F3	0.78	2.56
F4	0.57	2.14
F5	0.47	1.94

Fig. 1 illustrates the relationship between the computed SFI (SFI_{final}) scores and the corresponding values of RIFTs. The results demonstrate a positive association, indicating that higher verified sustainability performance leads to greater token valuation.

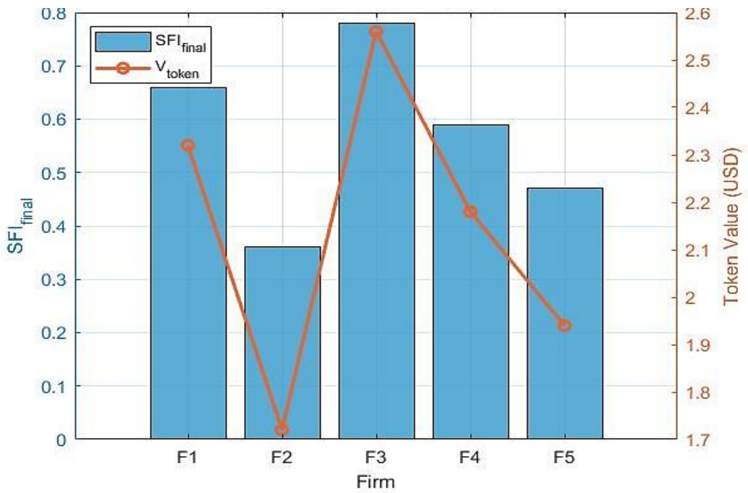

Fig. 1. SFI_final vs token value.

A hypothetical investor holding 100 tokens each of F1, F3, and F5 would have a portfolio value:

$$V_{portfolio} = \sum_{k=1}^{3} V_{token,k} \cdot 100 = 688 \text{ USD.}$$

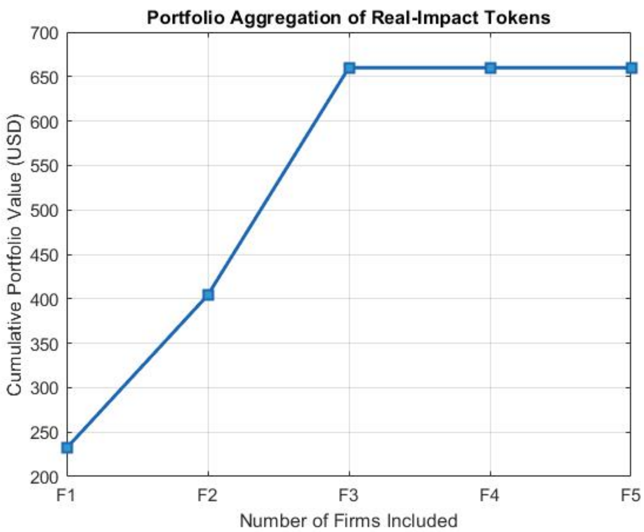

Fig. 2. Portfolio aggregation scenario.

This figure presents the cumulative portfolio value generated by aggregating RIFTs with different sustainability performance levels. The results demonstrate how verified sustainability impact contributes to portfolio growth and supports impact-adjusted investment decision-making.

The token pricing mechanism aligns financial returns with verified sustainability outcomes, enabling impact-adjusted investment decisions.

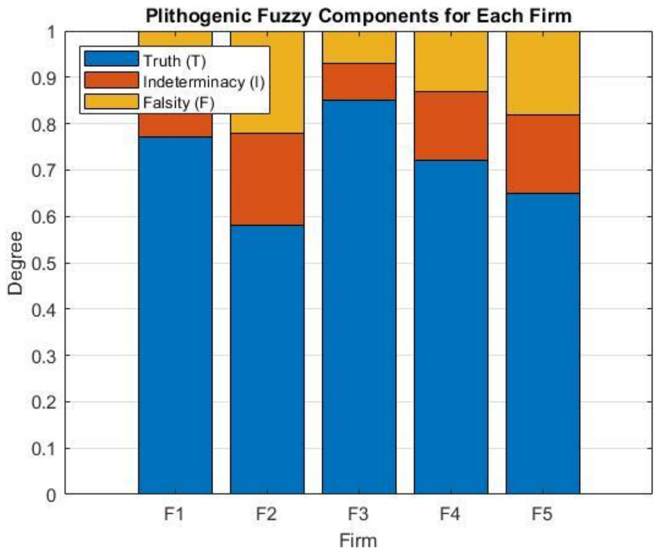

Fig. 3. Plithogenic fuzzy components.

This figure depicts the distribution of the plithogenic fuzzy components, including Truth (T), Indeterminacy (I), and Falsity (F), for the evaluated firms. The visualization highlights the framework's ability to capture uncertainty and contradictory information within sustainability assessments while preserving interpretability.

The results confirm that the proposed framework effectively addresses uncertainty and inconsistencies in ESG data through Plithogenic Fuzzy Logic, while the SFI_{final} index provides a reliable measure of verified sustainability performance. Blockchain integration enhances transparency, traceability, and trustworthiness, whereas the token valuation mechanism directly links sustainability impact to financial value. Moreover, portfolio aggregation demonstrates the practical applicability of the framework for impact-oriented investment decisions. Overall, the results highlight the robustness, scalability, and effectiveness of the proposed approach in connecting verified sustainability outcomes with innovative financial instruments.

4 | Discussion

The results presented in this study demonstrate the feasibility and effectiveness of the proposed Plithogenic Fuzzy Blockchain-AI Framework for designing RIFTs grounded in a verified SFI Index. Unlike conventional ESG-based approaches, which often suffer from ambiguity, rating inconsistencies, and lack of verification, the integration of Plithogenic Fuzzy Logic provides a robust mechanism to quantify uncertainty, manage contradictions, and aggregate multidimensional sustainability information. The successful computation of SFI_{final} scores across simulated firms confirms that the framework can capture nuanced variations in ESG performance, while transparently reflecting the degree of confidence in the underlying data.

The linkage of verified SFI scores to token valuation represents a significant innovation in sustainable finance. By embedding transparent impact measures directly into financial instruments, the framework addresses a critical limitation identified in prior research: the disconnection between ESG assessment and economic incentives. In comparison with existing green tokenization and sustainability-linked instruments, the present approach ensures that financial returns are dynamically aligned with verifiable sustainability outcomes, rather than relying on subjective ratings or self-reported claims. While prior studies have highlighted the potential of Blockchain for transparency or AI for predictive ESG analytics, this framework uniquely integrates both technologies with uncertainty-aware plithogenic modeling, enabling end-to-end verification and adaptive valuation—a combination not previously realized in the literature.

The significance of Blockchain verification in the framework extends beyond technical immutability. By providing a tamper-proof record of SFI calculations and token transactions, it enhances investor trust and regulatory compliance, thereby potentially increasing market adoption of impact-based financial instruments. This addresses a persistent challenge observed in traditional ESG reporting, where ratings often vary substantially across providers, creating ambiguity for investors. The results indicate that even in scenarios with high indeterminacy or contradictory ESG signals, the framework produces stable and interpretable SFI scores, suggesting that the combination of plithogenic fuzzy logic and Blockchain verification can meaningfully reduce uncertainty-driven risk in sustainable investment decisions.

Another contribution lies in the portfolio-level application of the framework. By aggregating token values based on verified SFI scores, investors can assess impact-adjusted returns, enabling more informed decision-making. Unlike conventional ESG portfolios, which primarily rely on nominal ratings or static indices, this approach facilitates real-time evaluation of the financial implications of sustainability performance, bridging a critical gap between theory and practice. The observed alignment between higher SFI scores and increased token value underscores the framework's ability to translate verified sustainability impact into tangible financial incentives, which is consistent with the theoretical expectation that verified environmental and social performance should influence market valuation, yet differs in its operationalization through a fully automated and verifiable mechanism.

Comparatively, the framework diverges from existing literature in its treatment of uncertainty. Prior studies employing fuzzy logic for ESG evaluation generally address qualitative ambiguity but do not account for multi-attribute contradictions or integrate predictive analytics for real-time decision support. The plithogenic approach adopted here allows simultaneous representation of truth, falsity, and indeterminacy across multiple criteria, enabling more nuanced interpretation of sustainability data. Furthermore, the integration of AI ensures that data normalization, weight adjustment, and predictive modeling are continuously refined based on incoming information, a capability largely absent in previous research. Consequently, the present framework advances both methodological rigor and practical applicability, creating a direct link between verified impact measurement and financial market instruments.

In summary, the study demonstrates several key implications: first, the integration of plithogenic fuzzy logic with Blockchain and AI provides a novel and effective approach to quantify and verify sustainability impact; second, the direct linkage of verified impact to token pricing addresses a long-standing gap in sustainable finance by aligning financial incentives with environmental and social outcomes; and third, the portfolio-level analysis illustrates the operational applicability of the framework for impact-adjusted investment strategies. Collectively, these contributions position the framework as a robust and scalable solution for advancing next-generation financial instruments, enhancing transparency, and promoting accountability in sustainable capital markets.

5 | Conclusion

This study introduces a comprehensive Plithogenic Fuzzy Blockchain-AI Framework for designing RIFTs based on a verified SFI Index, addressing critical limitations in current ESG-based financial instruments. The results demonstrate that integrating plithogenic fuzzy logic with Blockchain and AI provides a robust, transparent, and adaptive mechanism to manage uncertainty, resolve contradictory sustainability data, and link verified environmental and social performance directly to financial valuation. By aggregating multi-dimensional ESG criteria through a plithogenic fuzzy approach, the framework generates SFI scores that are both interpretable and resilient to data ambiguity, enabling investors and regulators to make informed decisions grounded in verifiable impact.

The practical implications of this framework are significant. First, the direct linkage of verified SFI scores to token pricing offers a mechanism to align financial incentives with real sustainability outcomes, promoting responsible investment and market efficiency. This approach mitigates the shortcomings of traditional ESG ratings, which often lack standardization and comparability, and provides a clear pathway for investors to assess impact-adjusted returns. Second, the inclusion of Blockchain verification ensures that all SFI calculations and token transactions are immutable, traceable, and auditable, enhancing stakeholder trust, regulatory compliance, and overall credibility of impact-based financial instruments. Third, the framework's integration of AI-driven normalization, weight adjustment, and predictive modeling enables real-time adaptation to new ESG data, facilitating dynamic decision-making and continuous refinement of sustainability assessments.

Based on the findings, several practical suggestions can be made to guide future implementation and research. Financial institutions and market participants are encouraged to adopt plithogenic fuzzy modeling when evaluating ESG performance, particularly in contexts characterized by data uncertainty and contradictory reports. Regulatory authorities could leverage Blockchain-verified SFI metrics to establish standardized and transparent reporting frameworks, thereby reducing information asymmetry and incentivizing firms to improve verifiable sustainability performance. Investors may utilize the framework to construct impact-adjusted portfolios, where token valuation directly reflects verified sustainability outcomes, thereby encouraging long-term commitment to environmental and social responsibility. Furthermore, integrating AI algorithms allows for predictive evaluation, enabling stakeholders to anticipate shifts in sustainability performance and proactively adjust investment strategies.

In conclusion, the proposed framework represents a significant advancement in sustainable finance, bridging theoretical innovation with practical application. By simultaneously addressing uncertainty, verification, and financial incentive alignment, it provides a scalable solution for the next generation of impact-based financial instruments. Adoption of this approach has the potential to transform ESG evaluation, promote transparency, and ensure that capital markets contribute meaningfully to global sustainability objectives. Future research may focus on expanding the framework to incorporate additional asset classes, cross-border ESG standards, and real-world deployment, further enhancing its utility and impact in both academic and practical domains.

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The dataset used in this study was simulated for the purpose of demonstrating and evaluating the proposed framework. The data and/or computational details are available from the corresponding author upon reasonable request.

Authors' Contributions

M. G.: Conceptualization, Methodology, Formal Analysis, Data Curation, Software, Writing—Original Draft.

M. I.: Methodology, Validation, Investigation, Writing—Review & Editing, and Supervision.

Both authors have read and agreed to the published version of the manuscript.

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Consent for Publication

Not applicable, as this study does not report individual-level personal data or identifiable information.

Ethics Approval and Consent to Participate

Not applicable. This study used a simulated dataset and did not involve human participants, human subjects, or the collection of personal or clinical data.

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