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Impacts of Blockchain Applications on Supply Chain Collaboration and Socio-environmental Performance: An Empirical Study

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ABSTRACT

The increasing complexity and volatility of global supply chains have heightened the need for innovative technologies that enhance collaboration and support sustainable operations. While blockchain technology (BCT) has gained significant attention for its potential to improve transparency, accountability, and information sharing, empirical evidence on its practical impact remains limited. This study investigates how three widely discussed BCT use cases, traceability, data-sharing, and smart contracts, influence supply chain collaboration (SCC) and socio-environmental performance (SEP). By focusing on these distinct applications, the study offers a nuanced perspective on the mechanisms through which blockchain enables inter-organizational coordination and advances sustainability objectives. A survey with supply chain professionals was conducted, and the data were analyzed using partial least squares structural equation modeling. The results reveal that all three BCT use cases exert significant positive effects on SCC and SEP, though their relative impact differs. Notably, traceability emerges as the strongest driver of improved socio-environmental outcomes through enhanced collaboration. This study contributes to the emerging body of knowledge on digital supply chain transformation by clarifying the differentiated value of blockchain functionalities. It further provides actionable insights for managers and policymakers seeking to implement blockchain-enabled sustainability strategies.

Keywords: *blockchain technology application, supply chain collaboration, socio-environmental performance, supply chain practice view, structural equation modelling.*

1. INTRODUCTION

Global supply chains are increasingly exposed to multifaceted socio-environmental disruptions, including persistent inflation, geopolitical conflicts, such as the Russia–Ukraine and Israel–Gaza wars, intensifying climate change, and growing concerns over forced labor and human rights violations (Eachus, 2024). These systemic challenges, compounded by the residual effects of the COVID-19 pandemic, have amplified operational volatility and highlighted deep-rooted fragilities within supply networks (Sultan, 2022). Specifically, the fragmentation of supply chain tiers across geographies and regulatory regimes continues to hinder real-time data exchange, resulting in reduced visibility, coordination failures, and weakened supply chain collaboration (SCC), all of which detract from firms' socio-environmental performance (SEP) (Baah *et al.,* 2022; Eachus, 2024; Saqib & Zhang, 2021).

Within this context, SCC has emerged as a strategic priority for enhancing supply chain resilience and sustainability. Extant literature highlights that timely, accurate information sharing and joint decision-making among partners can significantly improve responsiveness and embed shared social and environmental objectives (Kumar Singh & Modgil, 2023; Siems, Seuring, & Schilling, 2022). However, despite increased investments in digital integration platforms, traditional centralized information systems remain fragmented and incompatible across firms, limiting the operationalization of effective SCC (Rashid, Rasheed, & Amirah, 2024; Sun, Deng, & Ying, 2024). These infrastructural limitations raise critical concerns regarding the ability of current systems to support trustworthy, interoperable, and dynamic coordination across supply networks.

This disconnection between technological capability and practical collaboration outcomes has become increasingly apparent in regulatory developments. Recent initiatives such as the European Union's Digital Product Passport (European Commission, 2025; European Union, 2024) and the U.S. FDA's Food Traceability Final Rule (U.S. Food & Drug Administration, 2024, 2025) illustrate ongoing difficulties in achieving standardized, secure, and interoperable data sharing across supply networks. These challenges reveal an urgent need for more robust and tamper-resistant infrastructures capable of enabling collaborative governance and sustainability integration across organizational boundaries. They demonstrate the growing regulatory and stakeholder pressure to adopt robust, tamper-resistant infrastructures that can facilitate traceability, ensure compliance, and promote collaborative governance.

To address these limitations, the proliferation of Industry 4.0 technologies, including blockchain, the Internet of Things (IoT), Artificial Intelligence (AI), and advanced communication protocols, has introduced new opportunities for reconfiguring digital supply chain infrastructures (Aiting *et al.,* 2025; Boone-Sifuentes *et al.,* 2022; Zhang *et al.,* 2024). Among these technologies, blockchain technology (BCT) has emerged as a particularly promising innovation due to its decentralized architecture, immutability, and capability for enabling secure and transparent information exchange (Hari Mohan *et al.,* 2024; Kumar C & Selvaprabhu, 2023; Zhang, Yang, & Liu, 2023). Preliminary applications of BCT in diverse industries suggest its potential to enhance traceability, reinforce compliance, and reduce opportunistic behavior across supply chain stakeholders (Abreu, Pereira, & Barata, 2025; Liu, Zhang, & Zhen, 2023). Notable use cases include blockchain-enabled seafood tracking systems in Norway (Hogan, 2021; McBride, 2025), innovative solutions for luxury products authenticity proof adopted by multiple brands (Berardo, 2024; Hirschmiller, 2024), material tracking in the automotive industry with Tesla and BMW as examples (Ledger Insights, 2021, 2023) and carbon traceability pilots in agricultural value chains (Food and Agriculture Organization of the United Nations, 2022), each illustrating the growing global momentum behind blockchain-based collaboration. However, rigorous empirical validation remains sparse.

Despite the growing interest in BCT within supply chain discourse, empirical evidence linking its adoption to measurable improvements in SCC and SEP remains limited and fragmented. Much of the existing literature is conceptual, exploratory, or technologically oriented, offering limited understanding of the specific pathways through which distinct blockchain functionalities, such as traceability, smart contracts, and decentralized data sharing, affect collaborative dynamics and sustainability outcomes (Doran *et al.,* 2025; Joshi *et al.,* 2023; Wünsche & Fernqvist, 2022). This gap is particularly critical given the increasing pressure on firms to demonstrate the tangible value of digital transformation initiatives in complex, multi-actor supply chain environments. Without empirical validation, organizations risk misaligning digital transformation initiatives with strategic sustainability goals, thus leading to overinvesting in blockchain solutions without a clear understanding of their effectiveness. Therefore, rigorous empirical research is essential not only to advance theoretical development but also to provide evidence-based guidance for managers and policymakers seeking to deploy blockchain in ways that foster inter-organizational trust, regulatory compliance, and long-term sustainability integration.

Therefore, this study addresses a critical research gap by offering an empirically grounded examination of BCT's influence on SCC and SEP, applying the Supply Chain Practice View (SCPV) to uncover how blockchain-enabled collaborative practices translate into improved socio-environmental performance. This study responds to the need for empirical insight by exploring two core research questions: (1) How do blockchain applications affect SCC? (2) What are the subsequent effects on SEP? Specifically, the study investigates how three blockchain use cases, tracing and tracking, data sharing, and smart contract-based transactions, influence collaborative supply chain practices. Using the SCPV as a guiding analytical framework, the research examines how these enhanced collaborative practices mediate the relationship between blockchain technology and sustainability outcomes. In this study, sustainability performance is assessed in terms of both environmental aspects, such as carbon emissions, energy usage, and the use of recycled materials, and social aspects, including gender equality, labor diversity, employee satisfaction, and working conditions. By uncovering the operational mechanisms linking blockchain adoption to collaborative processes and sustainability performance, this study contributes to theoretical development and delivers practical guidance for supply chain managers and policymakers. Ultimately, it positions blockchain not merely as a digital innovation, but as a strategic enabler of integrated, resilient, and socially responsible supply chain ecosystems.

The structure of the paper is as follows. Section 2 reviews the relevant literature and conceptual foundations. Section 3 presents the theoretical model and hypotheses. Section 4 outlines the research methodology. Section 5 discusses the empirical findings. Section 6 elaborates on theoretical and managerial implications. Finally, Section 7 concludes with a summary of key findings and directions for future research.

2. RESEARCH BACKGROUND AND LITERATURE REVIEW

This literature review examines three interconnected areas that inform our research. We first review SCRM to establish the context and identify key decision types. We then examine behavioral decision factors to understand how individuals actually make risk-based decisions. Finally, we develop our hypotheses by integrating risk domain theory with supply chain decision-making contexts.

2.1 Research Background

2.1.1 Supply Chain Collaboration

CSCC is characterized by a diverse array of definitions, broadly categorized into two main types: process-oriented and relationship-oriented. The process-oriented perspective views SCC as a business process where multiple supply chain participants coordinate their actions to achieve shared objectives (Manthou, Vlachopoulou, & Folinas, 2004; Sheu, Rebecca Yen, & Chae, 2006). On the other hand, the relationship-oriented definition emphasizes the formation of close, long-term partnerships, where partners collaborate, and share information, resources, and risks to attain mutual goals (Bowersox, 1990; Golicic, Foggin, & Mentzer, 2003).

Building upon these foundational perspectives, a more comprehensive definition of SCC was introduced, identifying seven intertwined components (Cao & Zhang, 2011). These dimensions are not only interconnected but may also show potential causal connections between them. Together, they are positively associated with the value of SCC, reducing costs and shortening response times, optimizing the use of resources, and encouraging innovation (Lee & Kim, 2021). In this study, we examine SCC on three data-oriented components including information sharing, collaborative communication, and joint knowledge creation.

Information sharing in supply chain management entails the dissemination of crucial, accurate, and confidential data among supply chain partners (Baah *et al.,* 2022; Kumar & Pugazhendhi, 2012; Lotfi *et al.,* 2013). It is considered essential for effective SCC (Dubey *et al.,* 2021; Gonul Kochan *et al.,* 2018; Kembro & Selviaridis, 2015), often described as the core, lifeblood, and foundation of such collaborations (Lee & Whang, 2001; Oubrahim, Sefiani, & Happonen, 2023). According to the Global Logistics Research Team at Michigan State University, it involves the willingness to share strategic and operational data, such as inventory levels and forecasts, among network participants (Cao & Zhang, 2011).

Collaborative communication involves sharing messages and maintaining contact among partners, characterized by frequency, direction, mode, and strategy (Pan *et al.,* 2020). Effective communication typically involves open, regular, and balanced two-way exchanges, indicating strong inter-organizational relationships (Al-Omoush, de Lucas, & del Val, 2023; Goffin, Lemke, & Szwejczewski, 2006; Tuten & Urban, 2001). Regular and open communication can significantly improve visibility, ultimately enhancing supply chain performance (Umar & Wilson, 2021).

Joint knowledge creation involves partners collectively enhancing their understanding and responses to market and competitive dynamics (Gebhardt *et al.,* 2022; Wee *et al.,* 2016). This includes knowledge exploration (acquisition of new insights) and knowledge exploitation (assimilation and application of information) (Bhatt & Grover, 2005). Sharing and integrating knowledge among partners fosters innovation and sustains a competitive edge in the supply chain (Lim *et al.,* 2017). Along with information sharing and collaborative communication, joint knowledge creation enhances supply chain resilience by increasing visibility, velocity, and flexibility (Chiu & Lin, 2022; Scholten & Schilder, 2015)

2.1.2 Blockchain Applications in Sustainable Supply Chain

A distributed ledger system called blockchain originally gained prominence as the technology behind Bitcoin (Nakamoto, 2008). BCT is a network of connected computer systems that maintain multiple copies of a digital ledger of transactions. Each block in the chain contains a number of transactions and each participant's ledger updates with each new transaction (Böhme *et al.,* 2015). One of the key features of BCT is its resistance to data tampering. Each block uses a cryptographic hash to link to the previous block, making alterations detectable by the entire network (Christidis & Devetsikiotis, 2016; Pilkington, 2016; Xu, Chen, & Kou, 2019). This secure nature has led to various applications across industries such as finance, healthcare, and supply chain management (Alladi *et al.,* 2019; Crosby *et al.,* 2016).

Several studies propose BCT as a core enabler of supply chain sustainability. Research on Industry 4.0 and supply chain sustainability identifies thirteen ways these technologies enhance sustainability, emphasizing BCT's role in streamlining information flow and increasing transparency for better decision-making (Bag *et al.,* 2021). Past and current research also calls for new data-driven decision-making techniques integrating BCT and other technologies (Esmaeilian *et al.,* 2020). For instance, Manupati et al. (2020) introduces a BCT framework for monitoring supply chain performance and reducing emissions and costs, using smart contracts to track and manage carbon emissions. While Matenga and Mpofu (2022) suggests a BCT and cloud computing-based system for dynamic and flexible data-sharing while maintaining privacy among supply chain stakeholders. More recently, Agrawal et al. (2023) proposes a BCT system for secure information sharing and collaboration, utilizing smart contracts to enforce rules and facilitate resource sharing among supply chain partners.

Assuming the intrinsic features of BCT like immutability, security, and transparency (Kim & Shin, 2019), researchers and practitioners have introduced specific use cases to leverage those features of BCT with the goal of improving supply chain efficiency and enhanced sustainability. Synthesizing the literature reveals that the most focused BCT applications in sustainable supply chains are tracking and tracing systems, data-sharing platforms, and smart contract-based transactions. These main use cases are closely aligned with the findings from previous studies (Dutta *et al.,* 2020; Esmaeilian *et al.,* 2020; Gonczol *et al.,* 2020; Kouhizadeh & Sarkis, 2018).

Blockchain traceability applications (BTAs) leverage BCT to create an immutable and transparent record of a product's journey from origin to end-user (Pournader *et al.,* 2020; Queiroz, Telles, & Bonilla, 2020). In supply chains, BTAs enable precise tracking at every stage, significantly reducing instances of fraud, counterfeiting, and

Table 1 Summary of Related Studies

Paper	Investigated model	Methodology	Theoretical framework
Cao and Zhang (2011)	SCC → CA → FP	Empirical study	TCE, RV and extended RBV
Chin, Tat and Sulaiman (2015)	GSCM → SCS (moderated by EC)	Empirical study	RV
Kim and Shin (2019)	BCT → SCC → FP	Empirical study	RBV and RV
Dubey et al. (2020)	BCT → SCC	Empirical study	OIPT and RV
Khan et al. (2021)	BCT → GSCP → SP → FP	Empirical study	PBV
Park and Li (2021)	BCT → SCS	Literature review	ESG lens
Rejeb et al. (2022)	BCT → SCC	Literature review	N/A
Agrawal et al. (2023)	BCT → SCC	Systematic approach	System perspective
Munir et al. (2022)	BCT → SCS	Literature review	TBL and ESG lens
Yousefi and Tosarkani (2024)	BCT → FP + SEP	System-analysis-based simulation	System analysis (FCM, DEMATEL)
Ng, Ho and Wu (2023)	TIP (BCT, IoT, Big Data) → SCV + QMS	Case simulation, FARM	IPT, RDT, TCE
This study	BCT → SCC → SEP	Empirical study	SCPV

Abbreviations: CA, Collaborative Advantage; FP, Firm Performance; TCE, Transaction Cost Economics; RBV, Resource-Based View; RV, Relational View; IPT, Information Processing Theory; GSCM, Green Supply Chain Management; SCS, Supply Chain Sustainability; SCR, Supply Chain Resilience; EC, Environmental Collaboration; GSCP, Green Supply Chain Practices; SP, Sustainability Performance; ESG, Environmental, Social, and Governance; SSC, Sustainable Supply chain; FCM, Fuzzy Cognitive Map; DEMATEL, Decision-making Trial and Evaluation Laboratory; TIP Technologies Integrated Platform; QMS, Quality Management System; FARM, Fuzzy Association Rule Mining; SCV, Supply Chain Visibility; RDT, Resource Dependency Theory.

errors (Mackey & Nayyar, 2017; Tan, Gligor, & Ngah, 2022). This transparency enhances the reliability of the supply chain and strengthens consumer trust by providing a verifiable history of the products they purchase. The decentralized nature of BCT ensures that no single entity can alter historical data, thereby making the supply chain more secure and efficient (Addou *et al.,* 2023; Wu *et al.,* 2017).

Blockchain-based data-sharing applications (BDSAs) facilitate a secure, efficient, and transparent exchange of information within supply chains (Blossey, Eisenhardt, & Hahn, 2019; Nguyen *et al.,* 2025; Queiroz, Telles, & Bonilla, 2020; Sun, Wei, & Shen, 2024). By creating a decentralized and immutable ledger, BDSAs ensure that data are reliable and accessible to all supply chain stakeholders, thereby fostering a collaborative environment. Such an environment enhances operational efficiency, reduces errors, and aids in making informed decisions (Kangqian *et al.,* 2024; van Engelenburg, Janssen, & Klievink, 2018). The inherent transparency of BCT minimizes the risks of data tampering and enhances trust among users, making BDSAs indispensable for interconnected supply chains (Yue *et al.,* 2016; Zhang, Liu, & Hou, 2025).

Blockchain smart contract-based transaction applications (BSCAs) utilize smart contracts, which are self-executing contracts with the terms of the agreement directly written into code, to automate and enforce agreements within the supply chain (Durach *et al.,* 2021; Min, 2019). These applications enable the automatic triggering of actions, such as payments, notifications, or delivery confirmations, when predefined conditions are met, without the need for intermediaries. This automation increases efficiency, reduces the likelihood of disputes, and lowers transaction costs (Christidis & Devetsikiotis, 2016; Shao & Marwa, 2024). BSCAs can significantly streamline complex supply chain processes, ensuring that compliance, quality standards, and delivery terms are consistently met, thereby enhancing overall supply chain performance (Alqarni *et al.,* 2023; Vacca *et al.,* 2021).

2.1.3 Supply Chain Sustainability Performance

The World Commission on Environment and Development (Brundtland Commission, 1987) first introduced the concept of sustainability in 1987. Since then, over 300 definitions have emerged (Johnston *et al.,* 2007). The United Nations' 2005 definition (United Nations, 2015), encompassing environmental, social, and economic aspects, collectively known as the triple bottom line (TBL) or the three pillars, has been particularly influential (Seuring *et al.,* 2008). Since the early 2000s, the TBL has been used as an indicator of organizational sustainability (Elkington, 2013; Elkington & Rowlands, 1999). While the core principles of the TBL remain constant, frameworks have evolved, such as the United Nations' Sustainable Development Goals (SDGs) (United Nations, 2015) and the Taskforce for Nature-related Financial Disclosures (TNFD) framework for nature-related financial reporting (Bacon, 2023).

In supply chains, a key strategic aspect of sustainability is ensuring that processes, products, and activities comply with established sustainability criteria and certifications (Grimm, Hofstetter, & Sarkis, 2016). The TBL is reflected in firms' Environmental, Social, and Governance (ESG) initiatives. Environmental engagement measures a company's impact on the environment, including resource usage, energy consumption, waste production, and emissions (Saberi *et al.,* 2019; Sarkis, 2003). Social sustainability addresses human rights issues, workplace health and safety, diversity, and labor practices (Venkatesh *et al.,* 2020). Governance involves long-term success and stakeholder communication, as detailed in Morgan Stanley Capital International's 2019 ESG rating methodology report (MSCI, 2023). This ESG framework is widely used to demonstrate commitment to sustainable practices (Park & Li, 2021).

Each sustainability dimension, environmental, social, and economic, contributes uniquely to sustainable practices. Under the lens of sustainable supply chain management, these aspects overlap and interconnect, leading to complex strategies for sustainability (Mani, Gunasekaran, & Delgado, 2018). The study of Carter and Rogers (2008) proposed that companies integrating environmental, economic, and social engagements achieve greater economic success than those focusing on one or two TBL elements. This proposition incorporates insights from resource dependence theory, transaction cost economics, population ecology, and the resource-based view, suggesting that collaboration with supply chain partners enhances overall economic performance (Bubicz, Barbosa-Póvoa, & Carvalho, 2019). This positive influence is supported by several empirical studies (Cao & Zhang, 2011; Kim & Shin, 2019), which highlight the direct and indirect economic benefits of integrating socio-environmental factors into operations (Carter & Rogers, 2008).

2.2 Related Work

The Literature exploring the applications of BCT in enhancing SCC has only begun to emerge since 2016, with notable growth in academic and grey literature since 2020 (Han & Fang, 2024). This increase reflects the early-stage adoption of BCT across global supply chains, where real-world implementation remains limited. Existing research has primarily emphasized the conceptual potential of blockchain in supporting collaboration and transparency across partners. For instance, Agrawal *et al.* (2023) proposed a BCT framework to incentivize collaboration among supply chain partners through a systematic approach, while Rejeb *et al.* (2022) conducted a literature review highlighting BCT's capacity to improve traceability, trust, and data transparency in collaborative settings. Empirical evidence by Dubey et al. (2020) further reinforced BCT's favorable impact on collaboration and supply chain resilience.

More recently, research has increasingly turned toward systematic evaluations of BCT's role in improving sustainable supply chains. Munir *et al.* (2022) conducted a systematic literature review of 136 studies to examine blockchain's contributions to sustainable supply chain management across the TBL dimensions - economic, environmental, and social. Their study categorizes findings by sector, including aviation, agriculture, and pharmaceuticals, and highlights the multifaceted benefits of BCT, such as improved traceability, transparency, and process decentralization for economic sustainability; resource efficiency and emissions reduction for environmental sustainability; and enhanced accountability and fraud prevention for social governance. In addition to identifying critical success factors and adoption barriers, the study highlights emerging research trends, including the convergence of blockchain with circular economy and Industry 4.0 technologies. Complementing this, Yousefi and Tosarkani (2024) presented a system-analysis-based approach integrating Fuzzy Cognitive Maps (FCM) and DEMATEL techniques to identify and simulate causal interdependencies among BCT enablers and their effects on SSC performance. Their findings highlighted traceability, transparency, and smart contracts as key BCT enablers that dynamically enhance sustainable outcomes. This study advanced prior literature by moving beyond static evaluations and offering a dynamic, interaction-based analysis of enabler impacts. In parallel, Ng, Ho and Wu (2023) proposed an architecture integrating blockchain, IIoT, and big data analytics for quality-centric process control in supply chains. Their platform, featuring Fuzzy Association Rule Mining (FARM), enabled near real-time quality feedback loops and decision automation, thus ensuring supply chain visibility (SCV) and data integrity. This integration directly addressed the common oversight in QMS literature, which often assumed data accuracy and timeliness without accounting for system-level enablers like blockchain and IIoT.

On the other hand, theoretical exploration of SCC and SEP continues to evolve. Traditional frameworks such as transaction cost economics (TCE), the resource-based view (RBV), and the relational view (RV) have long been used to evaluate practices and resources that influence supply chain performance (Cao & Zhang, 2011; Chin, Tat, & Sulaiman, 2015; Kim & Shin, 2019). Emerging perspectives such as the practice-based view (PBV) (Khan *et al.,* 2021) and the supply chain practice view (SCPV) (Carter, Kosmol, & Kaufmann, 2017) offer more nuanced insights into BCT's operational impacts on SCC.

While studies such as Kim and Shin (2019) and Khan *et al.* (2021) focus on financial and green performance metrics, others like Park and Li (2021) and Munir et al. (2022) expand the scope to environmental and social indicators. The work of Yousefi and Tosarkani (2024) and Ng, Ho and Wu (2023) further push the frontier by introducing system-oriented methodologies to understand the interactional effects of BCT enablers and infrastructure technologies on performance.

Despite this progress, many studies remain confined to conceptual or theoretical domains. There is a continued need for empirically grounded investigations that unpack the practical mechanisms through which BCT enhances SCC and SEP. This study responds to that gap by using the SCPV framework to evaluate BCT applications in real-world settings, offering actionable insights for practitioners and policymakers. It thereby contributes to the growing literature advocating for modular, scalable, and system-aware blockchain adoption strategies in sustainable supply chain management.

3. THEORETICAL FRAMEWORK

The RBV (Barney, 1991) and the RV (Dyer & Singh, 1998) have been widely used to evaluate the impact of practices and resources on supply chain performance and sustainability. However, these theories may not fully capture the complexities and technological advancements of modern supply chains. RBV focuses on firm-specific resources and capabilities, suggesting that competitive advantage arises from resources that are valuable, rare, inimitable, and non-substitutable (VRIN) (Barney, 1991), while RV emphasizes inter-firm relationships and the creation of relational rents through partnerships and alliances (Dyer & Singh, 1998). Both perspectives offer valuable insights but fall short in addressing the interconnected nature of supply chain practices facilitated by contemporary technologies like BCT.

Building on these limitations, the PBV (Bromiley & Rau, 2014) focuses on specific practices driving firm performance but remains centered on individual firms rather than broader supply chain networks. The SCPV evolves from PBV to provide a comprehensive framework that includes inter-organizational practices (Carter, Kosmol, & Kaufmann, 2017). It also extends the analysis to practices spanning firm boundaries and involving multiple supply chain partners (Prajogo *et al.,* 2018; Wang, Lee, & Chan, 2023). Thus, it is applicable to assess the impacts of BCT applications, such as tracing and tracking, data sharing, and smart contracts on collaboration between different partners in the supply chain. Moreover, SCPV also takes into account the economic and socio-environmental dimensions of supply chain performance (Kosmol, Reimann, & Kaufmann, 2019), offering a broader perspective than RBV and RV. Nonetheless, SCPV evaluates the dynamic interactions between practices and performance, viewing them as continua rather than dichotomies (Carter, Kosmol, & Kaufmann, 2017). This comprehensive view aligns with our measurement model evaluating the impact of common use cases of BCT applications in the supply chain industry on SCC and SEP. Therefore, assessing such relationships through the SCPV could provide new insights into the strategic application of BCT in supply chains to enhance sustainability that is crucial in modern supply chain management.

In addition, the complexity of modern supply chains, characterized by global operations and diverse stakeholders, requires a theoretical framework that can adapt to varying contexts and scales. SCPV is particularly suitable for fulfilling those needs thanks to its focus on inter-organizational practices, holistic performance evaluation, relevance to innovative technologies, comprehensive performance metrics, and adaptability to complex supply chains. This adaptability is crucial for capturing the multifaceted effects of BCT on supply chain practices and performance.

4. HYPOTHESES DEVELOPMENT

Building on the SCPV and the preceding literature review, this section develops the hypotheses linking blockchain technology applications, SCC, and SEP. SCPV emphasizes that organizational and inter-organizational practices constitute key mechanisms through which technologies influence performance outcomes (Carter, *et al.,* 2017). In this study, blockchain applications are conceptualized as practice-enabling mechanisms that may influence sustainability outcomes directly and indirectly through collaborative supply chain processes. Accordingly, we develop hypotheses concerning (i) the effects of blockchain use cases on SCC, (ii) the direct effects of blockchain use cases on SEP, and (iii) the role of SCC as a predictor of SEP.

4.1 Blockchain Applications and Supply Chain Collaboration

BCT introduces a decentralized, tamper-resistant infrastructure that facilitates inter-organizational coordination by overcoming longstanding limitations of conventional information systems, namely, fragmented data silos, lack of trust, and low process transparency (Raj *et al.,* 2022; Saberi *et al.,* 2019). However, BCT is not monolithic; its impact on SCC depends on how specific applications operationalize its core functionalities, namely, traceability, immutable data-sharing, and self-executing smart contracts.

BTAs enhance collaboration primarily by increasing shared visibility over material, product, or transactional flows (Centobelli *et al.,* 2022; Zheng, Xu, & Qiu, 2023). By enabling all actors to access consistent and real-time provenance data, BTAs reduce information asymmetry, mitigate the risk of opportunistic behavior, and build inter-firm trust (Cole, Stevenson, & Aitken, 2019; Hogan, 2021; Vazquez Melendez, Bergey, & Smith, 2024). For instance, initiatives such as IBM and Maersk’s TradeLens platform demonstrate that traceability enhances coordination, especially in complex, multi-modal logistics settings (Jovanovic *et al.,* 2022).

BDSAs address the lack of secure and timely information flows that frequently hinder collaborative planning and communication. BDSAs facilitate multi-directional, tamper-proof data exchange among supply chain partners, supporting collaborative forecasting, synchronized replenishment, and joint problem solving (Hidayanto & Prabowo, 2019; Shamout, 2019; Sun, Wei, & Shen, 2024). Unlike traditional systems, BDSAs ensure immutability and access control, making collaborative communication more reliable and auditable (Blossey, Eisenhardt, & Hahn, 2019; Kangqian *et al.,* 2024).

BSCAs automate inter-organizational agreements by embedding them into self-executing code (European Parliament, 2020). This ensures predictability and enforcement of joint commitments, reducing the need for costly manual reconciliations or third-party arbitration (Alqarni *et al.,* 2023; Raj *et al.,* 2022). BSCAs thus support collaborative governance by institutionalizing transparency and compliance within the operational fabric of supply chains (Martinez *et al.,* 2019; Putri, Hariadi, & Rachmadi, 2023).

Accordingly, the following hypotheses are proposed:

- ***H1a:*** BTAs have a significant positive effect on SCC.
- ***H1b:*** BDSAs have a significant positive effect on SCC.
- ***H1c:*** BSCAs transactions have a significant positive effect on SCC.

4.2 Blockchain Applications and Socio-Environmental Performance

The use of BCT in supply chains has also generated interest for its potential to enhance SEP. The literature emphasizes three interrelated pathways: (1) improved traceability for compliance and ethical sourcing, (2) reliable data sharing for sustainability reporting and audits, and (3) automation of incentive structures and regulatory rules through smart contracts (Parmentola *et al.,* 2022; Saberi *et al.,* 2019; Upadhyay *et al.,* 2021).

BTAs support environmental and social accountability by enabling real-time monitoring of product origins, materials, and compliance statuses. This visibility is particularly important for detecting forced labor, ensuring fair trade practices, or verifying carbon footprints (Kshetri, 2024; Nath & Choudhury, 2024; Thanasi-Boçe & Hoxha, 2025). For example, blockchain-enabled traceability has

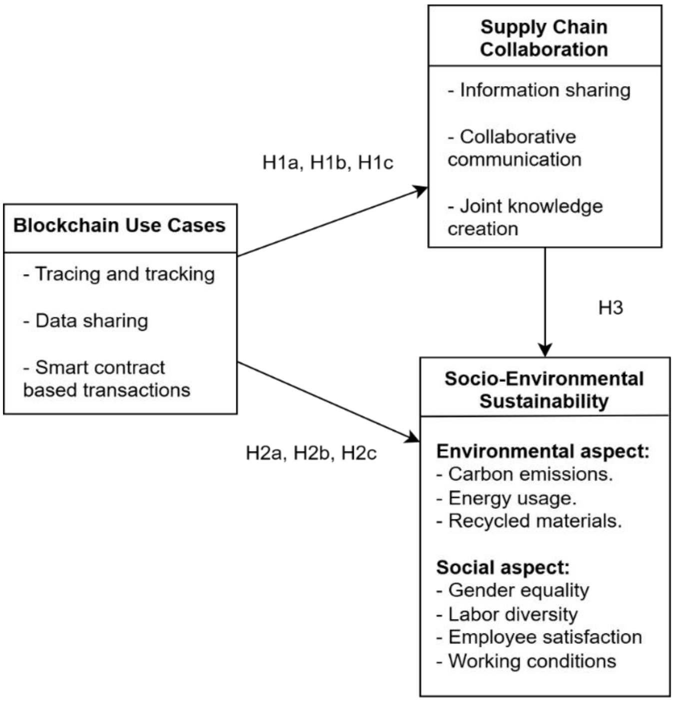

Figure 1 Conceptual Research Model Grounded in the Supply Chain Practice View (SCPV)

been adopted in seafood and cocoa supply chains to validate sustainability claims (Berardo, 2024; McBride, 2025).

BDSAs facilitate sustainability data transparency, allowing firms to capture and disseminate environmental and labor metrics with integrity (Musamih *et al.,* 2025; Nguyen *et al.,* 2025). This ensures more credible stakeholder reporting, reduces greenwashing risks, and supports joint sustainability initiatives across the supply chain (Kshetri, 2024; Zhang, Liu, & Hou, 2025). Empirically, such secure data-sharing systems have been shown to improve coordination on carbon tracking and circular economy practices (Ng, Ho, & Wu, 2023).

BSCAs advance SEP by institutionalizing pro-environmental behaviors and fair labor practices through programmable logic (Alabdulkarim *et al.,* 2023; Putri, Hariadi, & Rachmadi, 2023). Smart contracts can enforce compliance conditions. For instance, releasing payments only upon verified ethical sourcing or emissions reporting, thus aligning economic incentives with sustainability outcomes (Chaudhuri *et al.,* 2023; Stuit, Brockington, & Corbera, 2022).

Therefore, the following hypotheses are proposed:

- ***H2a:*** BTAs have a significant positive effect on supply chain SEP.
- ***H2b:*** BDSAs have a significant positive effect on supply chain SEP.
- ***H2c:*** BSCAs have a significant positive effect on supply chain SEP.

4.3 Supply Chain Collaboration and Socio-Environmental Sustainability

Extensive literature affirms the critical role of SCC in achieving environmental and social sustainability targets (Cao & Zhang, 2011; Kwon, Kim, & Martin, 2016; Youn et *al.,* 2013). Collaborative supply chains enable firms to engage in joint innovation, pool capabilities, and co-develop sustainability programs such as carbon reduction initiatives, supplier training programs, and ethical sourcing mechanisms (Al-Omoush, de Lucas, & del Val, 2023; Holloway, 2025). SCC also facilitates the alignment of incentives and the integration of sustainability metrics into shared performance dashboards, thereby reinforcing accountability across partners (Baah *et al.,* 2022).

Furthermore, SCC enhances the effectiveness of sustainability-oriented digital technologies by ensuring mutual understanding and joint commitment to long-term environmental and social goals (Baah *et al.*, 2022; Solaimani & van der Veen, 2022). The presence of robust collaborative practices (e.g., shared KPIs, transparent communication channels, joint knowledge creation) has been empirically linked to superior sustainability outcomes across diverse industries and regions (Arsawan *et al.,* 2023; Emon, Khan, & Siam, 2024; Fontoura & Coelho, 2022; Kyeremeh, Yamoah, & Yamoah, 2025; Rashid, Rasheed, & Amirah, 2023). Based on these considerations, we also proposed the following hypothesis:

- ***H3:*** SCC has a significant positive effect on supply chain SEP.

5. RESEARCH METHODOLOGY

5.1 Item Generation

The objective of developing measurement items is to ensure content validity through a comprehensive literature review and expert insights from academia and industry perspectives. A thorough review of prior studies is crucial for establishing an initial set of measurement items that encompass the scope of the construct holistically (Cao & Zhang, 2011; Kim & Shin, 2019). Detailed information about measurement instruments of all items is provided in Appendix A.

Table 2 Demographic Information of Survey Respondents (n=133)

Attributes	Sub attributes	Count	%
Gender	Male	79	59.4
	Female	49	36.8
	Others	5	3.8
Experience	1-3 years	28	21.1
	3-5 years	60	45.1
	5-10 years	35	26.3
	10+ years	10	7.5
Organization size	1-50 employees	29	21.8
	51-250 employees	46	34.6
	251-500 employees	28	21.1
	500+ employees	30	22.6
Organization location	Australia	14	10.5
	United Kingdom	33	24.8
	United States	61	45.9
	Others [a]	25	18.8
Industry	Agriculture	17	12.8
	Financial	28	21.1
	Food	33	24.8
	Retailer	13	9.77
	Textile	19	14.3
	Others [b]	28	21.1
Job title	Analysts	16	12.0
	Assistants	28	21.1
	Coordinators	18	13.5
	Directors	4	3.0
	Managers	40	30.1
	Planners	24	18.0
	Specialists	1	0.8
	Advisors	2	1.5

[a] Brazil (2), China (2), Denmark (2), Germany (1), Netherlands (1), Russia (2), Vietnam (7), Not disclosed (8).
[b] Automobile (1), Consultancy (4), Health (8), Logistics & Transportation (8), Manufacturing (2).

Our research evaluates the impact of BCT on supply chain operations through its practical applications rather than its inherent characteristics. Previous literature has examined BCT's association with green supply chain processes (Khan *et al.,* 2021) and its impact on supply chain partnerships and performance (Kim & Shin, 2019). Inspired by Kamble *et al.* (2023), our approach focuses on three common use cases of BCT applications: traceability (BTA), data-sharing (BDSA), and smart contract-based transactions (BSCA). These use cases were chosen for their prominence in recent literature and relevance to supply chain management and sustainability (Chang & Chen, 2020). Accordingly, blockchain's traceability feature enhances visibility along the supply chain (Han & Fang, 2024), while decentralized data-sharing implementation facilitates collaboration among partners (Queiroz, Telles, & Bonilla, 2020). And blockchain smart contracts are utilized to streamline financial operations and enable peer-to-peer transactions (Chang & Chen, 2020; Dutta *et al.,* 2020).

Importantly, each of the three blockchain use cases (BTA, BDSA, and BSCA) is operationalized as a single-item measure reflecting the firm's stage of adoption on a five-point scale ranging from "not under consideration" to "successfully implemented." As single-item constructs, these measures do not permit the assessment of internal consistency reliability or convergent validity. Moreover, the scale captures the maturity or stage of adoption rather than the intensity, scope, or quality of application. Adoption stage does not necessarily imply effective utilization or integration into collaborative routines, and therefore may only partially represent the theoretical mechanisms through which blockchain applications influence SCC and SEP. This operationalization was chosen to reduce respondent burden and because the three use cases represent concrete managerial practices rather than latent psychological constructs. Nevertheless, future research should consider developing multi-item scales that capture not only adoption stage but also depth of implementation, integration quality, and performance alignment to better reflect the constructs as theorized.

We only use items that relates to digital data operations from previous studies (Cao & Zhang, 2011; Kim & Shin, 2019) to evaluate SCC in this study. The dimensions include information sharing, collaborative communication, and joint knowledge creation, which are fundamental for effective collaboration and align with the core tenets of BCT applications (Jimenez-Jimenez, Martínez-Costa, & Sanchez Rodriguez, 2019).

Our study focuses on the social and environmental dimensions of supply chain sustainability, diverging from traditional financial and operational metrics (Cao & Zhang, 2011; Kim & Shin, 2019). This study uses seven distinct items selected from prior research (Goworek, 2011; Nizam *et al.,* 2019; Park & Li, 2021) and key UN documents

(United Nations, 2015; United Nations Environment Management Group, 2021). Environmental indicators include carbon emissions, energy usage, and recycled materials, while social indicators cover gender equality, labor diversity, employee satisfaction, and working conditions. Initially, we analyzed SEP metrics separately, but their significant correlation highlighted their interdependent nature. This led to integrating both dimensions into a single SEP metric, providing a holistic assessment of the supply chain's impact and simplifying the measurement process (Carter & Rogers, 2008).

5.2 Sampling Design and Data Collection

The survey instrument was developed using the Qualtrics survey platform, incorporating 5-point Likert scale questions. Such approach allows the research to understand the level of agreement with statements about BCT applications, SCC, and SEP. To enhance the validity and reliability of the survey, a pilot test was conducted with 15 research graduates and lecturers in supply chain. The items were randomized to mitigate order bias. Moreover, the target population of the survey consists of supply chain professionals with at least one year of industry experience, with an additional requirement of experience with BCT. To address potential common method bias, the survey items were modified, respondent anonymity was maintained, and participants with relevant knowledge and experience were selected.

The survey was disseminated through LinkedIn, leveraging an engaging poster to capture potential participants' attention. Participants were also encouraged to share the survey within their professional networks to maximize the reach. In addition to organic sharing, we also utilized LinkedIn Sales Navigator to directly reach out to supply chain professionals, ensuring the survey invitation targeted individuals with the relevant expertise and experience in BCT applications. A total of 83 personalized invitations were sent to eligible participants. To further enhance the response rate, follow-up reminders were issued after a week. This approach aims at increasing engagement and encouraging completion among those who have not yet responded. The survey was accessible for a period of two months, during which responses were continuously monitored. The decision to close the survey was made when the inflow of responses slowed significantly, indicating a plateau in participation. In total, 204 responses were recorded. After a thorough review, 133 were deemed complete and usable, resulting in a 65% completion rate. The data collected from the survey underwent a rigorous cleaning process to ensure accuracy and reliability for subsequent analysis. This process includes verifying the completeness of responses, checking for inconsistencies, and ensuring that all participants meet the predefined eligibility criteria. The demographic characteristics of the respondents are detailed in **Table 2**.

5.3 Measurement Model Assessment

This study adopts a hybrid analytical approach that combines Confirmatory Factor Analysis (CFA) using AMOS 29 and Partial Least Squares Structural Equation Modeling (PLS-SEM) for hypothesis testing. This two-stage methodology is justified by the dual objectives of the research: first, to ensure the psychometric rigor of the measurement model, and second, to explore and estimate structural relationships in a predictive, theory-developing context involving multiple endogenous constructs.

In the initial stage, CFA was conducted using AMOS 29 to evaluate the validity and reliability of the measurement model. This process involved several key assessments: (i) evaluating the reliability of the measurement models to ensure consistency in the responses, (ii) verifying convergent validity to ascertain that the items are closely related to their respective constructs, (iii) assessing unidimensionality to confirm that each construct is adequately captured by its associated items, and (iv) examining discriminant validity to establish that the constructs are distinct and not overly correlated with one another. This rigorous analysis was essential to guarantee the robustness and credibility of the survey results for subsequent hypothesis testing.

CFA using AMOS software was employed to perform several checks: (1) to evaluate unidimensionality and convergent validity, (2) to assess reliability, and (3) to determine discriminant validity for each construct with associated multi-item measures (Papke-Shields, Malhotra, & Grover, 2002). The process involved iterative refinements, including the exclusion of items with loadings below 0.5 and those displaying highly correlated errors, thereby enhancing the model fit to reach acceptable standards (Hair *et al.,* 2006). Deletions were made incrementally and only when they were justified by the underlying theory and contributed to an improved model structure (Hair *et al.,* 2006).

Unidimensionality was verified through fit indices, while the significance of each measurement indicator was scrutinized to confirm convergent validity. The model's overall fit was examined using various metrics, such as the comparative fit index (CFI), Tucker Lewis index (TLI), root mean square error of approximation (RMSEA), and the normalized chi-square, which is the chi-square value divided by the degrees of freedom (Bentler, 1990; Byrne, 1989; Chau, 1997; Hair *et al.,* 2006). Acceptable model fits were indicated by CFI values above 0.9 and TLI values above 0.9 (Hair *et al.,* 2006). According to recommendations, a good RMSEA value is a matter of discussion but is usually considered below 0.10 for models deemed generally acceptable (Hair *et al.,* 2006). The normalized chi-square is employed to assess the relative effectiveness of various models, with a value under 3.0 regarded as reasonable and below 2.0 as indicative of a good fit (Papke-Shields, Malhotra, & Grover, 2002; Segars & Grover, 1998).

Adhering to the guidelines from Hair et al. (2006), the composite reliability (CR) and average variance extracted (AVE) from a construct's multiple indicators serve as metrics for evaluating a construct's reliability. It is generally advised that AVE should exceed 0.5 and CR should be greater than 0.9. However, constructs may still be deemed acceptable when the AVE is below 0.5, provided the CR exceeds 0.6, thus allowing for the affirmation of the constructs' convergent validity (Lam, 2012).

Heterotrait-monotrait (HTMT) ratio, a modern method proposed by Henseler, Ringle and Sarstedt (2015), is used to examine the model's discriminant validity. This method is used because it is recommended for studies using the partial least squares structural equation modeling method (Cheung *et al.,* 2023), which is employed in this study. Accordingly,

Table 3 Full Collinearity VIF Values for CMB Assessment.

Construct	VIF
SCC	1.22
BTA	1.25
BDSA	1.15
BSCA	1.18

the HTMT ratio between constructs should be less than 0.85 to confirm the model's discriminant validity (Henseler, Ringle, & Sarstedt, 2015).

The process of testing the hypotheses in this study commences with a thorough evaluation of the model's fit. Once an adequate level of fit is confirmed, we proceed with a path analysis. This involves two key steps: Firstly, we apply the structural model to our dataset to explore potential relationships between the variables. This step is crucial to understand the direct and indirect interactions within the model. Secondly, we conduct a structural analysis to understand the statistical relationship between the variables and their significance. This sequential approach ensures a rigorous and methodical examination of the hypothesized relationships within this study.

Following the refinement and validation of the measurement model, the structural model was estimated using PLS-SEM. The choice of PLS-SEM is appropriate for this study due to its suitability for complex, exploratory models, its relaxed requirements concerning data distribution, and its predictive orientation—particularly relevant given the early-stage empirical nature of blockchain applications in sustainable supply chain contexts (Panigrahi *et al.,* 2023; wael Al-khatib & Khattab, 2024).

Because the study uses a single self-report survey, common method bias (CMB) is a potential threat. We implemented procedural remedies, including respondent anonymity, clear item wording, and randomization of item order. In addition, we applied at least one statistical diagnostic. First, we conducted Harman's single-factor test using an unrotated exploratory factor analysis: if a single factor does not account for the majority of variance, this suggests that common method variance is unlikely to dominate responses. Second (PLS-SEM-oriented), we assessed full collinearity variance inflation factors (VIFs) for the latent variables; VIF values below 3.3 indicate that CMB is unlikely to be a severe concern (Kock, 2015). Nevertheless, no diagnostic can fully eliminate CMB risk, and residual bias cannot be completely excluded; this limitation is considered when interpreting results.

Regarding sample adequacy, PLS-SEM is well suited for predictive structural models with moderate sample sizes and multiple endogenous constructs. As an initial heuristic, the "10-times rule" suggests that the minimum required sample size should be at least ten times the maximum number of structural paths directed at any endogenous construct. In the present model, the largest number of predictors occurs for socio-environmental performance (SEP), which is predicted by four variables (SCC, BTA, BDSA, and BSCA), yielding a minimum threshold of 40 observations. With a final sample of 133 responses, the study substantially exceeds this baseline requirement.

Beyond this heuristic, model adequacy is further evaluated through explanatory power and effect size diagnostics, including R^2 and adjusted R^2 for endogenous constructs, as well as Cohen's f^2 effect sizes. Statistical inference is assessed using non-parametric bootstrapping to ensure the stability of path estimates. In addition, robustness checks using alternative model specifications are conducted to examine whether the substantive findings remain consistent under different indicator configurations. Collectively, these procedures provide a comprehensive assessment of sample adequacy and structural stability.

6. RESULTS

This section reports the results of common method bias assessment, measurement model evaluation, and structural path analysis.

6.1 Assessment of Common Method Bias

Given that the empirical data were collected using a single self-report survey, CMB was assessed using both exploratory and collinearity-based diagnostics.

First, Harman's single-factor test was conducted using an unrotated exploratory factor analysis with principal axis factoring applied to all measurement items. The results indicate that the first factor accounts for 28.54% of the total variance, which is well below the commonly cited 50% threshold. This suggests that no single factor dominates the variance structure of the data and that common method variance is unlikely to be a serious concern.

Second, a full collinearity assessment was performed by examining VIFs in a regression model with SEP as the dependent variable and SCC, BTA, BDSA, and BSCA as predictors (see **Table 3**). All VIF values ranged from 1.15 to 1.25, substantially below the conservative threshold of 3.3 recommended for detecting common method bias in SEM-based studies (Kock, 2015). These results suggest a low likelihood that collinearity arising from a common measurement method materially biases the estimated relationships.

Taken together, the findings from Harman's single-factor test and the full collinearity VIF assessment suggest that common method bias is unlikely to significantly distort the results of this study. Nevertheless, as with all cross-sectional survey-based research, residual method bias cannot be entirely ruled out and should be considered when interpreting the findings.

6.2 Measurement Model Assessment Results

Before hypothesis testing, we assessed the measurement properties of the latent constructs. Given that SCC was initially operationalized as a multi-dimensional concept (seven dimensions), we first specified a confirmatory factor model in AMOS in which the SCC dimensions were allowed to correlate. Following standard CFA refinement procedures, we examined standardized loadings and modification indices to identify indicators that did not reliably represent the intended data-centric collaboration focus of this study.

Table 4 Model Fit Indices

Metrics	Values	Recommended
CFI	0.936	> 0.9
TLI	0.911	> 0.9
RMSEA	0.06	< 0.1
Normed χ^2	1.469	< 2.0

Table 5 Structural Model Evaluation and Explanatory Power

Endogenous Constructs	R^2	Adjusted R^2	p-value	f^2
SCC	0.229	0.211	< .001	0.297
SEP	0.499	0.484	< .001	0.996

Table 6 Confirmatory Factor Analysis Results

Constructs	Variables	Loading	Cronbach's alpha	CR	AVE
SCC	COLLAB3	0.659	0.675	0.677	0.416
	COLLAB5	0.522			
	COLLAB7	0.735			
SEP	ENV1	0.506	0.793	0.775	0.334
	ENV2	0.765			
	ENV4	0.536			
	SOC1	0.538			
	SOC2	0.586			
	SOC3	0.514			
	SOC4	0.559			

As a result, four SCC indicators (COLLAB1, COLLAB2, COLLAB4, and COLLAB6) were removed due to weak loadings and limited conceptual alignment with the study's emphasis on digital information sharing, collaborative communication, and joint knowledge creation. A detailed content mapping of retained and removed SCC items is provided in Appendix A2 to clarify domain coverage following measurement refinement. Similarly, ENV3 was removed from SEP due to insufficient loading. After refinement, the CFA exhibited acceptable model fit using commonly cited CB-SEM thresholds (**Table *4***), supporting unidimensionality of the retained measurement structure. Following validation of the measurement model, the structural relationships were estimated using bootstrapped regression analysis. The results indicate meaningful explanatory power for both endogenous constructs (**Table 5**). The predictors explain 22.9% of the variance in SCC and 49.9% of the variance in SEP. Adjusted R^2 values remain stable, suggesting limited overfitting. Bootstrapped estimates confirm the statistical significance of supported paths. In addition, Cohen's f^2 effect sizes indicate a medium-to-large structural effect for SCC and a large effect for SEP, reinforcing the substantive explanatory relevance of the model. Robustness checks using alternative indicator specifications yielded consistent structural patterns, supporting the stability of the findings.

To further assess structural stability, a split-sample sensitivity analysis was conducted. The dataset was randomly divided into two approximately equal subsamples (n_1 = 66; n_2 = 67), and the structural models were re-estimated separately. For SCC, explanatory power remained within an acceptable range (R^2 = 0.330 and 0.150), and the direction of all coefficients was preserved across subsamples. For SEP, explanatory power was highly consistent (R^2 = 0.521 and 0.505), with identical patterns of statistically significant and non-significant predictors across both subsets. No coefficient sign reversals were observed. Although statistical significance for some weaker paths varied due to reduced subsample size, the overall structural pattern remained substantively stable. These findings provide additional evidence of the robustness of the estimated relationships. **Table 6** reports indicator loadings and reliability/validity statistics for SCC and SEP. All retained indicators load significantly on their intended construct ($p < 0.01$), with loadings exceeding 0.50, indicating acceptable indicator reliability for exploratory-to-confirmatory measurement development. Internal consistency reliability is borderline for SCC (Cronbach's alpha = 0.675; CR = 0.677), and acceptable for SEP (Cronbach's alpha = 0.793; CR = 0.775). Although the AVE values for SCC (0.416) and SEP (0.334) fall below the conventional 0.50 threshold, CR remains acceptable (SCC = 0.677; SEP = 0.775). Prior methodological research indicates that when CR exceeds 0.60–0.70, constructs may still demonstrate adequate internal consistency despite lower AVE, particularly in the case of theoretically broad and multidimensional constructs (Lam, 2012). Both SCC and SEP are conceptualized as integrative constructs encompassing heterogeneous but related dimensions, like information sharing, communication, knowledge creation; environmental and social sustainability indicators, which can attenuate shared variance among indicators and depress AVE values. We therefore retained the constructs to preserve theoretical coverage and comparability with established measurement instruments, while interpreting structural relationships with appropriate caution. To ensure that

Table 7 Inter-item Correlations Used to Compute HTMT between SCC and SEP

	SOC1	SOC2	SOC3	SOC4	ENV1	ENV2	ENV4	COLLAB3	COLLAB5
SOC2	0.315								
SOC3	0.276	0.301							
SOC4	0.301	0.328	0.476						
ENV1	0.272	0.297	0.260	0.283					
ENV2	0.411	0.448	0.393	0.428	0.387				
ENV4	0.288	0.314	0.424	0.300	0.271	0.409			
COLLAB3	0.195	0.213	0.187	0.203	0.184	0.278	0.195		
COLLAB5	0.155	0.169	0.148	0.161	0.146	0.220	0.154	0.344	
COLLAB7	0.218	0.237	0.208	0.227	0.205	0.310	0.217	0.484	0.384

substantive conclusions were not driven by measurement specification, we conducted robustness checks using alternative indicator configurations, such as excluding lower-loading items and modelling environmental and social sustainability separately. These alternative specifications resulted in unstable measurement models and inconsistent structural estimates, supporting the empirical appropriateness of the integrated SCC and SEP constructs for the present dataset. Accordingly, although convergent validity is modest, the measurement structure is considered acceptable for theory-testing purposes within the study's exploratory–predictive framework.

Nevertheless, the relatively low AVE values and the reduction of SCC from seven initial indicators to three retained items represent limitations of the measurement model. While theoretical coverage of the core collaboration dimensions is preserved, some dimensional richness may have been attenuated, and results should therefore be interpreted with appropriate caution. Importantly, the three retained SCC indicators correspond directly to the three core data-oriented collaboration dimensions identified in Section 2.1.1 (information sharing, collaborative communication, and joint knowledge creation). Although dimensional breadth is reduced relative to the initial specification, the retained indicators preserve theoretical alignment with the construct's conceptual foundation.

Discriminant validity between SCC and SEP was assessed using the heterotrait-monotrait ratio (HTMT), computed from the inter-item correlations reported in **Table 7**. The HTMT value was 0.542, well below the conservative threshold of 0.85 (Henseler*, et al.*, 2015), supporting discriminant validity and indicating that SCC and SEP capture empirically distinct concepts in this dataset.

6.3 Path Analysis Results

We utilized PLS-SEM to evaluate the proposed Hypotheses 1-3. Following the CFA, three observed variables were selected as indicators to capture the essence of SCC, while SEP was quantified through seven distinct indicators. Moreover, three prevalent BCT use cases, considered as observed variables, were posited to serve as exogenous variables influencing the structural model. The resulting path diagram, complete with associated loadings, is depicted in **Figure 2**. It is noteworthy that the overall model fit was consistent with the original CFA results, as detailed in **Table 6**.

The analytical results provide support for Hypothesis H1a, indicating a statistically significant positive association between BCT traceability and SCC. Specifically, the path coefficient is 0.41 with a t-value of 3.78 ($p < 0.01$). In contrast, Hypotheses H1b and H1c are not supported. Although the estimated relationships between data-sharing applications and SCC ($\beta = 0.16$, $t = 1.54$) and between smart contract-based transactions and SCC ($\beta = 0.08$, $t = 0.76$) are positive, they do not reach statistical significance.

Regarding SEP, Hypothesis H2a is not supported, as the association between BTA and SEP is positive but statistically insignificant ($\beta = 0.01$, $t = 0.11$). Conversely, Hypotheses H2b and H2c receive empirical support. BDSAs are positively and significantly associated with SEP ($\beta = 0.45$, $t = 4.27$, $p < 0.01$), and BSCAs likewise exhibit a significant positive association with SEP ($\beta = 0.30$, $t = 3.29$, $p < 0.01$). Furthermore, Hypothesis H3 is supported, with SCC showing a significant positive association with SEP ($\beta = 0.35$, $t = 2.80$, $p < 0.01$).

In addition, a significant indirect association between BTA and SEP through SCC is observed (indirect $\beta = 0.15$, $t = 2.25$, $p < 0.05$). While the direct association between BTA and SEP is not significant, the mediated pathway suggests that higher levels of traceability adoption are related to stronger collaboration, which in turn is associated with improved socio-environmental performance. However, given the cross-sectional nature of the data, these findings should be interpreted as associative rather than strictly causal, and reverse causality cannot be ruled out

7. DISCUSSION

This study examined the differential associations between BCT use cases, SCC, and SEP using the SCPV as a guiding theoretical lens. The findings from the structural model reveal a nuanced picture, several hypotheses are supported, while others are not, offering insights into how BCT applications are related to collaborative and sustainability outcomes in supply chains. However, given the cross-sectional design of the study, the results should be interpreted as associative rather than strictly causal.

First, the results support H1a, indicating that BTAs are positively and significantly associated with SCC. Firms reporting higher levels of traceability adoption also report stronger collaborative practices. Traceability applications may increase the granularity and real-time availability of product-level data, potentially facilitating transparency and reducing information asymmetries among supply chain partners. The immutable nature of blockchain ledgers may also be associated with reduced opportunism and improved coordination, consistent with prior studies (Centobelli *et al.,* 2022; Cole, Stevenson, & Aitken, 2019; Hogan, 2021; Khanfar *et al.,* 2021; van Engelenburg, Janssen, & Klievink, 2018; Vazquez Melendez, Bergey, & Smith, 2024; Zheng,

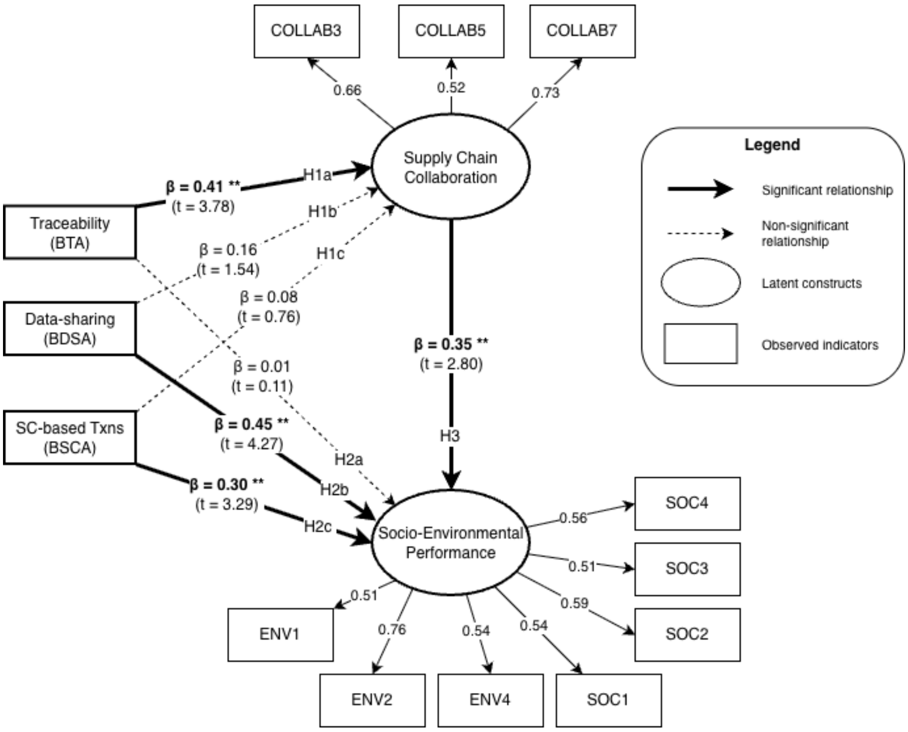

Figure 2 Structural Model Results from PLS-SEM Analysis

Xu, & Qiu, 2023). From the SCPV perspective, traceability practices appear aligned with collaborative routines that emphasize information sharing and uncertainty reduction.

Support for H2b indicates that BDSAs are positively associated with SEP. Firms reporting more advanced data-sharing adoption also report stronger socio-environmental performance outcomes. These applications may enable more transparent monitoring and secure exchange of sustainability-related data, which could contribute to improved accountability in sourcing, production, and distribution. This pattern aligns with SCPV's emphasis on joint practices that support environmental and social metrics and is consistent with emerging literature linking blockchain-enabled transparency to circular economy practices and compliance monitoring (Kshetri, 2024; Musamih *et al.,* 2025; Nguyen *et al.,* 2025; Zhang, Liu, & Hou, 2025).

Similarly, H2c is supported, suggesting that BSCAs are positively associated with SEP. Smart contract adoption is related to higher reported sustainability performance. The automation of transactional enforcement and programmable compliance conditions may be linked to improved process integrity and adherence to environmental or labor standards (Alabdulkarim *et al.,* 2023; Chaudhuri *et al.,* 2023; Putri, Hariadi, & Rachmadi, 2023; Stuit, Brockington, & Corbera, 2022). These associations are consistent with SCPV's argument that innovation-oriented practices embedded within governance routines may be linked to improved performance outcomes.

The positive relationship between SCC and SEP, as proposed in H3, is also supported. Firms reporting stronger collaboration also report stronger socio-environmental performance. This association is consistent with literature emphasizing collaboration as a mechanism through which firms align sustainability objectives, share resources, and coordinate responses to socio-environmental challenges (Arsawan *et al.,* 2023; Emon, Khan, & Siam, 2024; Fontoura & Coelho, 2022; Kyeremeh, Yamoah, & Yamoah, 2025; Rashid, Rasheed, & Amirah, 2023). SCPV similarly highlights how relational routines may be linked to broader performance outcomes (Mukherjee *et al.,* 2022).

In contrast, H1b and H1c are not supported. Data-sharing and smart contract applications are not significantly associated with SCC in this sample. While these technologies hold technical potential, their current deployment may not necessarily translate into perceived improvements in collaboration. Integration complexity, interoperability challenges, legal ambiguity, and partner capability gaps may moderate these relationships (Atul *et al.,* 2023; Ferreira, 2021; Kshetri, 2018; Sargent & Breese, 2024; Xu, Chong, & Chi, 2023).

Furthermore, H2a is not supported. BTAs are not directly associated with SEP in the structural model. This suggests that traceability adoption alone may not be sufficient to correspond with improved sustainability outcomes unless embedded within broader collaborative practices (Roy, 2021).

Importantly, a post hoc analysis revealed a significant indirect association between BTAs and SEP through SCC. Firms reporting higher traceability adoption also report stronger collaboration, which in turn is associated with higher socio-environmental performance. This mediated pattern suggests that collaboration may serve as a pathway through which traceability practices are linked to sustainability outcomes (Abu Afifa *et al.*, 2024; Oubrahim, Sefiani, & Happonen, 2023; Shujaat Mubarik *et al.,* 2023). However, alternative explanations are possible. For example, firms with stronger collaborative cultures may be more inclined to adopt blockchain technologies in the first place, raising the possibility of reverse causality.

Table 8 Results of the Hypothesis Testing

Hypotheses	Outcome
H1a: BTAs have a significant positive effect on SCC.	Supported
H1b: BDSAs have a significant positive effect on SCC.	Not supported
H1c: BSCAs have a significant positive effect on SCC.	Not supported
H2a: BTAs have a significant positive effect on SEP.	Not supported
H2b: BDSAs have a significant positive effect on SEP.	Supported
H2c: BSCAs have a significant positive effect on SEP.	Supported
H3: SCC has a significant positive effect on SEP.	Supported

Given the cross-sectional design and reliance on perceptual measures, the study cannot definitively establish causal direction. While the theoretical framework posits that BCT use cases influence SCC and SEP, it is equally plausible that firms with advanced collaborative capabilities or sustainability orientations are more likely to invest in blockchain adoption. Longitudinal or multi-wave studies would be required to disentangle temporal sequencing and confirm causal mechanisms.

From a theoretical standpoint, the findings are consistent with SCPV's emphasis on practice enactment rather than technology adoption alone. However, the results should be interpreted as evidence of statistically significant associations within the proposed model rather than definitive causal effects. Practically, this underscores that blockchain implementation should be accompanied by organizational readiness, partner alignment, and governance development, as these contextual factors may condition the strength and direction of observed relationships.

A further limitation relates to the use of a single, self-reported survey instrument to measure the predictors (BCT use cases), mediator (SCC), and outcome (SEP). Although procedural remedies, like anonymity and item randomization, and statistical diagnostics, such as Harman's single-factor test and full collinearity VIFs, suggest that common method bias is unlikely to dominate the results, shared method variance cannot be fully ruled out in cross-sectional perceptual data. Consequently, some relationships may be inflated due to common measurement context, and the findings should be interpreted with appropriate caution. Future research could mitigate this risk by collecting multi-source or time-lagged data, for instance, obtaining adoption information from IT managers and performance indicators from sustainability reports, or by incorporating objective archival measures where feasible.

7.1 Theoretical Implications

The present study offers several theoretical implications for the Supply Chain Practice View (SCPV). The findings indicate that reported adoption of BCT use cases is associated with variations in collaborative practices and socio-environmental performance outcomes. Rather than demonstrating deterministic effects, the results suggest that blockchain-related practices may be linked to relational and sustainability outcomes in ways consistent with SCPV's emphasis on enacted supply chain practices.

First, the positive association between traceability adoption and SCC suggests that firms reporting higher levels of blockchain-enabled visibility also report stronger collaborative routines. This pattern is consistent with SCPV's argument that information transparency and shared practices are related to relational alignment and coordination among partners. However, given the cross-sectional nature of the data, these findings should be interpreted as evidence of alignment between traceability practices and collaboration rather than confirmation of a unidirectional causal effect.

Second, the observed positive association between SCC and SEP reinforces SCPV's focus on relational performance as a key element connected to broader organizational outcomes. Firms reporting stronger collaborative practices also report higher socio-environmental performance, suggesting that relational mechanisms may be linked to sustainability-oriented outcomes. Additionally, the indirect association between BTAs and SEP through SCC is consistent with SCPV's conceptualization of interconnected practices, whereby technological routines and relational routines may jointly relate to performance dimensions. However, alternative interpretations remain plausible, including the possibility that firms with stronger sustainability orientations or collaborative capabilities may be more inclined to adopt blockchain applications.

At the same time, the lack of support for certain hypotheses suggests that SCPV may benefit from incorporating contextual constraints associated with digital technology adoption. Technical integration challenges, legal uncertainties, and organizational readiness factors may condition how blockchain-related practices relate to collaborative and sustainability outcomes. Incorporating these boundary conditions may strengthen SCPV's applicability to contemporary digitally enabled supply chains.

The findings are consistent with SCPV's emphasis on transparency, relational practices, and performance interdependencies, while also highlighting the need to account for contextual enablers and adoption constraints. Future research employing longitudinal or multi-source designs could further clarify the directionality and temporal sequencing of these relationships.

7.2 Practical Implications

From a managerial perspective, the study provides evidence-based insights into how blockchain adoption is associated with reported collaboration and sustainability outcomes. The results suggest that different blockchain functionalities may be linked to different dimensions of performance. For example, firms reporting more advanced data-sharing adoption also report stronger socio-environmental performance, indicating that aligning blockchain data-sharing systems with sustainability reporting processes may correspond with improved transparency and accountability. Similarly, smart contract adoption is associated with higher reported sustainability outcomes, suggesting that programmable compliance mechanisms may be aligned with sustainability objectives.

However, the findings caution against assuming that blockchain adoption automatically results in improved collaboration or sustainability performance. Traceability adoption, for instance, is not directly associated with socio-environmental performance in the structural model, and its relationship appears contingent upon collaborative integration. This suggests that blockchain implementation may need to be embedded within broader relational and governance strategies to be associated with desired outcomes.

Managers should therefore approach blockchain not solely as a technological investment, but as part of a broader socio-technical system. Cross-functional coordination among sustainability teams, procurement units, IT departments, and supply chain partners may be critical in aligning blockchain initiatives with strategic ESG objectives. Organizational readiness, data governance protocols, and partner capability development may moderate how blockchain practices relate to collaborative and sustainability outcomes.

Policymakers may also consider that regulatory clarity and interoperability standards are likely to influence how blockchain-based collaborations evolve. Clear guidance regarding liability, auditability, and data governance may shape how firms adopt and integrate blockchain technologies within sustainability-oriented supply chains.

While blockchain technologies are associated with promising collaborative and socio-environmental patterns in this study, their practical value appears contingent upon contextual alignment, governance structures, and implementation depth. Future research employing longitudinal designs would be valuable to determine whether these associations persist over time and to better understand potential causal mechanisms.

8. DISCUSSION

This study provides an empirical examination of the associations between prominent groups of blockchain technology (BCT) use cases, traceability, decentralized data-sharing, and smart contract-based transactions, and supply chain collaboration (SCC) and socio-environmental performance (SEP). Using PLS-SEM and survey data, the study evaluates a theoretically grounded model informed by the Supply Chain Practice View (SCPV). The measurement model draws on established literature to ensure conceptual alignment and acceptable psychometric properties, enabling an assessment of structural relationships within a predictive framework.

The findings suggest that traceability applications (BTAs) are positively associated with SCC and are indirectly associated with SEP through collaboration, although no direct association with SEP was observed. This pattern is consistent with SCPV's emphasis on relational mechanisms linking operational practices to broader performance outcomes. In addition, decentralized data-sharing applications (BDSAs) and smart contract-based applications (BSCAs) are positively associated with SEP, while their relationships with SCC are not statistically significant in this sample. These results extend prior research that has primarily focused on operational and financial outcomes by examining social and environmental dimensions within a unified empirical model.

Importantly, given the cross-sectional and perceptual nature of the data, the results should be interpreted as evidence of statistically significant associations rather than definitive causal effects. Alternative explanations remain plausible, including the possibility that firms with stronger collaborative capabilities or sustainability orientations may be more inclined to adopt blockchain applications. Longitudinal or multi-wave designs would be necessary to clarify temporal ordering and causal direction.

While the study offers valuable insights, several limitations suggest avenues for future research. First, the three blockchain use cases were measured using single-item adoption-stage indicators. Although appropriate for capturing implementation status, this operationalization does not assess depth, intensity, or quality of use and does not allow internal reliability assessment. Future studies should develop multi-item reflective or formative measures that capture the richness and integration depth of blockchain-enabled practices.

Second, although the sample size of 133 observations satisfies methodological requirements for PLS-SEM and stability checks were conducted, larger samples across broader geographic and industry contexts would strengthen generalizability and allow more advanced multi-group analyses. As blockchain applications continue to evolve, future research could also explore emerging use cases and classify them into more granular categories, potentially employing hierarchical or higher-order modeling approaches.

Third, this study does not explicitly examine heterogeneity across firm size, industry sector, or managerial role. The uneven distribution of respondents across organizational size categories limited the feasibility of subgroup comparisons. Given that blockchain adoption and its organizational implications may vary according to firm resources, governance structures, and technological maturity, future research should investigate potential moderating effects across firm size, sectoral characteristics, and managerial hierarchy.

Finally, future studies could explore alternative mediating or moderating mechanisms linking blockchain use cases to sustainability outcomes. For example, supply chain resilience, digital capability maturity, or supply chain visibility may serve as additional explanatory pathways. Examining these mechanisms through longitudinal or mixed-method designs would provide deeper insight into how blockchain-related practices are embedded within broader socio-technical systems.

This study contributes to the growing body of research examining blockchain applications in supply chains by identifying differentiated associations between specific use cases, collaboration, and socio-environmental performance. While the findings are promising, they should be interpreted within the methodological constraints of the study, and further empirical work is needed to clarify causal pathways and contextual contingencies.

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CONFLICTS OF INTEREST

The authors report there are no competing interests to declare.

DATA AVAILABILITY STATEMENTS

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Appendix A. Measurement Instruments

A1. Blockchain Applications

Kindly assess the blockchain applications currently under consideration or already implemented by your company using the following rating scale:

1 = not under consideration; 2 = in the initial planning phase, indicating early discussions and considerations that may not lead to final implementation; 3 = currently under consideration, indicating planned implementation but not yet executed; 4 = in the process of implementation; 5 = successfully implemented.

BTAs	To facilitate traceability of products/data jointly with supply chain partners.
BDSAs	To enable data-sharing with supply chain partners.
BSCAs	To take advantage of smart contracts to facilitate automated and trackable transactions.

A2. Supply Chain Collaboration

The items are designed to assess the level of a firm's collaboration with its supply chain partners and its socio-environmental performance. They employ a 5-point Likert-type scale for respondents to express their agreement or disagreement with each statement, as it pertains to their firm: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree. Items that were removed following the confirmatory factor analysis were noted with '*'.

COLLAB1*	Our company and partners have multiple channels of communication.
COLLAB2*	Our company and supply chain partners have agreements on the goals of the supply chain.
COLLAB3	Our company and supply chain partners exchange information.
COLLAB4*	Our company and partners support each other's decisions through consensus.
COLLAB5	Our company frequently contacts on a regular basis.
COLLAB6*	Our company and partners learn the intentions and capabilities of our competitors.
COLLAB7	Our company and partners share and acquire new and relevant knowledge from each other.

To further clarify the conceptual coverage of the refined SCC construct, Table A1 maps each retained indicator to its intended collaboration dimension as defined in Section 2.1.1. This mapping demonstrates how the three retained items correspond to the three core data-oriented collaboration dimensions: information sharing, collaborative communication, and joint knowledge creation. We also briefly describe the aspects represented by removed items to clarify domain reduction following CFA refinement.

Table A1 Mapping of Retained SCC Indicators to Collaboration Dimensions

Collaboration Dimension	Retained Item	Conceptual Coverage	Removed Items (Lost Aspects)
Information Sharing	COLLAB3	Direct operational exchange of data between partners	COLLAB2 (goal alignment), COLLAB6 (competitive intelligence learning)
Collaborative Communication	COLLAB5	Ongoing interaction frequency and communication intensity	COLLAB1 (multiple communication channels)
Joint Knowledge Creation	COLLAB7	Mutual learning and co-creation of knowledge	COLLAB4 (decision consensus support)

Although the retained indicators preserve representation of the three theoretically specified data-oriented collaboration dimensions, the removal of four items reduces dimensional richness. Specifically, elements related to formal goal alignment, communication channel diversity, consensus-based governance, and competitive intelligence learning are not fully captured in the refined model. Consequently, the operationalization reflects a more data-centric and interaction-focused interpretation of collaboration rather than a fully institutional or governance-oriented one.

A3. Socio-Environmental Performance

The items are designed to assess the level of a firm's collaboration with its supply chain partners and its socio-environmental performance. They employ a 5-point Likert-type scale for respondents to express their agreement or disagreement with each statement, as it pertains to their firm: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree. Items that were removed following the confirmatory factor analysis were noted with '*'.

ENV1	Reduced carbon emissions.
ENV2	Optimized energy usage.
ENV3*	Reduced amount of waste.
ENV4	Increased circulated materials.
SOC1	High employee satisfaction.
SOC2	Good working condition/environment.
SOC3	More equality (gender ratio, salary, etc.).
SOC4	More labor diversity (background, ethnic, etc.).