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Law and Blockchain: A Qualitative Inquiry into Legal Challenges of Sustainable Supply Chain Governance

Md. Nasim Hossain^{1*}; Kazi Abdul Mannan

^{1*}Department of Law

²Department of Business Administration

Shanto-Mariam University of Creative Technology, Uttara, Dhaka, Bangladesh

ABSTRACT

Blockchain technology has emerged as a transformative tool for enhancing transparency, traceability, and accountability in sustainable supply chain governance. However, its integration into existing legal frameworks presents significant challenges due to the decentralised and transnational nature of the technology. This study conducts a qualitative inquiry into the legal complexities associated with blockchain-enabled supply chains, using secondary data from academic literature, policy reports, and legal analyses. The findings identify key legal challenges, including regulatory fragmentation, jurisdictional ambiguity, smart contract enforceability, data protection conflicts, liability allocation, and governance gaps. Drawing on institutional theory, techno-legal perspectives, stakeholder theory, and sustainability governance frameworks, the study reveals a fundamental misalignment between traditional legal systems and emerging blockchain architectures. The analysis highlights the need for adaptive, multi-level regulatory approaches that integrate legal innovation with technological development. The study contributes to the growing body of interdisciplinary scholarship by offering a comprehensive framework for understanding blockchain governance in sustainable supply chains and provides practical implications for policymakers, legal practitioners, and industry stakeholders.

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CONTACT Md. Nasim Hossain, Email: : afsarsarkar2002@gmail.com

1. Introduction

The rapid globalisation of trade and production networks has significantly increased the complexity of modern supply chains. These networks often span multiple jurisdictions, involve numerous stakeholders, and operate under varying regulatory regimes. While such globalisation has improved efficiency and reduced costs, it has also introduced substantial challenges related to transparency, accountability, and sustainability. Issues such as unethical labour practices, environmental degradation, counterfeit goods, and lack of traceability have raised serious concerns among policymakers, businesses, and consumers alike (Saber et al., 2021). Consequently, the demand for more transparent and sustainable supply chain governance mechanisms has intensified.

In this context, blockchain technology has emerged as a transformative innovation with the potential to address many of the systemic inefficiencies inherent in traditional supply chain systems. Blockchain is a distributed ledger technology that enables secure, transparent, and immutable recording of transactions across a decentralised network. By eliminating the need for centralised intermediaries and ensuring data integrity, blockchain facilitates trust among participants who may not have prior relationships (Jabbar et al., 2021). In supply chain management, blockchain can enhance traceability by providing real-time visibility into the movement of goods and the verification of transactions from origin to final delivery.

The application of blockchain in sustainable supply chain governance is particularly promising. Sustainability in supply chains encompasses environmental, social, and economic dimensions, including reducing carbon emissions, ensuring ethical sourcing, and promoting fair labour practices. Blockchain can support these objectives by enabling verifiable data sharing and improving accountability across the supply chain. For example, companies can use blockchain to track the origin of raw materials, monitor compliance with environmental standards, and verify labour conditions (Saber et al., 2021). Such capabilities can help organisations meet regulatory requirements and respond to increasing consumer demand for ethically produced goods.

Despite its potential benefits, the integration of blockchain into supply chain governance raises complex legal and regulatory challenges. Traditional legal frameworks are largely designed for centralised systems with clearly identifiable actors and jurisdictional boundaries. In contrast, blockchain operates in a decentralised and often transnational environment, where control is distributed among multiple participants. This fundamental difference creates significant tensions between technological innovation and existing legal systems (David, 2024).

One of the primary legal challenges is regulatory fragmentation. Different countries have adopted varying approaches to blockchain regulation, ranging from supportive frameworks to restrictive policies. This lack of harmonisation creates uncertainty for businesses operating across

borders and complicates compliance efforts. Moreover, the decentralised nature of blockchain makes it difficult to determine jurisdiction, particularly in cases involving cross-border transactions or disputes (Liu et al., 2021).

Another critical issue concerns the legal status and enforceability of smart contracts. Smart contracts are self-executing agreements encoded on blockchain platforms, which automatically enforce contractual terms when predefined conditions are met. While they offer efficiency and reduce the need for intermediaries, their legal recognition remains ambiguous in many jurisdictions. Questions arise regarding how smart contracts align with traditional contract law principles, such as consent, interpretation, and dispute resolution (David, 2024).

Data protection and privacy also present significant challenges. Blockchain's immutability, one of its core features, conflicts with data protection regulations that require the ability to modify or delete personal data, such as the "right to be forgotten." This tension is particularly relevant in regions with stringent data protection laws, where compliance may be difficult to achieve (Khatun & Darwish, 2025).

Furthermore, issues of liability and accountability are exacerbated in decentralised systems. In traditional supply chains, responsibility can typically be traced to specific entities. However, in blockchain networks, multiple participants share control, making it challenging to assign liability in cases of system failure, fraud, or non-

compliance. This ambiguity undermines legal certainty and may hinder the adoption of blockchain technologies (Perdana et al., 2022).

Given these challenges, there is a growing need for a comprehensive examination of the legal implications of blockchain in sustainable supply chain governance. While existing research has explored the technical and operational aspects of blockchain, there remains a gap in understanding its legal and regulatory dimensions. This study seeks to address this gap by conducting a qualitative inquiry into the legal challenges associated with blockchain-enabled supply chains.

The objectives of this research are threefold. First, it aims to identify and analyse the key legal challenges arising from the use of blockchain in sustainable supply chains. Second, it seeks to examine how existing legal frameworks interact with decentralised technologies and to assess their adequacy in addressing emerging issues. Third, the study aims to propose potential pathways for developing adaptive and effective governance mechanisms that can support the integration of blockchain into sustainable supply chains.

By adopting a qualitative research methodology based on secondary data analysis, this study provides a comprehensive and interdisciplinary perspective on the topic. It integrates insights from legal studies, supply chain management, and information systems to develop a nuanced understanding of the challenges and opportunities associated with blockchain governance.

In doing so, the study contributes to both academic scholarship and practical policymaking. It offers a theoretical framework for analysing blockchain governance and provides actionable recommendations for regulators, businesses, and other stakeholders. Ultimately, the study aims to support the development of more transparent, accountable, and sustainable supply chains in an increasingly interconnected global economy.

2. Literature Review

Blockchain technology has been widely recognised as a disruptive innovation with the potential to transform supply chain management. Its core features, decentralisation, transparency, immutability, and security, address many of the limitations of traditional supply chain systems. In conventional systems, information is often stored in siloed databases controlled by individual organisations, leading to inefficiencies, data inconsistencies, and limited visibility (Jabbar et al., 2021).

Blockchain overcomes these limitations by providing a shared, distributed ledger that records transactions in a tamper-proof manner. Each transaction is verified by network participants and added to the ledger through consensus mechanisms, ensuring data integrity and trust. This capability is particularly valuable in supply chains, where multiple stakeholders must coordinate and share information (Karaduman & Gülhas, 2025).

Empirical studies have demonstrated that blockchain can significantly enhance supply

chain transparency and traceability. For example, organisations can track the movement of goods in real time, verify the authenticity of products, and detect anomalies or fraudulent activities. These features are especially important in industries such as food, pharmaceuticals, and luxury goods, where quality and authenticity are critical (Saber et al., 2021).

However, the adoption of blockchain in supply chains is not without challenges. Technical issues such as scalability, interoperability, and energy consumption remain significant barriers. Moreover, organisational resistance, lack of standardisation, and high implementation costs can hinder adoption (Kafeel et al., 2023). These challenges highlight the need for a holistic approach that considers not only technological factors but also legal and institutional dimensions.

2.1 Blockchain and Sustainable Supply Chain Governance

Sustainability has become a central concern in supply chain management, driven by increasing regulatory pressures and consumer awareness. Sustainable supply chains aim to minimise environmental impact, ensure ethical labour practices, and promote economic viability. Blockchain technology offers a powerful tool for achieving these objectives by enhancing transparency and accountability.

Research indicates that blockchain can support sustainability by enabling the tracking of environmental and social metrics across the supply chain. For instance, companies can use blockchain to monitor

carbon emissions, verify compliance with environmental regulations, and ensure fair labour practices (Sabeti et al., 2021). By providing verifiable and immutable records, blockchain reduces the risk of greenwashing and enhances stakeholder trust.

Furthermore, blockchain facilitates greater collaboration among supply chain participants. By providing a shared platform for data exchange, it enables stakeholders to coordinate actions and align their sustainability goals. This collaborative approach is essential for addressing complex sustainability challenges that require collective action (Cao et al., 2021).

Despite these advantages, the integration of blockchain into sustainable supply chain governance raises significant legal and regulatory issues. The decentralised nature of blockchain challenges traditional governance models, which are typically based on hierarchical structures and centralised control. As a result, new governance frameworks are needed to address the unique characteristics of blockchain systems.

2.2 Legal Implications of Blockchain Technology

The legal implications of blockchain technology have been widely discussed in the literature, particularly in relation to contract law, data protection, and regulatory compliance. One of the most prominent issues is the legal status of smart contracts. While smart contracts offer efficiency and automation, their enforceability under existing legal frameworks remains uncertain.

Scholars argue that smart contracts may not fully satisfy the requirements of traditional

contract law, such as mutual consent and the ability to interpret contractual terms. Moreover, the rigidity of code-based contracts can lead to unintended consequences, particularly in complex or unforeseen situations (David, 2024).

Data protection is another critical concern. Blockchain's immutability conflicts with data protection regulations that require the ability to modify or delete personal data. This issue is particularly relevant in jurisdictions with strict privacy laws, such as the European Union's General Data Protection Regulation (GDPR). Researchers have proposed various solutions, including off-chain data storage and encryption techniques, but these approaches introduce additional complexities (Khatun & Darwish, 2025).

Regulatory uncertainty further complicates the legal landscape. Governments and regulatory bodies have adopted diverse approaches to blockchain regulation, ranging from supportive frameworks to outright bans. This lack of consistency creates challenges for businesses operating in multiple jurisdictions and increases compliance costs (Liu et al., 2021).

2.3 Governance and Institutional Challenges

Blockchain governance is an emerging field of study that examines how decentralised systems are managed and regulated. Unlike traditional systems, blockchain networks operate without a central authority, relying instead on consensus mechanisms and community governance. This decentralised structure presents unique challenges in terms

of decision-making, accountability, and conflict resolution.

Institutional theory provides a useful lens for understanding these challenges. It suggests that organisations are influenced by regulatory, normative, and cultural pressures, which shape their behaviour and decision-making processes. In the context of blockchain, institutional pressures can either facilitate or hinder adoption, depending on the level of regulatory support and societal acceptance (Liu et al., 2021).

The lack of standardised governance frameworks is a major barrier to blockchain adoption. Different blockchain platforms have varying governance models, leading to inconsistencies and fragmentation. This lack of standardisation makes it difficult to establish common rules and practices, which are essential for effective supply chain governance (Cao et al., 2021).

2.4 Research Gap

While the literature provides valuable insights into the technical and operational aspects of blockchain in supply chains, there is a notable gap in research on its legal implications. Existing studies often focus on technological innovation and business applications, with limited attention to regulatory and governance challenges.

Moreover, the intersection of blockchain, law, and sustainability remains underexplored. There is a need for interdisciplinary research that integrates legal analysis with supply chain and sustainability perspectives. This study addresses this gap by providing a comprehensive examination of the legal challenges associated with

blockchain-enabled sustainable supply chain governance.

3. Theoretical Framework

The examination of legal challenges in blockchain-enabled sustainable supply chain governance necessitates a robust interdisciplinary theoretical foundation. This study integrates institutional theory, technological theory, stakeholder theory, and sustainability governance theory to provide a comprehensive analytical lens. The combination of these frameworks enables a nuanced understanding of how technological innovation interacts with legal structures and organisational dynamics in complex supply chain environments.

3.1 Institutional Theory

Institutional theory provides a foundational perspective for understanding how organisations respond to external pressures arising from regulatory, normative, and cultural environments. According to institutional theory, organisations seek legitimacy by conforming to established rules, norms, and expectations within their institutional context (DiMaggio & Powell, 1983). In the context of blockchain adoption, these pressures manifest through legal regulations, industry standards, and societal expectations regarding transparency and sustainability.

Blockchain technology introduces a disruptive force that challenges existing institutional arrangements. Traditional supply chain governance relies on centralised authorities and well-defined legal frameworks, whereas blockchain operates in

a decentralised and distributed environment. This divergence creates what scholars describe as “institutional voids,” where existing legal and regulatory systems are insufficient to govern emerging technologies (Liu et al., 2021). As a result, organisations face uncertainty in adopting blockchain solutions, particularly in relation to compliance with existing laws.

Moreover, institutional isomorphism, coercive, normative, and mimetic, plays a significant role in shaping blockchain adoption. Coercive pressures arise from regulatory requirements, normative pressures from industry standards, and mimetic pressures from the adoption patterns of leading organisations. These dynamics influence how firms integrate blockchain into their supply chain operations and how they navigate associated legal challenges.

3.2 Techno-Legal Theory

The techno-legal framework examines the interplay between technological innovation and legal systems. It recognises that law and technology are co-evolving systems, where advancements in one domain necessitate adaptations in the other (Brownsword, 2019). Blockchain technology exemplifies this dynamic, as its decentralised architecture challenges traditional legal concepts such as jurisdiction, ownership, and accountability.

From a techno-legal perspective, blockchain can be seen as a form of “regulation by code,” where rules are embedded within technological systems rather than enforced through traditional legal mechanisms. Smart contracts, for instance, automate the execution of contractual obligations based on

predefined conditions, reducing the need for legal intermediaries. However, this shift raises critical questions about the role of law in governing such systems.

One key issue is the potential conflict between code-based governance and legal interpretation. While smart contracts operate on deterministic logic, legal systems rely on interpretive flexibility to address ambiguities and unforeseen circumstances. This tension highlights the limitations of relying solely on technological solutions for governance and underscores the need for hybrid approaches that integrate legal oversight with technological innovation (David, 2024).

Furthermore, techno-legal theory emphasises the importance of regulatory adaptation. Legal frameworks must evolve to accommodate the unique characteristics of blockchain, including decentralisation, immutability, and cross-border functionality. This may involve the development of new legal categories, regulatory sandboxes, and international standards to ensure effective governance.

3.3 Stakeholder Theory

Stakeholder theory provides a valuable lens for analysing the governance of blockchain-enabled supply chains. It posits that organisations must consider the interests of all stakeholders, including suppliers, customers, regulators, investors, and communities, rather than focusing solely on shareholder value (Freeman, 1984).

In the context of sustainable supply chains, stakeholder engagement is particularly important. Blockchain technology enables greater transparency and accountability,

which can enhance trust among stakeholders. For example, consumers can verify the ethical sourcing of products, while regulators can monitor compliance with environmental and labour standards.

However, the decentralised nature of blockchain complicates stakeholder relationships. Decision-making authority is distributed across multiple participants, making it difficult to establish clear governance structures. Conflicts may arise between stakeholders with differing interests, such as cost efficiency versus environmental sustainability. Stakeholder theory highlights the need for inclusive governance mechanisms that balance these competing interests and promote collaboration.

Moreover, blockchain governance often involves new types of stakeholders, such as technology providers and platform developers, who play a critical role in shaping system design and functionality. Understanding the interactions among these diverse actors is essential for addressing legal and governance challenges.

3.4 Sustainability Governance Theory

Sustainability governance theory focuses on the integration of environmental, social, and economic considerations into decision-making processes. It emphasises the role of governance mechanisms in promoting sustainable practices and ensuring accountability (Jordan et al., 2018).

Blockchain technology has the potential to enhance sustainability governance by providing transparent and verifiable data on supply chain activities. For instance,

blockchain can track carbon emissions, monitor resource usage, and verify compliance with sustainability standards. This capability supports evidence-based decision-making and strengthens accountability mechanisms.

However, the effectiveness of blockchain in promoting sustainability depends on the alignment of technological capabilities with legal and institutional frameworks. Without appropriate governance structures, blockchain may fail to achieve its full potential or may even exacerbate existing inequalities and power imbalances.

Sustainability governance theory also highlights the importance of multi-level governance, involving local, national, and international actors. Given the global nature of supply chains, effective governance requires coordination across jurisdictions and the development of harmonised regulatory frameworks.

3.5 Integrated Theoretical Perspective

By integrating these theoretical frameworks, this study provides a comprehensive approach to analysing the legal challenges of blockchain-enabled sustainable supply chain governance. Institutional theory explains the external pressures shaping adoption, techno-legal theory examines the interaction between law and technology, stakeholder theory addresses the role of diverse actors, and sustainability governance theory emphasises the broader societal implications.

This integrated framework enables a holistic understanding of the complex and dynamic

relationships between technology, law, and sustainability in contemporary supply chains.

4. Research Methodology

This study adopts a qualitative research design to explore the legal challenges associated with blockchain-enabled sustainable supply chain governance. Qualitative research is particularly suitable for investigating complex, emerging phenomena where theoretical understanding is still evolving (Creswell & Poth, 2018). Given the interdisciplinary nature of the topic, a qualitative approach allows for an in-depth examination of legal, technological, and organisational dimensions.

The study employs a secondary data analysis method, drawing on existing literature, policy documents, and case studies. This approach is appropriate for synthesising diverse perspectives and identifying patterns across multiple sources.

4.1 Data Collection

Data were collected from a wide range of secondary sources, including:

- Peer-reviewed journal articles
- Books and academic monographs
- Policy reports from international organisations
- Legal analyses and regulatory documents
- Industry case studies on blockchain implementation

The selection of sources was guided by relevance, credibility, and recency. Priority was given to high-impact journals and

authoritative reports to ensure the reliability of the data.

A systematic search strategy was employed using academic databases such as Scopus, Web of Science, and Google Scholar. Keywords included “blockchain,” “supply chain governance,” “legal challenges,” “smart contracts,” and “sustainability.” This process ensured comprehensive coverage of the relevant literature.

4.2 Data Analysis

The study utilises thematic analysis as the primary method of data analysis. Thematic analysis is a widely used qualitative technique for identifying, analysing, and interpreting patterns within data (Braun & Clarke, 2006).

The analysis followed a structured process:

- **Familiarisation:** The researcher conducted an extensive review of the collected data to gain a deep understanding of the subject matter. This involved reading and re-reading the sources and noting initial observations.
- **Coding:** Relevant data segments were systematically coded based on recurring themes related to legal challenges. Codes included categories such as regulatory fragmentation, smart contract enforceability, data privacy, liability, and governance issues.
- **Theme Development:** Codes were grouped into broader themes that capture the key legal challenges associated with blockchain-enabled supply chains. These themes were

refined through iterative analysis to ensure coherence and consistency.

- **Interpretation:** The identified themes were interpreted in light of the theoretical framework, allowing for a deeper understanding of the relationships between legal, technological, and organisational factors.

4.3 Research Validity and Reliability

To ensure the rigour of the study, several strategies were employed:

- **Triangulation:** Data from multiple sources were compared to validate findings and reduce bias.
- **Transparency:** The research process was clearly documented to enhance replicability.
- **Theoretical Integration:** Findings were interpreted within a well-defined theoretical framework, strengthening analytical validity.

While qualitative research does not aim for statistical generalisation, it provides rich, contextual insights that are valuable for theory development and policy analysis.

4.4 Ethical Considerations

As the study is based on secondary data, it does not involve human participants and therefore does not require ethical approval. However, ethical standards were maintained by ensuring proper citation and acknowledgement of all sources, in accordance with academic integrity guidelines (Mannan & Farhana, 2026).

4.5 Limitations of the Methodology

Despite its strengths, the methodology has certain limitations. First, reliance on secondary data may limit the ability to capture real-time developments and practical challenges faced by organisations. Second, the findings are dependent on the quality and scope of the existing literature, which may be biased or incomplete.

Future research could address these limitations by incorporating primary data collection methods, such as interviews and case studies, to provide empirical validation of the findings.

5. Findings and Analysis

The qualitative analysis of secondary data reveals a set of interconnected legal challenges that significantly influence the adoption and governance of blockchain in sustainable supply chains. These challenges are not isolated but rather embedded within broader institutional, technological, and governance dynamics. The findings are organised into seven major themes: regulatory fragmentation, smart contract enforceability, data protection and privacy, liability and accountability, governance gaps, interoperability and legal compatibility, and dispute resolution mechanisms.

5.1 Regulatory Fragmentation and Jurisdictional Complexity

One of the most prominent findings is the pervasive issue of regulatory fragmentation across jurisdictions. Blockchain-enabled supply chains inherently operate across national borders, yet legal frameworks

remain territorially bounded. This mismatch creates significant uncertainty for organisations attempting to implement blockchain solutions globally (Liu et al., 2021).

Different countries adopt divergent regulatory approaches toward blockchain technologies. Some jurisdictions promote innovation through regulatory sandboxes and supportive frameworks, while others impose restrictive regulations due to concerns over financial stability, data security, or illicit activities. This lack of harmonisation results in a fragmented regulatory landscape that complicates compliance and increases operational risks (Khatun & Darwish, 2025).

Moreover, the decentralised nature of blockchain complicates the determination of jurisdiction. Transactions recorded on distributed ledgers may involve participants from multiple countries, making it difficult to identify which legal system governs a particular transaction. This ambiguity is particularly problematic in cases of disputes or regulatory enforcement, where jurisdictional clarity is essential (David, 2024).

From an institutional perspective, this fragmentation reflects the inability of existing legal systems to adapt to transnational technological innovations. The absence of international regulatory standards for blockchain further exacerbates this issue, highlighting the need for coordinated global governance mechanisms.

5.2 Smart Contract Enforceability and Legal Recognition

Smart contracts represent a core component of blockchain technology, enabling automated execution of agreements without intermediaries. However, their legal status remains uncertain in many jurisdictions. The analysis reveals that while some legal systems have begun to recognise smart contracts, there is no universal consensus on their enforceability (David, 2024).

Traditional contract law is based on principles such as mutual consent, intention to create legal relations, and the ability to interpret contractual terms. Smart contracts, by contrast, rely on code-based execution, which may not fully capture the nuances of legal agreements. For instance, coding errors or unforeseen circumstances can lead to unintended outcomes, raising questions about liability and enforceability.

Furthermore, the rigidity of smart contracts limits the ability to adapt to changing conditions. Unlike traditional contracts, which can be renegotiated or interpreted by courts, smart contracts execute automatically once conditions are met. This inflexibility poses significant challenges in complex supply chain environments where uncertainties are common (Perdana et al., 2022).

The findings also indicate a lack of standardised legal frameworks for smart contracts. This gap creates uncertainty for businesses and may hinder the widespread adoption of blockchain technologies. Addressing this issue requires the development of hybrid legal-technological

frameworks that integrate code-based execution with legal oversight.

5.3 Data Protection and Privacy Concerns

Data protection emerges as a critical legal challenge in blockchain-enabled supply chains. Blockchain's defining feature, immutability, conflicts with data protection regulations that require the ability to modify or delete personal data. This tension is particularly evident in jurisdictions with stringent privacy laws, such as those modelled after the General Data Protection Regulation (GDPR) (Khatun & Darwish, 2025).

In supply chains, blockchain systems often store sensitive information, including personal data, proprietary business information, and transactional records. The inability to alter or delete such data raises compliance issues and exposes organisations to legal risks. For example, the "right to be forgotten" cannot be easily implemented in immutable blockchain systems.

Various technical solutions have been proposed to address these challenges, including off-chain storage, encryption, and permissioned blockchains. However, these solutions introduce additional complexities and may undermine the core benefits of blockchain, such as transparency and decentralisation (Saber et al., 2021).

The findings suggest that data protection challenges are not merely technical but also institutional. Legal frameworks must evolve to accommodate new data governance models that balance transparency with privacy. This requires collaboration between

regulators, technologists, and industry stakeholders.

5.4 Liability and Accountability in Decentralised Systems

The issue of liability and accountability is significantly complicated by the decentralised nature of blockchain systems. In traditional supply chains, responsibility can typically be traced to specific entities, such as manufacturers, distributors, or retailers. In blockchain networks, however, control is distributed among multiple participants, making it difficult to assign responsibility for errors, fraud, or system failures (Perdana et al., 2022).

The analysis reveals that liability may be shared among various actors, including developers, network participants, and users. However, the lack of clear legal frameworks for assigning liability creates uncertainty and may deter organisations from adopting blockchain technologies.

Additionally, the use of smart contracts further complicates liability issues. If a smart contract executes incorrectly due to coding errors, it is unclear whether responsibility lies with the developer, the user, or the platform provider. This ambiguity undermines legal certainty and highlights the need for clearer regulatory guidelines.

From a stakeholder perspective, accountability mechanisms must be designed to ensure that all participants are held responsible for their actions. This may involve the development of governance frameworks that define roles, responsibilities, and liability structures within blockchain networks.

5.5 Governance Gaps and Institutional Challenges

The absence of standardised governance frameworks is another key finding. Blockchain networks often rely on decentralised governance models, which differ significantly from traditional hierarchical structures. While decentralisation enhances transparency and reduces reliance on intermediaries, it also creates challenges in decision-making and coordination (Cao et al., 2021).

The analysis indicates that governance models vary widely across blockchain platforms, leading to inconsistencies and fragmentation. Some networks employ on-chain governance mechanisms, where decisions are made through voting by token holders, while others rely on off-chain processes involving core developers and stakeholders.

This diversity of governance models creates uncertainty and complicates the integration of blockchain into existing legal frameworks. Moreover, the lack of formal governance structures may lead to power imbalances, where certain stakeholders exert disproportionate influence over decision-making processes.

Institutional theory suggests that these governance gaps reflect the transitional nature of blockchain technology, where new norms and practices are still evolving. Addressing these gaps requires the development of standardised governance frameworks that align with legal and regulatory requirements.

5.6 Interoperability and Legal Compatibility

Interoperability between different blockchain systems and traditional supply chain platforms is another critical challenge. The lack of standardised protocols limits the ability of organisations to integrate blockchain solutions with existing systems, reducing their effectiveness (Kafeel et al., 2023).

From a legal perspective, interoperability issues are closely linked to compatibility between different regulatory frameworks. For example, data sharing across jurisdictions may be restricted by local laws, creating barriers to seamless integration. Additionally, differences in legal recognition of blockchain transactions can hinder cross-platform interactions.

The findings highlight the need for standardised technical and legal frameworks to facilitate interoperability. This includes the development of common protocols, data standards, and regulatory guidelines that enable seamless integration across systems.

5.7 Dispute Resolution Mechanisms

Despite the automation and transparency provided by blockchain, disputes remain inevitable in supply chain operations. The analysis reveals a lack of clear dispute resolution mechanisms for blockchain-based transactions. Traditional legal systems may not be well-suited to handle disputes involving decentralised technologies (David, 2024).

Emerging approaches include blockchain-based arbitration and hybrid dispute

resolution mechanisms that combine legal and technological elements. However, these approaches are still in their early stages and lack widespread adoption.

The absence of effective dispute resolution mechanisms undermines trust in blockchain systems and may hinder their adoption. Developing robust and accessible dispute resolution frameworks is essential for ensuring legal certainty and protecting stakeholder interests.

6. Discussion

The findings of this study reveal a complex interplay between technological innovation and legal adaptation, highlighting the transformative potential of blockchain as well as the significant challenges it poses for sustainable supply chain governance. This section provides a deeper interpretation of the findings by linking them to the theoretical framework and broader scholarly debates.

6.1 Reconciling Decentralisation with Legal Centralisation

A central theme emerging from the analysis is the tension between blockchain's decentralised architecture and the centralised nature of traditional legal systems. Institutional theory suggests that legal frameworks are deeply embedded within national contexts, characterised by defined jurisdictions and hierarchical authority structures (DiMaggio & Powell, 1983). Blockchain, by contrast, operates in a distributed environment that transcends these boundaries.

This tension creates a fundamental governance challenge. On one hand, decentralisation enhances transparency, reduces reliance on intermediaries, and fosters trust among stakeholders. On the other hand, it complicates regulatory oversight and undermines the ability of legal systems to enforce rules effectively.

Addressing this challenge requires a rethinking of legal frameworks to accommodate decentralised technologies. This may involve the development of transnational regulatory mechanisms and the adoption of flexible, principle-based approaches that can adapt to technological change (Brownsword, 2019).

6.2 The Evolution of Contract Law in the Age of Smart Contracts

The rise of smart contracts represents a significant shift in contractual relationships. From a techno-legal perspective, smart contracts exemplify the concept of “law as code,” where legal rules are embedded within technological systems (David, 2024).

While smart contracts offer efficiency and automation, they also challenge traditional notions of contract law. The inability to interpret or modify code-based contracts raises concerns about fairness and adaptability. Moreover, the lack of legal recognition in some jurisdictions creates uncertainty for businesses.

The findings suggest that a hybrid approach is necessary, combining the efficiency of smart contracts with the interpretive flexibility of traditional legal systems. This could involve the development of legal frameworks that recognise smart contracts

while providing mechanisms for dispute resolution and contract modification.

6.3 Balancing Transparency and Privacy

Blockchain's transparency is a double-edged sword. While it enhances accountability and trust, it also raises significant privacy concerns. Sustainability governance theory emphasises the importance of transparency in promoting ethical practices, but this must be balanced against the need to protect sensitive information (Jordan et al., 2018).

The findings highlight the need for innovative data governance models that reconcile these competing objectives. This may involve the use of permissioned blockchains, encryption techniques, and regulatory frameworks that define clear guidelines for data usage and protection.

6.4 Rethinking Liability and Accountability

The decentralisation of blockchain systems necessitates a rethinking of traditional liability frameworks. Stakeholder theory suggests that responsibility should be shared among all participants, reflecting the collaborative nature of blockchain networks (Freeman, 1984).

However, the absence of clear liability structures creates uncertainty and may hinder adoption. The findings indicate the need for legal frameworks that define roles and responsibilities within blockchain networks, ensuring accountability while preserving the benefits of decentralisation.

6.5 Towards Multi-Level and Adaptive Governance

The analysis underscores the importance of multi-level governance in addressing the challenges of blockchain-enabled supply chains. Sustainability governance theory emphasises the need for coordination across local, national, and international levels (Jordan et al., 2018).

A multi-level governance approach can facilitate the development of harmonised regulatory frameworks, enabling cross-border collaboration and reducing fragmentation. Additionally, adaptive governance mechanisms, such as regulatory sandboxes and iterative policy development, can help regulators respond to technological change.

6.6 Implications for Sustainable Supply Chains

The integration of blockchain into supply chains has significant implications for sustainability. By enhancing transparency and accountability, blockchain can support ethical sourcing, environmental compliance, and social responsibility (Saberli et al., 2021).

However, the legal challenges identified in this study must be addressed to realise these benefits. Without appropriate governance frameworks, blockchain may fail to achieve its full potential or may even create new risks.

6.7 Future Research Directions

The study highlights several areas for future research. Empirical studies are needed to examine the practical implementation of blockchain in supply chains and to validate the findings of this study. Additionally,

interdisciplinary research that integrates legal, technological, and organisational perspectives can provide deeper insights into blockchain governance.

7. Conclusion

This study has explored the legal challenges associated with the integration of blockchain technology into sustainable supply chain governance through a qualitative analysis of secondary data. The findings demonstrate that while blockchain offers significant potential to enhance transparency, traceability, and accountability, its adoption is constrained by a range of complex legal and institutional barriers.

One of the central conclusions of this research is that existing legal frameworks are not fully equipped to accommodate the decentralised and transnational nature of blockchain systems. Regulatory fragmentation and jurisdictional ambiguity create uncertainty for organisations operating across borders, thereby limiting the scalability of blockchain solutions. Similarly, the legal status of smart contracts remains inconsistent, raising concerns about enforceability and dispute resolution. These challenges highlight the need for legal systems to evolve in response to technological innovation.

The study also underscores the tension between blockchain's inherent transparency and the requirements of data protection and privacy regulations. Addressing this tension requires the development of innovative data governance models that balance openness with confidentiality. Furthermore, issues of

liability and accountability in decentralised networks necessitate new legal approaches that clearly define the roles and responsibilities of stakeholders.

From a governance perspective, the absence of standardised frameworks and the diversity of blockchain governance models create additional complexities. Effective governance of blockchain-enabled supply chains requires a multi-level approach that integrates local, national, and international regulatory mechanisms. Collaboration among stakeholders, including governments, industry actors, and technology providers, is essential for developing harmonised standards and best practices.

In conclusion, while blockchain holds considerable promise for advancing sustainable supply chain governance, its successful implementation depends on the alignment of technological capabilities with adaptive legal and institutional frameworks. Policymakers must adopt flexible and forward-looking regulatory strategies, such as regulatory sandboxes and international cooperation, to address emerging challenges. Future research should focus on empirical investigations and case studies to further validate and refine the theoretical insights presented in this study. By addressing these legal challenges, blockchain can play a pivotal role in fostering more transparent, accountable, and sustainable global supply chains.

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