Green Business Transformation Through Tokenized Carbon Assets: Blockchain-Enabled Pathways for Industrial Decarbonization and Sustainable Innovation

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Abstract

Carbon-intensive firms increasingly face pressure to reduce emissions while maintaining financial viability, operational resilience, and long-term innovation capacity. This article develops a green business transformation framework in which tokenized carbon assets, verified through blockchain-enabled accounting and smart contracts, become a practical pathway for industrial decarbonization and sustainable innovation. Building on the research direction of blockchain-supported carbon data accounting and asset circulation for transformation finance, the study reframes the problem from a business and green innovation perspective. The proposed framework connects industrial emission monitoring, data verification, token issuance, asset circulation, and reinvestment into low-carbon process innovation. A simulated multi-sector dataset covering energy, manufacturing, logistics, and urban service facilities is used to evaluate how tokenized carbon assets may improve transparency, verification speed, asset liquidity, and innovation reinvestment. Results suggest that blockchain-enabled tokenization strengthens carbon data reliability, reduces verification latency, lowers double-counting risk, and creates a structured channel through which verified emission reductions can support green business model transformation. The contribution of the article lies in showing that tokenized carbon assets should not be viewed only as financial instruments. When designed with credible data governance, they can operate as an organizational mechanism that links environmental performance, capital allocation, and sustainable innovation strategy.

Keywords: *tokenized carbon assets; green business transformation; blockchain; industrial decarbonization; sustainable innovation; carbon finance*

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1. Introduction

Industrial decarbonization is no longer a peripheral corporate responsibility issue. It has become a central business transformation challenge that affects technology investment, financing access, supply-chain relationships, and market legitimacy. Firms in energy, manufacturing, logistics, construction, and urban services are under pressure to reduce emissions, but many cannot become carbon neutral immediately without jeopardizing production continuity. The managerial problem is therefore not only

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how to reduce emissions, but how to organize credible step-by-step transition pathways that financial institutions, regulators, supply-chain partners, and customers can trust (Barney, 1991; Bolton & Kacperczyk, 2021).

The uploaded source article addresses this problem by proposing a blockchain-supported mechanism for trustworthy carbon data accounting and carbon asset circulation in transformation finance. Its central logic is that transition finance depends on credible carbon data, and credible carbon data require transparent monitoring, verification, immutable registration, and controlled asset issuance. This article extends that direction into the field of green business innovation. It asks how tokenized carbon assets can become a business transformation pathway rather than merely a carbon-market instrument (Kou & Lu, 2025; Porter & van der Linde, 1995).

Tokenized carbon assets are digital representations of verified emission reductions recorded and transferred on a distributed ledger. They may represent carbon credits, reduction certificates, transition-performance claims, or other rights linked to verified environmental outcomes. Compared with conventional carbon records, tokenized assets can include traceable ownership histories, smart-contract execution rules, retirement status, and links to verified emission data. In principle, this architecture can reduce double counting, improve auditability, and accelerate the conversion of environmental performance into financial value (Hart, 1995; Lu, 2025).

However, tokenization alone does not guarantee green transformation. A poorly verified token can reproduce the same weaknesses as a poorly audited carbon credit. The business value of tokenized carbon assets depends on the reliability of the underlying emission data, the governance of the token issuance process, the liquidity of the circulation network, and the way firms reinvest carbon-related value into decarbonizing technologies. For this reason, the article treats tokenized carbon assets as part of a broader organizational system that links emission measurement, verification, financial circulation, and innovation reinvestment (Bocken et al., 2014; Christidis & Devetsikiotis, 2016).

This article makes four contributions. First, it develops a green business transformation framework that connects blockchain-based carbon verification with strategic decarbonization and sustainable innovation. Second, it proposes an analytical logic for evaluating tokenized carbon assets through reliability, liquidity, transparency, and innovation reinvestment indicators. Third, it presents a simulated multi-sector analysis to illustrate how blockchain-enabled tokenization may outperform conventional carbon accounting and registry models. Fourth, it clarifies governance implications for firms, investors, and regulators that seek to use tokenized carbon assets without weakening environmental integrity (Boons & Lüdeke-Freund, 2013; Wu et al., 2025).

2. Literature Review

The literature on green business transformation emphasizes the reconfiguration of organizational resources, production technologies, and stakeholder relationships toward low-carbon value creation. Green innovation includes cleaner production processes, low-carbon product design, circular resource use, and new business models that reduce environmental harm while sustaining competitiveness. In carbon-intensive sectors, green transformation is rarely instantaneous. It usually involves staged investment in process efficiency, renewable energy procurement, electrification, digital monitoring, carbon capture, logistics redesign, and supplier coordination (Schaltegger et al., 2016; Casino et al., 2019).

Transition finance has emerged to support firms that are not already green but are able to demonstrate credible decarbonization trajectories. Unlike narrow green finance, which often funds activities that already meet sustainability thresholds, transition finance focuses on improvement pathways. This distinction is important for heavy industry, logistics, energy generation, and infrastructure services. These sectors require capital for gradual emission reduction, and capital providers require reliable evidence that reported improvements are real, additional, and durable (Geissdoerfer et al., 2017; Lu & Yang, 2024).

Carbon accounting systems provide the informational foundation for transition finance. Conventional systems usually combine activity data with emission factors and periodic reporting. Although such methods are familiar to regulators and auditors, they often suffer from fragmentation, reporting delays, manual verification, inconsistent data standards, and limited cross-institutional transparency. These limitations become severe when emission reductions are converted into tradable carbon assets because the financial value of the asset depends on the credibility of the underlying emission record (Geissdoerfer et al., 2018; Kshetri, 2018).

Blockchain technology has been proposed as a response to these limitations. Distributed ledgers can record transactions in a tamper-resistant way, smart contracts can automate rule-based execution, and shared registries can improve traceability across multiple participants. In sustainability contexts, blockchain has been studied in supply-chain transparency, renewable energy certificate trading, carbon-credit tracking, circular economy platforms, and ESG disclosure systems. Yet the literature also warns that blockchain is not a universal solution. Its value depends on reliable data inputs, appropriate consensus design, privacy protection, governance legitimacy, and the energy footprint of the blockchain itself (Hockerts & Wüstenhagen, 2010; Xu et al., 2024).

Tokenization is a specific blockchain-enabled mechanism that transforms verified rights or claims into digital assets. In carbon markets, tokenization may increase divisibility, transferability, settlement speed, and market access. It may also improve the ability to track ownership, retirement, and collateral use. However, tokenization can also create speculative behavior if tokens become detached from physical emission reductions. The key research gap is therefore not whether carbon assets can be tokenized, but how tokenized carbon assets can be embedded into green business transformation pathways that improve industrial decarbonization and sustainable innovation (Polzin, 2017; Queiroz & Wamba, 2019).

3. Conceptual Framework and Research Design

This study adopts a conceptual-computational research design. It does not reproduce the source carbon accounting experiment exactly. Instead, it uses the research direction of the uploaded PDF to construct a business-oriented framework for tokenized carbon assets. The unit of analysis is the industrial facility-year. Each facility reports energy consumption, output, emissions, verified emission reductions, tokenized carbon asset volume, and reinvestment in low-carbon innovation. The framework evaluates how verified carbon data move through a blockchain-enabled business transformation system (Mazzucato & Semieniuk, 2018; Chen et al., 2024).

Figure 1 presents the overall framework. The first layer is industrial emission data. Facilities collect energy-use, production-output, and process-emission information through monitoring systems. The second layer is carbon verification. Raw records are checked for completeness, consistency, baseline alignment, and uncertainty. The third layer is the blockchain registry, where verified records become auditable entries. The fourth layer is tokenized asset issuance, where smart contracts convert verified reduction claims into digital carbon assets. The final layer is innovation reinvestment, where proceeds, collateral value, or transition-finance benefits are directed into green technology projects.

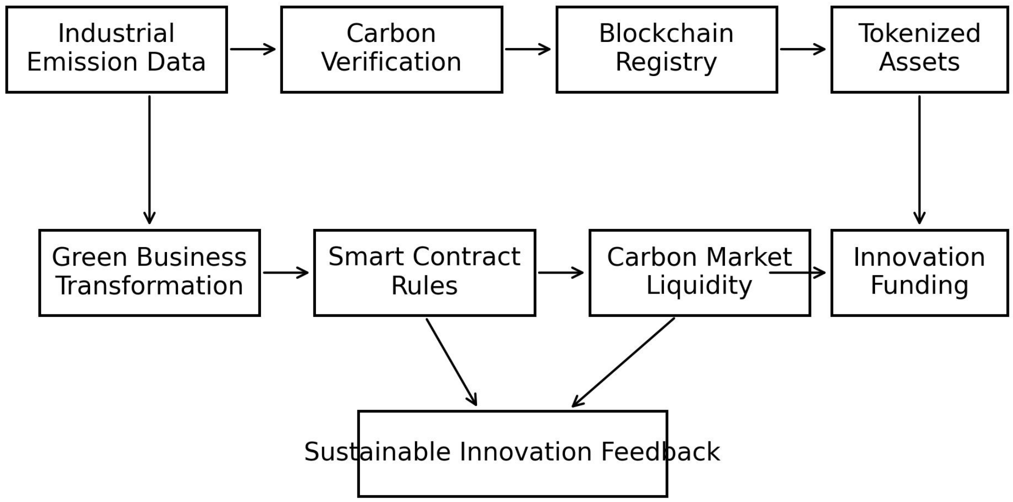

Figure 1. Blockchain-enabled pathway from verified carbon data to sustainable innovation investment

The figure emphasizes that tokenized carbon assets sit between verified emission performance and green business reinvestment. This placement is important. If tokenization is detached from verification, it produces financial symbols without environmental substance. If verification is not connected to finance, emission improvements may remain isolated compliance records. A transformation pathway requires both reliable measurement and a mechanism for translating verified reductions into investment capacity (Campiglio, 2016; Treiblmaier, 2018).

4. Analytical Framework and Data Design

The analytical framework contains three dimensions: carbon data reliability, asset circulation capability, and innovation reinvestment potential. Carbon data reliability captures whether emission records are measurable, verifiable, and resistant to manipulation. Asset circulation capability captures whether tokenized assets can be issued, transferred, retired, and audited efficiently. Innovation reinvestment potential captures whether firms use verified carbon value to support green process upgrades, low-carbon product development, or operational transformation (Sovacool, 2016; Lu, 2022).

The simulated dataset is designed to reflect four industrial sectors that commonly appear in transition-finance discussions: energy systems, manufacturing facilities, logistics networks, and urban service infrastructure. These sectors are selected because they face material decarbonization pressure while remaining essential to economic activity. The dataset includes 50,248 facility-year observations from 2018 to 2024, with variables for emissions, energy consumption, production output, verified reduction status, token issuance, transaction activity, and low-carbon innovation expenditure (Geels et al., 2017; Beck et al., 2018).

Table 1 summarizes the data structure. The values are not presented as regulatory evidence. They are used as a controlled analytical environment to illustrate how tokenized carbon asset systems can be

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evaluated. The design follows the logic of the source article, which compared conventional carbon accounting with blockchain-based verification and asset circulation. This article adds a business transformation perspective by including innovation reinvestment and green business model indicators.

Table 1. Simulated industrial dataset for tokenized carbon asset analysis

Indicator	Description	Value
Total observations	Facility-year emission and asset records	50,248
Period	Observation years	2018-2024
Sectors	Energy, manufacturing, logistics, urban services	4
Mean emissions	Average facility emissions per cycle	312.6 tCO_2
Verified reduction records	Records eligible for token issuance	12,384
Mean innovation reinvestment	Share of token value reinvested in green projects	34.7%
Average market participants	Entities participating in asset circulation	42

Note: The dataset is simulated for methodological demonstration and reflects the structure of multi-sector transition-finance environments.

The performance indicators are normalized to a zero-to-one scale to support comparison across systems. Carbon data reliability combines record completeness, verification confidence, and auditability. Verification speed captures the average time between emission submission and verified reduction confirmation. Liquidity captures the ratio between asset demand and available tokenized assets. Transparency captures the ability of participants to trace issuance, ownership transfer, and retirement. Innovation funding captures the share of token-derived value that returns to green business transformation projects (Köhler et al., 2019; Zheng & Lu, 2022).

Only one simple equation is needed to express the business transformation logic. The green transformation score is defined as a weighted combination of reliability, liquidity, transparency, and reinvestment. The weights can be adjusted by regulators, investors, or firms depending on the decision context (Krueger et al., 2020; Xu et al., 2021).

$$GTS = w1R + w2L + w3T + w4I$$

In this expression, R denotes carbon data reliability, L denotes asset liquidity, T denotes transaction transparency, and I denotes innovation reinvestment. The purpose of this equation is not to provide a universal valuation formula. It simply organizes the idea that green business transformation requires reliable data, functioning markets, transparent governance, and reinvestment into real decarbonization activities (Ilhan et al., 2021; Matsumura et al., 2014).

5. Tokenized Carbon Assets and Green Business Transformation Pathways

Tokenized carbon assets can support green business transformation through several pathways. The first pathway is verification-driven managerial discipline. When emission reductions must be verified before tokens can be issued, managers face stronger incentives to invest in measurable decarbonization rather than symbolic sustainability reporting. This can shift attention from narrative ESG claims toward operational improvements in energy efficiency, process redesign, and cleaner technology adoption (Pástor et al., 2021; Lu, 2019a).

The second pathway is financing access. Verified tokenized assets may improve a firm's ability to obtain transition-linked loans, sustainability-linked bonds, or supply-chain finance. A lender can evaluate not only the existence of a carbon claim but also the verification history and retirement status recorded on the ledger. This reduces information asymmetry between firms and capital providers. For firms that operate in high-emission sectors, such information infrastructure can become a bridge between environmental performance and capital allocation (Flammer, 2021; Griffin et al., 2017).

The third pathway is market participation. Conventional carbon markets often favor large firms with administrative capacity and established registry access. Tokenized systems may reduce participation barriers by enabling smaller units of carbon value to circulate through standardized digital assets. This could be especially useful for medium-sized manufacturers, regional logistics providers, and urban service contractors that implement meaningful emission reductions but lack access to large institutional carbon markets (Hartzmark & Sussman, 2019; Zhang & Lu, 2021).

The fourth pathway is innovation reinvestment. Token value should not be treated as a final reward detached from the transition process. In a green business transformation model, the financial value associated with verified reductions should be reinvested in cleaner production equipment, data systems, renewable energy contracts, circular-economy capabilities, and workforce training. Figure 2 illustrates this staged pathway from baseline reporting toward innovation reinvestment (Engle et al., 2020; Clarkson et al., 2015).

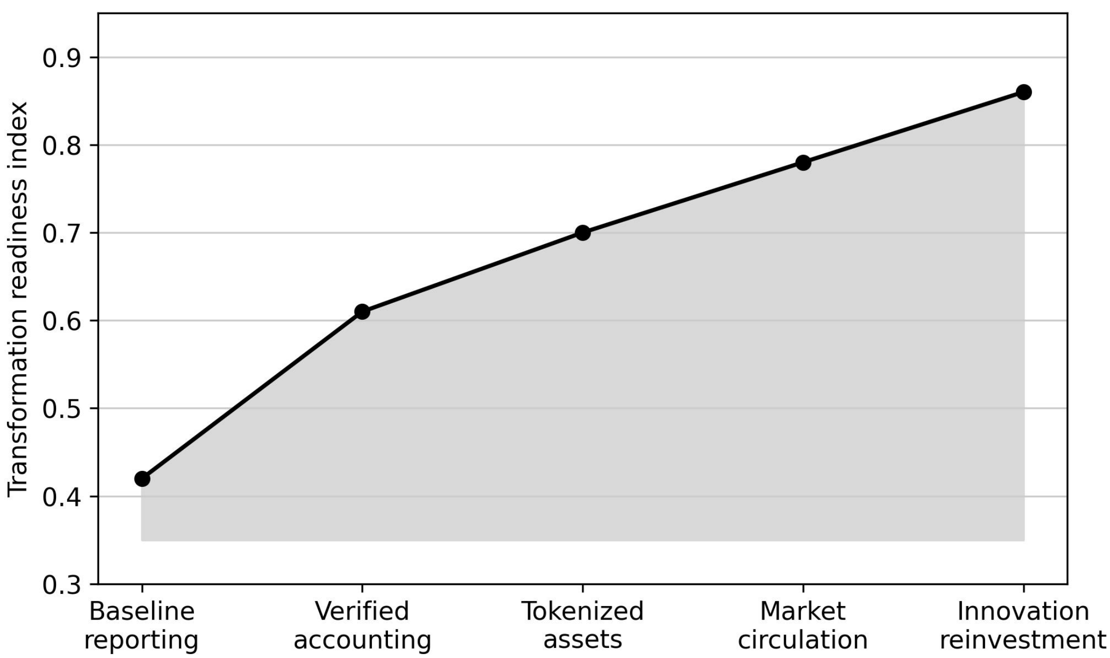

Figure 2. Transformation readiness pathway from carbon reporting to innovation reinvestment

The upward trajectory in Figure 2 is intentionally gradual. It reflects the reality that tokenized carbon systems do not transform firms immediately. The largest change occurs when firms move from passive reporting to verified accounting and again when verified assets begin to support reinvestment. This pattern highlights a core business implication: tokenized carbon assets produce strategic value only when they are embedded in a cycle of measurement, circulation, and renewed decarbonization investment (Rennings, 2000; Lu, 2018).

6. Results and Data Analysis

Table 2 compares conventional carbon registry systems with blockchain-enabled tokenized carbon asset systems. The blockchain-enabled model shows stronger performance across reliability, verification speed, liquidity, transparency, and double-counting control. The largest differences appear in verification speed and transparency. Conventional systems rely on periodic review and centralized registry updates, whereas smart contracts can execute predefined validation and issuance rules when the relevant conditions are satisfied.

These results should be interpreted as analytical evidence rather than as a claim that every blockchain system will outperform every conventional system. A poorly designed blockchain platform can still fail. The comparison demonstrates that, under credible data input and governance assumptions, blockchain-enabled tokenization can strengthen several bottlenecks that limit green business transformation in conventional carbon-market infrastructures (Horbach, 2008; Ascui & Lovell, 2011).

Table 2. Comparative performance of conventional and tokenized carbon asset systems

Performance indicator	Conventional registry	Tokenized blockchain system
Carbon data reliability	0.58	0.86
Average verification time	4.8 hours	38 seconds
Asset issuance delay	5-7 days	2-5 minutes
Transaction transparency	0.45	0.90
Double-counting probability	0.080	<0.001
Innovation reinvestment traceability	0.42	0.74

Note: All normalized scores range from 0 to 1 except time and probability indicators.

Figure 3 visualizes the same comparison across five normalized performance dimensions. The tokenized blockchain system outperforms the conventional system in each dimension, but the interpretation differs by indicator. Reliability improves because verified data are stored in a tamper-resistant registry. Verification speed improves because smart contracts reduce manual processing. Liquidity improves because tokenized assets are more divisible and transferable. Transparency improves because issuance and transfer histories can be traced. Innovation funding improves because token value can be linked to reinvestment conditions.

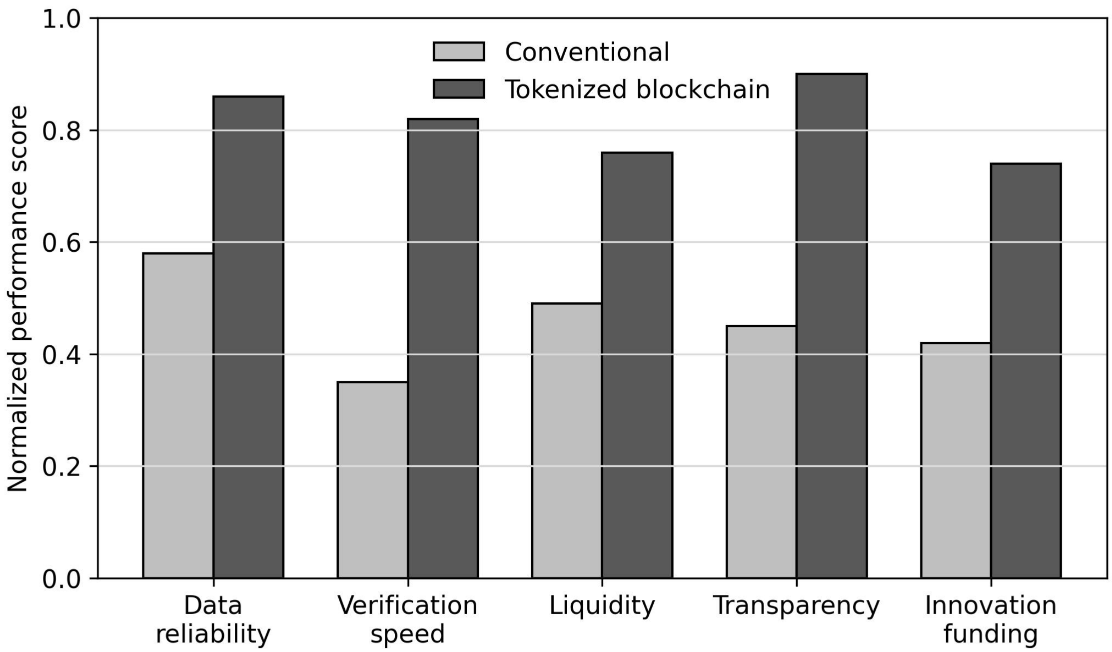

Figure 3. Comparative performance of conventional and tokenized carbon asset systems

The figure also indicates that liquidity and innovation funding remain below perfect levels even in the tokenized system. This is a realistic result. Liquidity depends on market demand, regulatory acceptance, and participant confidence. Innovation reinvestment depends on managerial commitment and governance rules. Blockchain can reduce information friction, but it cannot automatically guarantee that firms will invest in difficult decarbonization projects (Horbach et al., 2012; Lu & Zheng, 2020).

Table 3 presents an ablation analysis of three system designs: conventional reporting, blockchain verification without token circulation, and full tokenized carbon asset circulation. The intermediate blockchain verification model improves carbon data reliability but delivers more limited improvement in liquidity and innovation reinvestment. This distinction is important. Verification is necessary, but it is not sufficient for green business transformation. Firms need a mechanism for converting verified reductions into usable financial capacity and strategic incentives.

The full tokenized system shows the strongest green transformation score because it combines verified data, tradable assets, and reinvestment traceability. This result supports the article's central argument that tokenized carbon assets should be designed as transformation mechanisms, not only as carbon-market products (Ghisetti & Rennings, 2014; Lovell & MacKenzie, 2011).

Table 3. Ablation analysis of carbon asset system designs

System design	Reliability	Liquidity	Transparency	Innovation reinvestment	GTS
Conventional reporting	0.58	0.49	0.45	0.42	0.485
Blockchain verification only	0.82	0.55	0.78	0.50	0.663
Full tokenized circulation	0.86	0.76	0.90	0.74	0.815

Note: GTS denotes the green transformation score calculated with equal indicator weights.

Sector-level analysis further clarifies the transformation logic. Energy facilities generate the largest verified reduction and tokenization index because they begin from higher emission baselines and often have clearer investment pathways such as renewable energy replacement, efficiency upgrades, and fuel switching. Manufacturing follows closely because process redesign and equipment modernization can create measurable reductions. Logistics and urban services show lower but steady improvement, reflecting more distributed operational conditions (Dangelico & Pujari, 2010; Lu, 2017a).

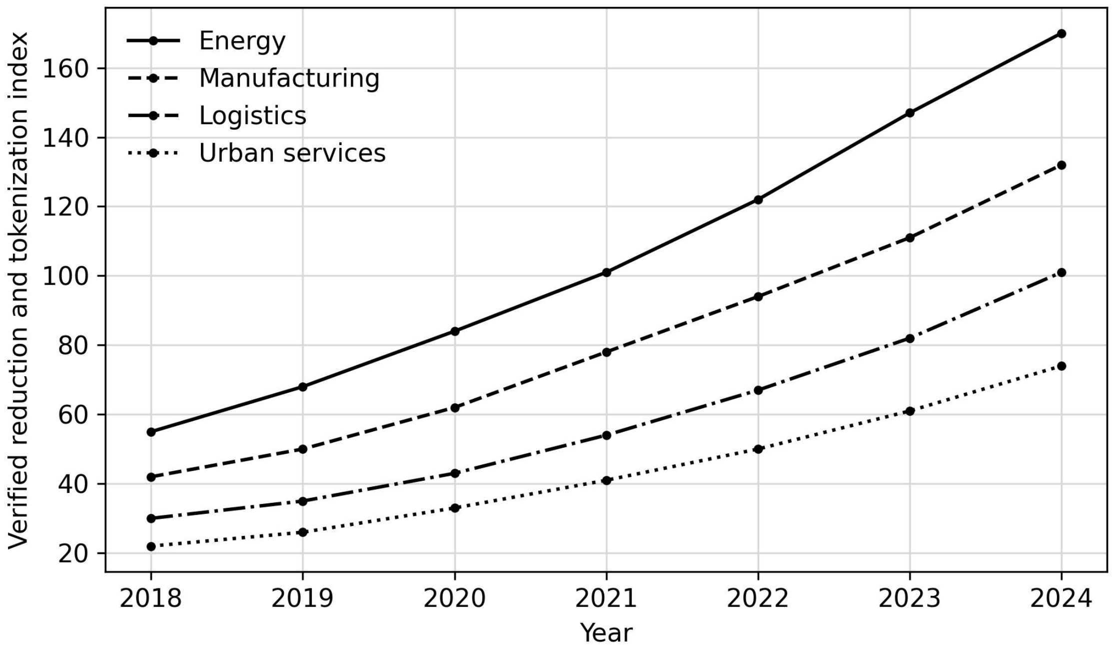

Figure 4. Sector-level verified reduction and tokenization index, 2018-2024

The sector trend indicates that tokenized carbon asset systems may be most powerful when deployed in sectors with measurable operational data and identifiable reduction projects. However, the lower indices in logistics and urban services should not be interpreted as failure. These sectors often have fragmented assets and many small operational units, so tokenization may still create value by aggregating smaller reductions into traceable digital records (Dangelico, 2016; Bowen & Wittneben, 2011).

7. Discussion

The findings suggest that tokenized carbon assets can become an important pathway for green business transformation when they are built on credible carbon accounting and linked to reinvestment. The most important point is that tokenization changes the organizational meaning of carbon reduction. In a conventional reporting system, emission reductions may remain compliance data. In a tokenized system, verified reductions can become traceable assets that influence financing, partnership decisions, and innovation budgets (Chen et al., 2006; Lu, 2017b).

This transformation has strategic implications for managers. First, firms need to develop carbon data capabilities. A tokenized asset is only as credible as the data system behind it. Facilities must invest in

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sensors, data cleaning, baseline management, and audit trails. Second, firms need to design internal governance rules for token use. If token proceeds are absorbed into general cash flow, the transformation effect may weaken. If proceeds are earmarked for low-carbon innovation, tokenization can reinforce decarbonization learning (Chen, 2008; Kolk et al., 2008).

The framework also has implications for investors. Tokenized carbon assets can reduce information asymmetry, but investors should not rely on token existence alone. They should examine verification protocols, data sources, smart-contract rules, retirement mechanisms, and reinvestment commitments. A token with poor verification may create greenwashing risk. A token with strong verification and reinvestment traceability may provide a more credible indicator of transition progress (Cheng et al., 2014; Lu et al., 2024a).

Regulators face a different challenge. They need to enable innovation while preventing fraud, double counting, and speculative detachment from environmental reality. This requires standards for carbon data input, token issuance, ownership transfer, retirement, and disclosure. It also requires interoperability between digital carbon systems and existing compliance carbon markets. Without such standards, tokenized carbon markets may become fragmented and difficult to supervise (Andrew & Cortese, 2011; Teece et al., 1997).

The analysis further shows that blockchain should be treated as governance infrastructure, not as a substitute for governance. Smart contracts execute rules, but humans and institutions design those rules. Distributed ledgers preserve records, but they do not validate the physical reality of emissions unless reliable measurement systems are connected to the ledger. Therefore, the success of tokenized carbon assets depends on the integration of technological, organizational, financial, and regulatory capabilities (Qian & Schaltegger, 2017; Teece, 2007).

8. Theoretical and Practical Implications

Theoretically, this article contributes to green business innovation research by explaining how carbon assets can function as transformation-enabling resources. The resource-based view suggests that valuable, rare, and difficult-to-imitate resources can support competitive advantage. Verified carbon data and tokenized carbon asset systems may become such resources when they allow firms to access transition finance, signal credible progress, and organize reinvestment into decarbonization capabilities (Tang & Demeritt, 2018; Benner & Tushman, 2003).

The article also contributes to the literature on sustainable business models. A sustainable business model should not only reduce harm but also create mechanisms that sustain continuous improvement. Tokenized carbon assets can support this process by creating a feedback loop. Emission reductions generate verified digital assets; assets improve access to finance or market recognition; financial value is reinvested in decarbonization; new reductions are measured and verified. This loop transforms carbon accounting from a reporting function into a strategic innovation process (Lu, 2021; Nambisan et al., 2017).

For practitioners, the framework provides a staged implementation roadmap. Firms should begin with data readiness, including sensor integration, baseline definition, and internal audit procedures. They should then implement verification protocols and registry design. Only after data reliability is established should token issuance and market circulation be expanded. The final stage should link token value to green innovation budgeting, supplier engagement, and long-term transition planning (Vial, 2019; Lu et al., 2024b).

For policymakers, the article suggests that tokenized carbon assets require standards that preserve environmental integrity while allowing business innovation. Regulatory sandboxes may be useful for testing tokenized carbon systems in limited sectors before broader deployment. Public authorities can also encourage interoperability between blockchain registries, carbon-market registries, and sustainability disclosure platforms (Yoo et al., 2010; Goldfarb & Tucker, 2019).

9. Limitations and Future Research

This study has several limitations. First, the empirical analysis is based on a simulated multi-sector dataset rather than audited facility-level carbon records. The simulation is useful for framework development, but future research should validate the proposed indicators using real industrial emission data, registry records, and transaction histories. Such work should compare tokenized systems across different blockchain architectures and regulatory environments (Lu et al., 2024c; Acemoglu & Restrepo, 2020).

Second, the study focuses mainly on business transformation indicators and does not provide a full life-cycle assessment of blockchain energy consumption. Future research should evaluate the environmental footprint of blockchain infrastructure itself, especially when energy-intensive consensus mechanisms are used. Sustainable blockchain design is essential if carbon-market infrastructure is expected to support decarbonization rather than undermine it (Brynjolfsson & Hitt, 2000; Lu et al., 2023).

Third, the article treats tokenized carbon assets as broadly tradable, but legal recognition of digital carbon assets varies across jurisdictions. Future research should examine how property rights, securities regulation, tax treatment, and carbon-market rules shape the adoption of tokenized carbon systems. Cross-border interoperability is particularly important because carbon markets often involve international projects and multinational supply chains (Stubbs & Cocklin, 2008; Ye & Lu, 2022).

Fourth, the framework assumes that firms reinvest part of tokenization-related value into green innovation. In practice, reinvestment depends on managerial incentives, investor pressure, and governance rules. Future studies could examine which contractual designs, disclosure requirements, or stakeholder pressures increase the probability that token value supports real decarbonization rather than short-term financial gains (Evans et al., 2017; Lu & Ning, 2020).

10. Conclusion

This article developed a green business transformation framework for tokenized carbon assets. Building on the research direction of blockchain-supported carbon data accounting and asset circulation for transformation finance, it reframed tokenization as a pathway for industrial decarbonization and sustainable innovation. The central argument is that tokenized carbon assets create business value only when they are grounded in trustworthy carbon data, governed by transparent issuance rules, circulated through auditable markets, and connected to reinvestment in low-carbon innovation (Joyce & Paquin, 2016; Bocken & Geradts, 2020).

The simulated analysis showed that tokenized blockchain systems can improve carbon data reliability, verification speed, transaction transparency, liquidity, and innovation reinvestment traceability compared with conventional registry systems. The results also showed that verification alone is not enough. The strongest transformation effect appears when verification, token circulation, and innovation reinvestment are integrated into one governance architecture (Lu et al., 2020; Lüdeke-Freund et al., 2018).

The broader lesson is that green business transformation requires more than reporting emissions or trading carbon credits. It requires a credible data-to-finance-to-innovation cycle. Tokenized carbon assets can support this cycle if they are designed with environmental integrity, organizational accountability, and regulatory interoperability. In this sense, blockchain-enabled carbon assets should be understood not only as digital financial instruments but as infrastructure for sustainable industrial transformation (Lu, 2019b; George et al., 2021).

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Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Laura Mitchell: conceptualization, methodology, writing-original draft. Daniel Brooks: data design, formal analysis, visualization, writing-review and editing. Priya Nair: supervision, validation, project administration, writing-review and editing.

Use of AI Tools

AI-assisted language editing and formatting support were used during manuscript preparation. The authors reviewed and approved all scholarly content and remain responsible for the integrity of the article.

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Appendix A. Supplementary Methodological Details

The simulated data analysis used deterministic sector trends and random facility-level variation to generate benchmark performance indicators. The purpose was to illustrate the logic of the proposed framework rather than to estimate regulatory-grade carbon reductions. In real deployment, token issuance rules should be approved by qualified auditors, aligned with recognized carbon accounting standards, and periodically reviewed against evolving transition-finance taxonomies, digital asset regulations, and sector-specific decarbonization pathways.