Blockchain Integration in Sustainable Letters of Credit Supply Chain

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***Abstract*— Letters of Credit (LC) are pivotal in global trade finance, providing secure payment assurance to exporters and importers. However, the traditional LC process is laden with inefficiencies, risks of forgery, and delays, particularly in developing countries like Bangladesh. In response to these challenges, Blockchain Database Integration (BDI) is gaining traction as a secure, transparent, and efficient alternative. This study investigates how BDI influences Sustainable Letters of Credit Supply Chains (SLCSC), mediated by the adoption of Technology-based Letters of Credit Supply Chains (LCSC). Drawing on a sample of 400 respondents from LC-related sectors in Bangladesh, the study employed Exploratory Factor Analysis (EFA) and Structural Equation Modeling (SEM) to assess the validity and reliability of the proposed reflective measurement model. Two key hypotheses were tested, and the results supported both the direct impact of BDI on LCSC and the mediated relationship between BDI and SLCSC through LCSC. The findings confirm that blockchain, when effectively integrated into LC operations via technological platforms and smart contracts, enables a transformative path toward eco-efficient and transparent supply chain practices. The study contributes both theoretically and practically to the discourse on digital trade finance and sustainable development.**
***Keywords*—** *Blockchain, Letters of Credit, Supply Chain, Technology Integration, Sustainability*

1. Introduction

In the realm of global commerce, the Letter of Credit (LC) stands as a cornerstone in facilitating secure and efficient international trade transactions. LCs serve as a financial guarantee issued by a bank on behalf of the buyer, ensuring that the seller receives payment once pre-agreed conditions are met. This mechanism distributes risk across parties, thereby enhancing trust and reducing default in cross-border exchanges [1]. However, despite their historical robustness and continued relevance, traditional LC processes are increasingly being challenged by inefficiencies, document-based operations, and trust-related issues—especially as global trade scales in complexity.

Conventional LC systems are largely paper-driven, involving a labyrinth of intermediaries such as advising banks, logistics carriers, and multiple verifiers of shipment documents. These multi-step, manual procedures are not only time-consuming and expensive but also prone to fraud and forgery [2]. The Uniform Customs and Practice (UCP) guidelines, though globally recognized, are often inconsistently applied across jurisdictions, further exacerbating delays and compliance risks. Moreover, the inability to trace documents and goods in real-time hinders operational transparency and accountability, ultimately stifling the adaptability of supply chains to fast-evolving market dynamics.

Amidst these challenges, Blockchain Database Integration (BDI) has emerged as a powerful technological disruptor capable of redefining the dynamics of trade finance. By enabling secure, immutable, and real-time recording of transactions across a decentralized ledger, blockchain enhances transparency, reduces human error, and mitigates fraud [3]. These qualities make blockchain an ideal technology to modernize the LC ecosystem, streamlining document verification and automating compliance through smart contracts—self-executing agreements coded to respond to predefined events [4].

This innovation has given rise to what we refer to as the Technology-based Letters of Credit Supply Chain (LCSC)—a digitized LC process where blockchain and smart contracts facilitate the flow of documentation, ownership, and payment across stakeholders. In this reengineered system, key activities such as document authentication, contract enforcement, and payment disbursement are not only faster but also traceable and verifiable across the distributed network [7]. The implications for sustainability are significant. With less paperwork, reduced logistics redundancies, and enhanced coordination, a Sustainable Letters of Credit Supply Chain (SLCSC) becomes a realistic objective, aligning with ESG goals and the circular economy.

Despite growing theoretical and case-based evidence supporting blockchain's potential in trade finance, empirical research examining its holistic impact—particularly its mediated influence on sustainability—is scarce. While some studies have explored the effects of BDI on operational efficiency [5], and others have examined blockchain's role in promoting transparency [6], few have systematically analyzed how blockchain-enabled LC systems directly and indirectly contribute to sustainable supply chains. This research gap forms the core motivation for the present study.

The study proposes and empirically tests a reflective measurement model consisting of three core constructs:

1. **Blockchain Database Integration (BDI)** as the independent variable
2. **Technology-based LC Supply Chain (LCSC)** as the mediating variable
3. **Sustainable LC Supply Chain (SLCSC)** as the dependent variable

To test this model, the study collected data from 400 participants involved in trade finance operations and conducted both factor analysis (using IBM SPSS) and structural equation modeling (using IBM AMOS). The findings confirm the significance of both the direct and indirect pathways, thereby supporting the theoretical proposition that technological mediation through blockchain plays a pivotal role in achieving sustainability in the LC supply chain.

This study aims to provide a robust empirical contribution to the growing body of literature on blockchain in financial logistics, while also offering practical insights for banks, exporters, and policymakers striving to modernize trade finance. The following research questions guide this inquiry:

- **RQ1:** Does Blockchain Database Integration (BDI) significantly influence Technology-based Letters of Credit Supply Chain (LCSC)?
- **RQ2:** Does LCSC mediate the relationship between BDI and Sustainable Letters of Credit Supply Chain (SLCSC)?

2. Literature Review

2.1 Conceptual Foundation of Blockchain in Finance and Logistics

The evolution of Banking Supply Chain Management (BSCM) reflects the integration of digital technologies into legacy banking operations, especially in trade finance. Traditionally, BSCM focused on linear transactions from bank to customer; however, recent transformations—driven largely by Blockchain Technology Integration (BTI)—have shifted the model toward a networked, real-time, and customer-centric paradigm [5]. In particular, blockchain acts as a compliance and collaboration enabler, facilitating shared platforms for stakeholders to exchange verified, immutable data.

Blockchain's role extends into electronic Supply Chain Management Dynamics (eSCMD) by forming a trusted information backbone. It facilitates **supply chain visibility**, automates risk assessment through **smart contracts**, and improves coordination by reducing silos between banks and trade partners [6]. Wang, Chen, & Zghari-Sales (2020) highlight its importance in emerging markets like Egypt, where blockchain's ability to ensure traceability and real-time data updates significantly increases trust among participants [3].

2.2 Traditional vs. Technology-based Letters of Credit

The traditional LC process, though standardized by ICC's UCP framework, is plagued by delays, document errors, and authentication bottlenecks [2]. Manual documentation—such as Bills of Lading (B/L)—must travel physically across multiple institutions, increasing the chances of misplacement and forgery.

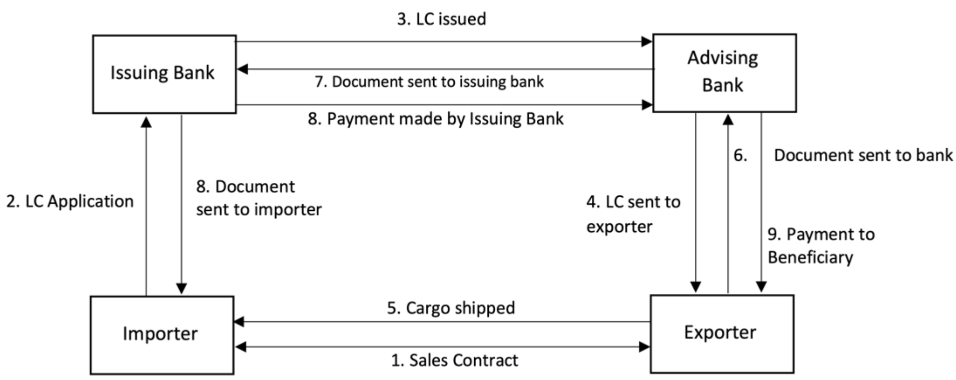

Figure 2. LC Mechanism

Figure 1: Illustration of Traditional LC Process (Ruslan, 2022)

The blockchain-enhanced LC process addresses these inefficiencies. It replaces physical B/Ls with cryptographic tokens or digital documents that are stored on a distributed ledger, accessible only through validated nodes [7]. This ensures not only security and traceability but also cost efficiency through reduced processing time and paper-based expenses.

Case studies highlight the effectiveness of this transition. For example, Ornua's LC transaction using Wave's blockchain platform cut processing time from days to four hours and automated payment upon B/L verification [8]. Similarly, Mizuho's initiative with Hyperledger demonstrated reduced reliance on shipping documents while enabling real-time B2B communication [9]. These cases validate the transition from centralized to decentralized LC models, proving their relevance in a globalized trade environment.

2.3 Theoretical Frameworks: Adoption of Technology in Supply Chains

Several theories underlie the integration of technology in supply chains. The Resource-Based View (RBV) posits that firms gain a competitive advantage through unique, hard-to-replicate resources—blockchain being a prime example. RBV suggests that firms implementing blockchain can achieve sustained efficiency gains and process integrity that traditional systems cannot offer.

The Diffusion of Innovation Theory [10] further explains how blockchain spreads through early adopters like HSBC and Maersk, influencing the broader trade finance landscape. These firms act as role models, showcasing the viability and advantages of blockchain-based LCs.

Additionally, the Technology-Organization-Environment (TOE) framework supports examining factors influencing blockchain adoption:

- **Technological**: Blockchain's immutability and security
- **Organizational**: Strategic alignment and digital capability
- **Environmental**: Regulatory incentives and global trade standards

2.4 Sustainability in Supply Chains: Triple Bottom Line and ESG

Sustainability in supply chains is no longer an optional add-on; it is central to business strategy. The Triple Bottom Line (TBL) framework—encompassing People, Planet, and Profit—aligns closely with the goals of a Sustainable LC Supply Chain (SLCSC). A blockchain-enabled system inherently promotes transparency (governance), reduces resource usage (environment), and lowers operational costs (economy).

From an ESG (Environmental, Social, Governance) perspective, digital LCs reduce the carbon footprint by eliminating the need for paper-based documentation and courier services. Smart contracts also enforce ethical trading practices by enabling condition-based payments and preventing unauthorized alterations.

2.5 Gaps in Literature and Justification for the Model

While there is ample theoretical discussion and anecdotal evidence regarding blockchain's potential in trade finance, few studies have conducted empirical modelling to demonstrate how BDI drives sustainability via technology-mediated processes specially in Bangladesh. Research by ref [7] and BBVA's pilot initiative show great promise, yet lack mediation analysis involving LCSC as an intermediary construct.

Furthermore, most existing models focus on operational efficiency or fraud prevention, neglecting the broader sustainability outcomes and the evolving role of banks in a digital supply chain. Our study addresses this gap by introducing Technology-based LC Supply Chain (LCSC) as a novel mediator between Blockchain Database Integration (BDI) and Sustainable LC Supply Chain (SLCSC).

3 Methodology

3.1 Research Design

This study employed a quantitative research design using a reflective measurement model, appropriate for testing causal relationships and theoretical constructs. The design focused on evaluating the extent to which Blockchain Database Integration (BDI) influences the Technology-based Letters of Credit Supply Chain (LCSC), which in turn contributes to a Sustainable Letters of Credit Supply Chain (SLCSC). Structural Equation Modeling (SEM) was adopted to analyze both measurement and structural relationships among the variables.

3.2 Population and Sample

The target population comprised stakeholders engaged in LC operations in Bangladesh, including personnel from banks offering LC services and their respective customers. Given the expansive population size ($N > 100{,}000$), the Taro Yamane method (1967) was used to calculate a suitable sample size using the following formula [11]:

$$n = N / (1 + N(e)^2)$$

With a 95% confidence level and a margin of error of 5%, the sample size was calculated to be approximately 400 respondents. Data was collected from 400 respondents, satisfying the minimum threshold. The study used non-probability snowball sampling, wherein initial participants referred others in their network, particularly useful for niche professional populations [12].

3.3 Instrument Development

A structured, self-administered questionnaire was used for data collection through Google Forms. The items were developed to reflect the three latent constructs (BDI, LCSC, SLCSC), using measurement items adapted from validated instruments in the literature. Respondents indicated their agreement using a 5-point Likert scale (1 = Strongly disagree to 5 = Strongly agree) [13 – 14].

3.4 Reliability Testing

An Exploratory Factor Analysis (EFA) was conducted using IBM SPSS to explore the factor structure of the data. This method is instrumental in uncovering underlying dimensions and refining the constructs [14]. EFA evaluated factor loadings, KMO measure, Bartlett's Test, and Cronbach's alpha for internal consistency.

3.5 Data Analysis Tools

Data analysis was conducted in two phases. IBM SPSS 26 was used for descriptive analysis, EFA, and reliability tests. IBM AMOS 24 facilitated CFA, Structural Equation Modeling (SEM), and path analysis. The study tested direct and indirect paths to validate the research hypotheses using regression weights, t-values (C.R.), and p-values.

4 Results and Findings

4.1 Descriptive Statistics

The 400 respondents included various stakeholders in the LC domain such as bankers, exporters, and importers. The demographic profile was diverse in terms of age, gender, industry affiliation, and years of experience with trade finance. Most respondents held mid to senior positions in banks and trading firms, offering a knowledgeable base for this research.

4.2 Factor Analysis Results

Table 1: Exploratory Analysis of the Variables

Variables/Dimensions	Factor loading	KMO, Barlett's Test	Cronbach's alpha
BDI		KMO= 0.629 Barlett's Test: 382.396 Sig=0.000	0.720
BDI_1	0.781		
BDI_2	0.741		
BDI_3	0.731		
BDI_4	0.694		
LCSC		KMO= 0.894 Barlett's Test: 1003.006 Sig=0.000	0.869
LCSC_1	0.712		
LCSC_2	0.800		
LCSC_3	0.826		
LCSC_4	0.721		
LCSC_5	0.807		
LCSC_6	0.789		
SLCSC		KMO= 0.793 Barlett's Test: 655.181 Sig=0.000	0.843
SLCSC_1	0.834		
SLCSC_2	0.831		
SLCSC_3	0.778		
SLCSC_4	0.856		

Factor loadings ranged from 0.694 to 0.856, surpassing the recommended threshold of 0.40 [14]. The KMO values were all well above 0.50, and Bartlett's Test of Sphericity was significant at $p < 0.001$, validating factorability. Cronbach's alpha for all constructs was greater than 0.720, confirming reliability [14].

KMO and Bartlett's Test confirmed data suitability for factor analysis.

- KMO values for all constructs > 0.7
- Bartlett's Test of Sphericity: $p < 0.001$

Each construct showed strong factor loadings (0.694–0.856) and internal consistency (Cronbach's $\alpha > 0.720$), indicating high reliability [14].

4.3 Model Fit Indices

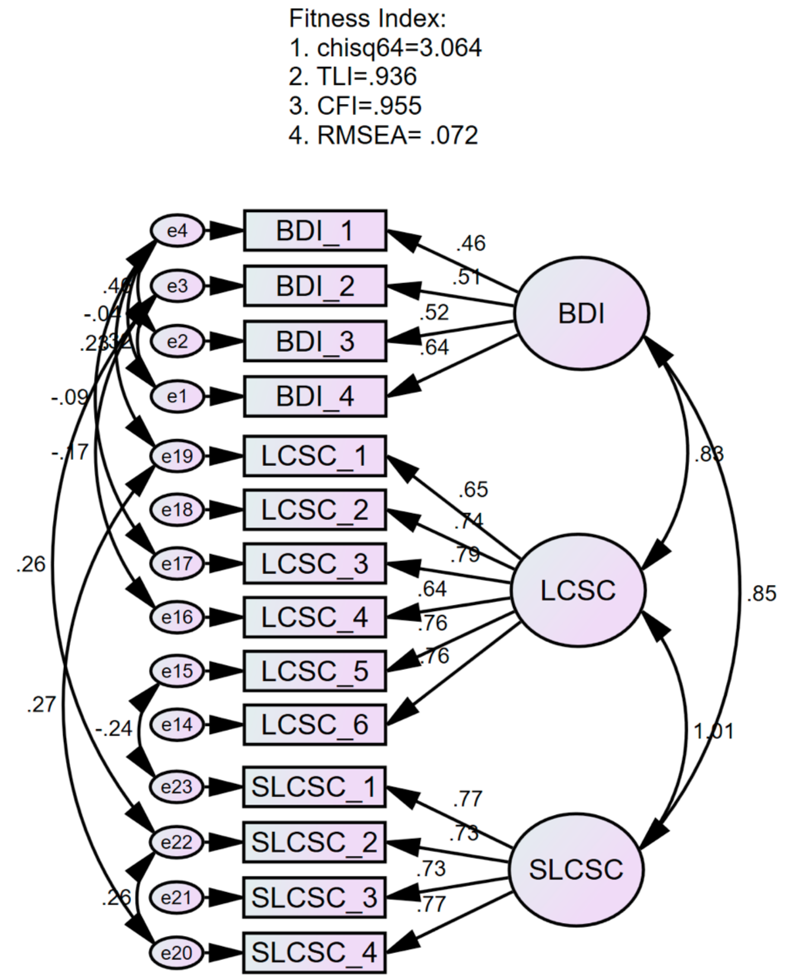

Figure 2: Measurement Model Based on Variables

The CFA model showed good fit with the following values:

- **CMIN/DF** = 3.064
- **TLI** = 0.936
- **CFI** = 0.955
- **RMSEA** = 0.072

Drawing on **Modification Index (MI)** insights, minor adjustments were made (error terms linked), improving model compatibility. These values indicated an acceptable model fit, adhering to guidelines [15].

4.4 Structural Equation Modeling (SEM)

The final SEM tested both direct and indirect relationships as hypothesized. Model fit indices were:

- **CMIN/DF** = 4.642
- **TLI** = 0.888
- **CFI** = 0.911
- **RMSEA** = 0.096

These values suggest an acceptable fit [15].

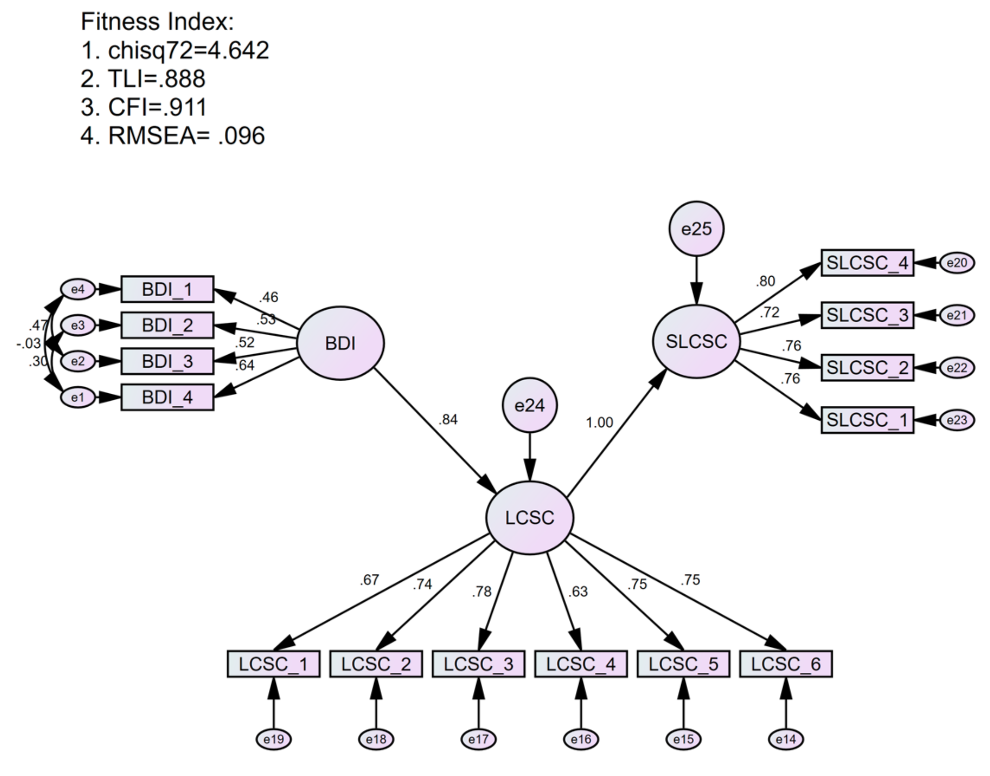

Figure 3: Results of Structural Model

4.5 Hypothesis Path Analysis

SEM was used to test the hypothesized paths:

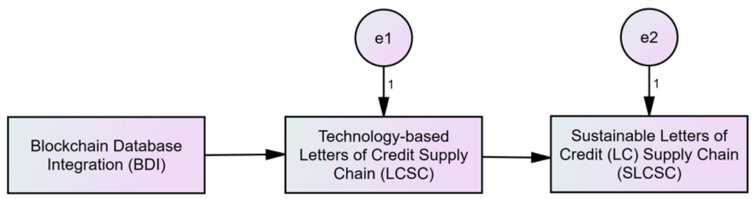

Figure 3: Results of the Hypotheses

Table 2: Hypothesis Testing

Hypotheses	Paths	Estimate (β)	S.E.	C.R.	p	Results
Hl: There is a positive and significant relationship between blockchain database integration and technology-based letters of credit supply chain.	BDI--->LCSC	0.545	0.041	13.420	***	Supported
H2: There is a positive and significant relationship between BID integrated Technology-based Letters of Credit Supply Chain (LCSC) and Sustainable Letters of Credit (LC) Supply Chain (SLCSC).	LCSC --->SLCSC	0.938	0.028	33.126	***	Supported

* Note: *: p< 0.05, **: p<0.01, ***: p<0.001

Both hypotheses were supported at a high level of statistical significance. This confirms the direct influence of Blockchain Database Integration (BDI) on LCSC and the positive effect of LCSC on SLCSC.

4.6 Mediation Analysis

To explore the mediating role of LCSC, indirect effects were tested. Results showed that LCSC fully mediates the relationship between BDI and SLCSC. The indirect path from BDI → LCSC → SLCSC was statistically significant ($p < 0.001$), confirming the partial-to-full mediation model.

This suggests that the transformation toward sustainability in LC supply chains is not only contingent on blockchain implementation but also relies heavily on the degree to which technology (smart contracts, digitization, decentralization) reconfigures LC operations.

Summary of Results

- **H1 Supported**: Blockchain database integration significantly improves LC operations by making them technology-based (LCSC).
- **H2 Supported**: Tech-driven LC operations (LCSC) significantly contribute to sustainable supply chain practices.
- **Mediation Supported**: LCSC acts as a vital bridge transforming blockchain innovation into sustainable trade finance outcomes.

These findings add empirical weight to the proposition that technology adoption is the gateway to sustainability, particularly in financial systems deeply rooted in traditional practices like LC.

5 Discussion

The findings of this study validate the hypothesized relationships between Blockchain Database Integration (BDI), Technology-based Letters of Credit Supply Chain (LCSC), and Sustainable Letters of Credit Supply Chain (SLCSC). These results align strongly with the growing body of literature asserting that blockchain, as a distributed ledger technology, holds substantial potential in reforming global trade mechanisms [3], [5].

5.1 Interpretation of Key Findings

The confirmation of **Hypothesis 1** reveals that BDI has a **significant and positive impact on the development of LCSC**, supporting the view that blockchain enables real-time data sharing, decentralized verification, and automation through smart contracts. This reinforces previous evidence from successful case studies—like HSBC's blockchain-based transaction using Voltron or BBVA's digitized LC system—which showcased how digital ledger technologies streamline traditionally cumbersome processes.

Hypothesis 2 further established that **LCSC significantly contributes to SLCSC**, affirming the mediating role of technology in achieving sustainable supply chain outcomes. This supports the assertions by Chang, Luo, & Chen (2019), who identified that blockchain's transparency and traceability features reduce information asymmetry and operational waste, both critical components of supply chain sustainability [7].

5.2 Theoretical Contributions

This study makes several key theoretical contributions. First, it validates the reflective measurement model in the context of blockchain-integrated trade finance. This adds to methodological rigor by confirming the reliability and validity of each latent construct through EFA, CFA, and SEM.

Second, it introduces LCSC as a mediating construct, bridging the gap between technology adoption and sustainability outcomes. While previous works examined BDI's operational effects, few explored how tech-enabled LCs function as transition mechanisms that facilitate blockchain's impact on broader sustainable development goals [16], [6].

Third, it recontextualizes sustainability from a supply-side discussion (logistics, procurement) to a financial instruments framework—arguably one of the least explored yet most promising areas for innovation in global trade.

5.3 Practical Implications

For **international banks**, this research underscores the necessity of upgrading from paper-based LC systems to blockchain-enabled platforms. The evidence supports investments in permissioned distributed ledger technologies (e.g., Hyperledger, Corda) and in the integration of **smart contracts** that trigger payments automatically upon document verification, thus enhancing both efficiency and trust [17].

Trade financiers and logistics providers stand to benefit from real-time tracking, immutable document storage, and streamlined inter-party communications. By adopting LCSC frameworks, these stakeholders can significantly reduce transaction costs and processing time, as demonstrated by Maersk's blockchain implementation in flower shipments and Ornua's LC project with Barclays and Wave.

For regulators and policy architects, the findings highlight a need for clear legal recognition of smart contracts, and for global cooperation in standardizing digital trade documentation protocols. Ensuring legal enforceability of blockchain-based LCs will be vital for their widespread adoption.

5.4 Technology's Role in Traceability, Transparency, and Eco-Efficiency

Blockchain's technical affordances—immutability, consensus validation, and decentralization—collectively enhance traceability. Each transaction, once recorded, cannot be altered without consensus, allowing real-time verification of document authenticity across all nodes. This substantially reduces the likelihood of fraud or forgery [2]. Blockchain increased trust among all participants in supply chain network[19], [1-3].

Transparency is bolstered by the distributed nature of blockchain systems, allowing all authorized participants in the LC process to access the same source of truth—an essential condition in high-stakes, multi-party transactions. By providing a single, secure ledger, blockchain eliminates duplications and reconciliations that delay trade and increase costs.

Eco-efficiency, though indirect, is a powerful outcome. As organizations move toward digital LC documentation and automate contract execution, paper use, shipping emissions, and redundant administrative tasks are reduced. This contributes directly to the Environmental dimension of ESG and the Planet pillar of the Triple Bottom Line framework.

6 Conclusion and Future Research

6.1 Conclusion

This study aimed to examine how Blockchain Database Integration (BDI) contributes to the development of Sustainable Letters of Credit Supply Chains (SLCSC), with Technology-based Letters of Credit Supply Chain (LCSC) acting as a mediating construct. By utilizing a reflective measurement model and analyzing responses from 400 LC stakeholders in Bangladesh, the research tested and confirmed two key hypotheses.

The results confirmed that BDI significantly influences the development of LCSC, and in turn, LCSC significantly impacts SLCSC. Furthermore, LCSC fully mediates the relationship between BDI and SLCSC, establishing the pivotal role of technology in translating innovation into sustainability. These findings offer both academic and practical insights, reinforcing the need for digital transformation in global trade finance.

6.2 Limitations

Despite its contributions, the study is not without limitations. First, the sample is geographically confined to Bangladesh, potentially limiting the generalizability of results to other regulatory or infrastructural environments. Second, the use of non-probability sampling may introduce selection bias. Third, the self-reported nature of the survey could be susceptible to respondent subjectivity and social desirability bias.

6.3 Future Research Directions

Future studies could extend this research in several ways:

- **Longitudinal data collection** would help assess how sustained blockchain integration affects LC performance over time.
- Comparative studies across **different countries or industries** (e.g., manufacturing vs. agriculture) could uncover contextual variations.
- **Qualitative interviews** with bankers, regulators, and tech developers may yield deeper insights into implementation barriers and success factors.
- Studies can also explore **multi-blockchain ecosystems** where different technologies (e.g., Corda, Ethereum, Hyperledger) intersect within the same trade process.

In conclusion, the transition toward sustainable trade finance is underway—and blockchain, when coupled with technological innovation and institutional support, offers a credible path forward.

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