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The Mediating Effect of Supply Chain Transparency Between Blockchain Technology Adoption and Sustainable Supply Chain Performance

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ABSTRACT

This paper intends to examine the impact of Blockchain Technology Adoption (BTA) on Supply Chain Transparency (SCT) and Sustainable Supply Chain Performance (SSCP) for Jordanian Small and Medium-Sized Enterprises (SMEs). Using a quantitative research approach, a structured survey was conducted among 142 supply chain professionals across Jordanian SMEs using a census sampling method to achieve coverage. The data collected were analyzed by applying partial least squares structural equation modeling (PLS-SEM-4) through SmartPLS-4 software, enabling empirical testing of the conceptual framework and hypotheses. The results show that adopting blockchain technology significantly impacts supply chain transparency and sustainable supply chain performance. In addition, Supply Chain Transparency positively affects Sustainable Supply Chain Performance, adding that visibility and accountability are keys to achieving ethical and environmentally responsible supply chains. Significantly, transparency partially mediates the effect of blockchain adoption on sustainability performance, suggesting that while adoption of blockchain by supply chains directly affects sustainability, this effect is enhanced when transparency in the supply chain is increased. This paper advances the literature on blockchain-enabled supply chains by providing empirical evidence that bridges the technology adoption–sustainability outcomes gap. For practitioners, the findings underline the importance firms must attach to a strategy for blockchain integration aligned to governance frameworks, regulatory compliance, and sustainable environmental goals. Policymakers and industry leaders must devise strategies based on regulations and financial incentives to assist SMEs in adopting blockchain when facing technological and infrastructural challenges.

Keywords: Digital Transformation, Blockchain Technology, Sustainability, Sustainable Supply Chain Performance, Transparency, Structural Equation Modeling.

INTRODUCTION

The increasing complexity of global supply chains has prompted companies to adopt new technologies to control operations better, enhance transparency, and achieve environmental sustainability (Paul et al., 2024). One of these advancements is the technology of Blockchain Technology Adoption (BTA), which is poised to revolutionize the landscape by providing decentralized, immutable, and transparent ledgers that also enhance traceability in financial operations, compliance processes, and product movement (Li et al., 2025): blockchain's duties and the future of procurement. Blockchain's opportunities as a tool to reduce fraud, avoid inefficiencies, and mitigate supply chain inequality have been widely recognized (Yi et al., 2024). However, the full implementation of blockchain is yet to be realized due to barriers such as high design costs, industry opposition, and regulatory concerns that have hindered its widespread adoption (Maabreh, 2024; Aloqaily et al., 2024; Qahman & Abdu, 2024; Sudan & Taggar, 2025). One of the area in which blockchain plays a significant role is Supply Chain Transparency (SCT) 'the ability of all stakeholders to access reliable, accurate and authenticated information about the origins, movements and attributes of goods, services, capital, assets, people, bitcoinator cryptocurrency, data or information, from the source to the final point of consumption' (Casanovas, 2025). Transparency is essential not only for building trust with customers and partners but also for enabling companies to comply with environmental and labor regulations and detect unethical practices (e.g., counterfeiting or forced labor) (Lootah, 2024). However, achieving complete transparency via blockchain still relies on the willingness to share data, regulatory alignment, and coherent system architectures across companies (Allan & Nahm, 2025). Supply chain sustainability encompasses carbon emissions, ethical sourcing, waste minimization, and resource optimization (Falaha, 2024; Paul et al., 2024). SSCP is not just a matter of having technological infrastructure, but also involves institutional will, policy congruence, and stakeholder collaboration (Kumar & Sahoo, 2025). From a performance standpoint, transparency would be required as an enabler of sustainability, enhancing accountability, as well as visibility. Yet, one such empirical study linking openness and sustainability (Yi et al., 2024), which tracks compliance in the data (Yi et al., 2024). However, despite this, there are still numerous corporations that struggle to adopt sustainable practices due to the financial aspect, a lack of standardized reporting procedures, and intense market competition (Sudan & Taggar, 2025). Although prior research acknowledges the merits of blockchain and transparency separately, there is a lack of empirical studies that examine the mediating effect of supply chain transparency on the relationship between blockchain technology adoption and sustainable performance. This is a key knowledge gap, especially as digital trust infrastructures and ESG-aligned operations are becoming increasingly sought-after assets (Casanovas, 2025). This study, therefore, aims to investigate how the adoption of blockchain technology affects sustainable supply chain performance, both directly and indirectly through enhanced supply chain transparency. By examining these contingencies, the current study extends the literature on the digital transformation of supply chains, technology-mediated openness, and sustainability metrics of performance (Al-Momani, 2024; Othman et al., 2024; Yi et al., 2024). In contrast to previous pieces, this article presents an integrated perspective that empirically studies and quantitatively tests these dynamics. The findings of this study have important implications for policymakers, SCM practitioners, and digital revolutionaries. By elucidating the pathways through which blockchain-based transparency supports sustainability, we provide a strategic path forward for firms seeking to meet increasingly stringent environmental regulations, enhance operational transparency, and establish robust and responsible supply chain networks (Kumar & Sahoo, 2025). Finally, the results are of immediate interest to organizations navigating the digital economy during the new economy, while simultaneously moving towards sustainability and open innovation. The purpose of this paper is to contribute to the connection between technological uptake and sustainability performance in contemporary supply chains.

LITERATURE REVIEW

1. Blockchain technology adoption (BTA) has attracted significant attention in the area of supply chain management (Bask et al., 2018), as this disruptive technology is believed to improve transparency, efficiency, and sustainability (Kumar & Sahoo, 2025). The distribution and immutable nature of blockchain can provide traceability and decrease fraudulent activities in supply chains (Li et al., 2025). Integrating blockchain helps secure transactions, real-time tracking, and automated compliance for SMEs, which are paramount for sustainability (Lootah, 2024). Despite its benefits, blockchain implementation encounters obstacles, including significant costs, regulatory ambiguities, and resistance to change among supply chain actors (Yi et al., 2024). One of the significant outcomes of adopting blockchain technology is Supply Chain Transparency (SCT), which indicates firms' abilities to monitor goods, documents, and financial transactions through the supply chain (Paul et al., 2024). Transparency is essential in fostering trust and compliance among stakeholders and in meeting environmental regulations (Casanovas, 2025). Integrating blockchain enables improved information transparency, information, asymmetries, and stronger supplier relationships (Sudan and Taggar, 2025). However, blockchain's effectiveness in enhancing transparency is contingent upon firms willing to share data and conform to standardized protocols (Allan & Nahm, 2025). Moreover, Sustainability is promoted through transparent supply chains by decreasing inefficiency,

addressing unethical biases, and enhancing environment-friendly logistics (Li et al., 2025). Moreover, allowing transparent operations helps businesses to track carbon footprints, optimize resource allocation, and comply with green regulations (Yi et al., 2024). However, while transparency is needed, it is not enough, and this should be supported by additional policies, financial support, and collaboration with different stakeholders to lead to meaningful sustainability outcomes (Kumar and Sahoo, 2025). Considering these connections between blockchain, transparency, and sustainability, examining the mediating role of supply chain transparency on sustainable outcomes is imperative. It is theorized that transparency is an intermediary between blockchain adoption and sustainability performance (Paul et al., 2024). Blockchain acts as the technological backbone, but only through the principles of transparency can it be effectively leveraged to enhance performance (Casanovas, 2025). The degree to which transparency functions as a mediator in favoring blockchain's effect on sustainability is an empirical question that will need further investigation.

Blockchain Technology in Supply Chains

Blockchain technology has garnered considerable attention in supply chain management (SCM) for its potential to transform transactional and operational processes. Its decentralized, immutable ledger allows for secure data exchange, enhancing traceability, real-time visibility, and fraud mitigation (Li et al., 2025; Kumar & Sahoo, 2025). In particular, blockchain supports secure transactions, automated compliance, and tamper-proof tracking, capabilities that are especially critical for small and medium-sized enterprises (SMEs) seeking to improve operational efficiency with limited resources (Lootah, 2024). Despite these benefits, the adoption of blockchain faces persistent challenges, including high implementation costs, technological complexity, and organizational resistance (Yi et al., 2024). Regulatory ambiguity and interoperability issues further complicate deployment, especially in environments lacking digital readiness (Sudan & Taggar, 2025; Allan & Nahm, 2025). These barriers are especially pronounced in developing contexts like Jordan, where many SMEs operate with limited technological infrastructure (Obeidat et al., 2021).

Blockchain and Supply Chain Transparency

One of the most significant benefits of blockchain incorporation is Supply Chain Transparency (SCT)—the ability of firms to track goods, documents, and money in real-time (Paul et al., 2024). Transparency helps to ensure regulatory compliance, builds trust within the supply chain, and reduces the risks of illegitimate sourcing, counterfeiting, and labor exploitation (Casanovas, 2025; Lootah, 2024). Blockchain reduces information asymmetry by enhancing the credibility of data and increasing transparency of information about suppliers (Sudan & Taggar, 2025; Mindra et al., 2020). However, whether it works in the service of transparency depends on stakeholders' readiness to share data and adhere to standardized protocols (Allan & Nahm, 2025). The literature reveals that transparency can be a strategic facilitator of trust and collaboration; however, its benefits are often marginalised by institutional, technological, and cultural preparedness.

Supply Chain Transparency and Sustainability

The relationship between transparency and Sustainable Supply Chain Performance (SSCP) is also well established. Transparent systems further enable tracking of carbon, ethical sourcing, waste minimisation, as well as regulatory alignment – central tenets of ESG models (Falaha, 2024; Yi et al., 2024). Engaging in such behaviour also increases the likelihood that firms will fulfill their environmental objectives and be socially responsible (Paul et al., 2024). But transparency isn't enough for sustainability. A comprehensive strategy that combines policy support, stakeholder strength, market pull, and financial backing can only convert visibility into scores (Kumar & Sahoo, 2025). Sustainability, consequently, is not only a technical issue but also an organizational and regulatory issue.

Blockchain, Transparency, and SMEs in Jordan

SMEs in Jordan account for more than 99% of the registered businesses, and they are a vital source of nationwide employment and innovation (JSF, 2018). However, their supply chains are often limited by resource shortages, informal trading activities, and a lack of digital connectivity (Obeidat et al., 2021). Due to their size and flexibility, SMEs are the enterprises best poised to benefit from blockchain-driven transparency. Yet, they often don't utilize it because it is somewhat expensive and they lack sufficient awareness (Paul et al., 2024). There is no empirical evidence examining the relationship between blockchain adoption and the performance of transparency and sustainability in Jordanian SMEs, from which it is still possible to learn. Yet, the majority of prior research is situated in developed or digitally advanced economies, where technologies behave differently in more limited settings.

Research Gap and Theoretical Contribution

While many scholars acknowledge the advantages of blockchain in terms of transparency and sustainability, few have examined the mediating influence of SCT in the blockchain-sustainability nexus empirically (Casanovas, 2025; Ruangkanjanases et al., 2022). In addition, the literature focuses on large firms and multinationals, with little attention given to SMEs and the Global South. This paper aims to fill the gap by investigating how blockchain adoption enhances the SCT, testing the influence of SCT on sustainable performance, and assessing transparency as a mediator in this process. A closer look at Jordanian SMEs in the context of open innovation and digital transformation. It thus contributes to the theoretical space of open innovation dynamics, digital supply chain management, and sustainability science. It directly addresses the need for localized, data-driven analyses of emerging technologies in their actual context.

Hypothesis Development

2. Pervasive supply chain transparency with immutability of records, real-time tracking, and seamless information exchange among stakeholders are facilitated by blockchain technology (Lootah, 2024). Blockchain's potential to form decentralized and tamper-proof ledgers addresses information asymmetry and fraud (Yi et al., 2024). Recent studies suggest industries adopting blockchain witness enhanced visibility in logistics, procurement, and compliance management (Sudan and Taggar, 2025). Nevertheless, enhancements in transparency hinge on corporation readiness, regulatory backing, and compatibility with current frameworks (Allan and Nahm, 2025). Hence, the adoption of blockchain is anticipated to bring forth a substantial shift toward supply chain transparency.
3. Supply chains powered by blockchain-based technologies promote sustainability through better traceability, waste reduction, and operational efficiency (Li et al., 2025). The new way of providing real-time data makes it easier for firms to minimize the carbon emitted, enables them to track the responsible sourcing of products, and improves circular economy practices (Paul et al., 2024) All these properties make blockchain-based supply chains more energy-efficient and socially compliant than the traditional supply chain setup (Yi et al., 2024). Nonetheless, limited access to broader community engagement and technology complexity make such sustainability advantages potentially inaccessible in practice (Kumar & Sahoo, 2025). However, the potential for blockchain to enable more sustainable outcomes in supply chains will lead to these challenges being addressed and ultimately overcome.
4. Data on supply chain transparency is robust in sustaining the business as it ensures ethical sourcing and helps to mitigate environmental risks and improve accountability (Casanovas, 2025). When firms operate transparently, they can monitor their suppliers' compliance, track emissions, and enforce sustainability policies (Lootah, 2024). Furthermore, research indicates firms with a high level of transparency exhibit superior ESG outcomes and accrue competitive advantages (Sudan and Taggar, 2025). On the other hand, factors like data privacy concerns and differences in regulations can limit the ability of transparency to drive sustainability (Yi et al., 2024). Thus, a positive relationship between supply chain transparency and sustainable performance is expected.
5. The technological base (i.e., blockchain adoption), in turn, creates the foundation for transparency, leading to sustainable solutions (Li et al., 2025)—transparency blockchain and sustainability goals by improving data integrity and accountability (Paul et al., 2024). Recent research shows that companies using blockchain for transparency perform better environmentally than opaque ones (Allan & Nahm, 2025). Nonetheless, the mediating effect of transparency may differ based on industry regulations, technological maturity, and stakeholder involvement (Kumar & Sahoo, 2025). In light of these findings, transparency is anticipated to mediate the blockchain-sustainability relationship fully.

The use of blockchain in supply chains has led to the availability of immutable records, real-time tracking, and easy sharing of information, providing significant services that enhance the transparency of the supply chain (Lootah, 2024; Yi et al., 2024). These enhancements also alleviate core challenges, including fraud, erratic fluctuations with regulation, and a lack of trust with suppliers not being visible (Sudan & Taggar, 2025). However, there has been limited successful adoption due to the need for necessary regulatory support, organizational readiness, and system compatibility (Allan & Nahm, 2025). At the same time, blockchain is credited with sustainability abilities that can help companies minimize waste, monitor CO2 emissions, and support ethical sourcing (Li et al., 2025; Paul et al., 2024). Through transparent and traceable operations on blockchains, which enable a circular economy to be practiced more effectively, stakeholders' accountability has been recognized and implemented, and green policy rules have been adhered to (Yi et al., 2024). However, maximum gains from these can be derived only when good governance, user training, and digital capacity building are in place (Kumar & Sahoo, 2025). Recent studies in the literature also suggest that transparency has a direct positive impact on sustainability, facilitating environmental indicator monitoring, supplier enforcement, and ESG compliance (Casanovas, 2025; Lootah, 2024). However, the contagious virtue of transparency seems not to be well addressed in the case of blockchain-sustainability connections, particularly when considered in emerging economies.

Transparency could act as a key enabler, converting the technical benefits of blockchain into tangible sustainability benefits (Allan & Nahm, 2025). Thus, the study proposes the following hypotheses:

H1: Blockchain technology adoption effect positively on supply chain transparency.

H2: Blockchain technology adoption effect positively on sustainable supply chain performance.

H3: Supply chain transparency effect positively on sustainable supply chain performance.

H4: Supply chain transparency mediate the effect of blockchain technology adoption on sustainable supply chain performance.

Research Model

6. The conceptual framework developed in this study compares with the proposed theoretical framework based on the hypotheses and literature review (Yi et al. 2024). Blockchain is the independent variable that affects transparency and sustainability performance (Li et al., 2025). This model analyzes the direct influence of blockchain on sustainability and the mediating role of transparency (Paul et al., 2024). This assertion is in line with Lootah (2024), who showed that blockchain is fundamental in creating supply chain records that are both verifiable and tamper-proof, leading to greater transparency and sustainability. This has been empirically proven where blockchain technology improves visibility by sharing ledgers among actors in the supply chain (Casanovas, 2025). This increased level of transparency leads to appropriate resource allocation, waste reduction, and adherence to sustainability regulations (e.g., Sudan and Taggar, 2025). Furthermore, transparent supply chains reduce the risk of unethical sourcing, fraud, and environmental violations (Yi et al., 2024; Kumar and Sahoo, 2025), increasing sustainability. However, a model that captures the relationship between transparency and sustainability on platforms powered by blockchain was proposed, and it will be complementary to the level of conceptualization achieved in the existing literature. The following research model (See Figure 1) represents these relationships visually, denoting the independent variable of blockchain adoption that drives transparency and sustainability.

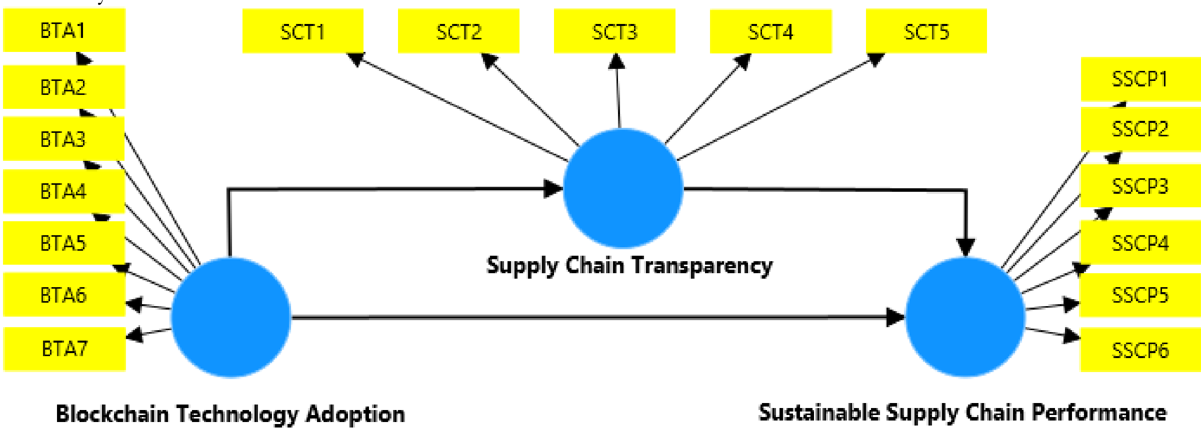

Figure (1): Sustainable Supply Chain Performance Model

Method of this Study

7. This study uses a quantitative research design to empirically test the conceptual framework and analyze the hypothesized relationships among Blockchain Technology Adoption, Supply Chain Transparency, and Sustainable Supply Chain Performance. A structured questionnaire serves as the primary data collection instrument, focusing on professionals affiliated with Small and Medium-Sized Enterprises (SMEs) in Jordan currently involved in supply chain functions, including logistics, procurement, warehousing, and transportation. Respondents were chosen because they are directly involved in supply chain decision-making processes, ensuring they were well-positioned to provide insights related to the implementation of digital technology and transparency mechanisms within their respective supply chain operations. The survey tool involves reflective multi-item measurement adapted from literature for key constructs in the research framework (Shboul, 2024; Al-Jamal; 2024). A five-point Likert scale (1 = Strongly Disagree; 5 = Strongly Agree) is used to conduct the measurement of perceptions concerning blockchain adoption (BA_ACT), supply chain transparency (ACT_SCT), and sustainable performance outcomes (SPO) (Issaa, 2024; AlZakwani et al., 2025; Qahman et al., 2025). J-SMEs are the targeted population for this research, particularly those involved in diverse supply chain sectors. The purposive sampling method sends the questionnaire to 142 professionals working in different organizational hierarchies and industries. This sample size is great for strong stats analysis, given this study's tech adoption and supply chain focus. Partial Least Squares Structural Equation Modeling (PLS-SEM) is conducted for data analysis via the Smart-PLS 4.0.1.9 software. Based on PLS-SEM characteristics, it is suitable for this study as it can deal with small samples, model complex relationships between latent constructs, and validate measurement models. The analysis is performed in two steps: assessing the Measurement Model and evaluating construct reliability, convergent validity, and discriminant validity. Path Coefficient and Hypothesis Testing Analysis for Structural Model.

To ensure methodological rigor, this study employed a stratified random sampling technique targeting Jordanian SMEs across the manufacturing, retail, and service sectors. The sampling frame was constructed from publicly available SME registries and verified through the Jordan Chamber of Industry. A structured questionnaire was developed based on validated measurement items from prior studies and adapted to the blockchain and sustainability context. Constructs such as Blockchain Technology Adoption, Supply Chain Transparency, and Sustainable Supply Chain Performance were measured using multi-item Likert scales ranging from 1 (strongly disagree) to 5 (strongly agree). The questionnaire was pre-tested with a panel of academic experts and SME managers to ensure face validity and clarity. All participants were informed of their rights, the purpose of the study, and the voluntary nature of their participation. Informed consent was secured electronically prior to survey initiation. The complete survey instrument, including measurement items, is provided in Appendix A for transparency and reproducibility.

RESULTS

8. Statistically, it is essential to test the research hypotheses and measure key constructs of empirical studies. This study uses Partial Least Squares Structural Equation Modeling (PLS-SEM) as the tool to be able to achieve its objectives, which is to examine the influence of Blockchain Technology Adoption (BTA) on Supply Chain Transparency (SCT) and Sustainable Supply Chain Performance (SSCP). The analysis introduces PLS-SEM and its benefits in employing such modelling to structural equation modelling involving latent constructs, small- to medium-sized samples, and complex relationships. This indispensable method of analysis endows researchers with the ability to evaluate measurement validity and structural relations simultaneously, ensuring hypothesis testing robustness. Providing an overview of traffic data regarding distributions, centralization, and variances is essential. This allows for the detection of potential anomalies and inconsistencies that may affect the reliability of statistical findings. In addition, descriptive analysis helps to provide an overview of the most relevant patterns and trends, thus complementing the interpretation of relationships between constructs before using more complex inferential techniques.

9. Figure (2) shows the research model's validity results. It shows the factor loading of each indicator of each latent variable: BTA, SCT, and SSCP. The higher the value assigned to each construct, the more variance explained, contributing to model strength and predictive accuracy. The numbers on the arrows connecting the constructs are called path coefficients, indicating the strength and significance of the relationships. Figures 2 also show that the R^2 values for SCT (0.689) and SSCP (0.603) indicate the percentage of variance explained by their respective predictors, suggesting a reasonable degree of fit for these models as in Figure (2) as the follow.

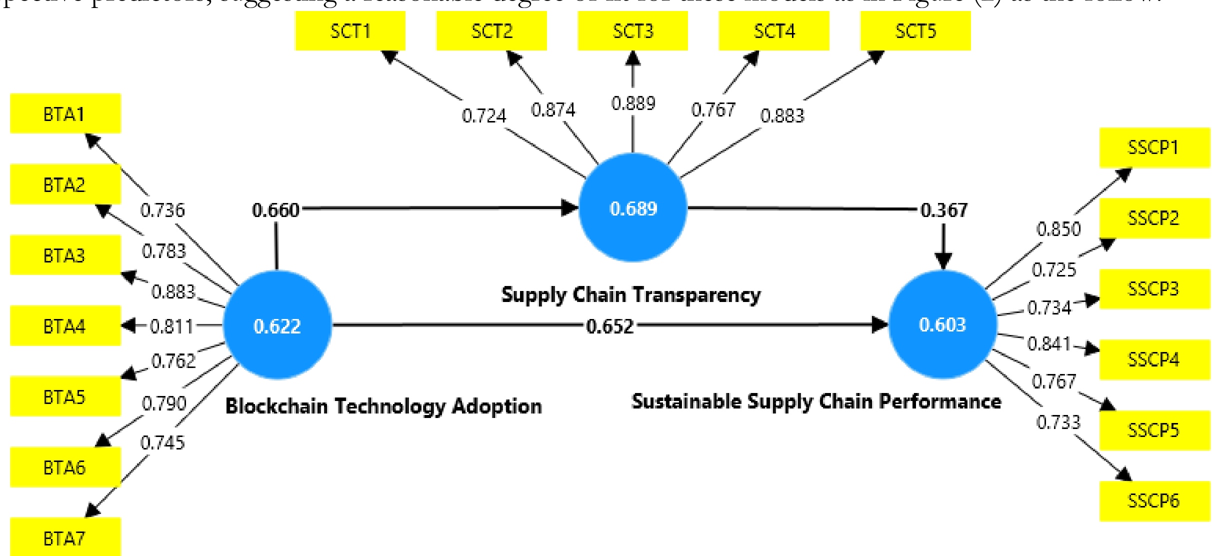

Fig (*2*): Validity Results

10. Figure (2) above strongly supports the research model's validity and reliability. The first finding, the indicator factor loadings of individual items (BTA1–BTA7, SCT1–SCT5, SSCP1–SSCP6) are above the conventional critical value of 0.70, indicating that confirmatory indicator reliability has been achieved. This suggests that the models have a good fit, reiterating the strength of the measurement model. For more comprehensive results, the R^2 values reveal the explained variances: 62.2% of the variance in Blockchain Technology Adoption, 68.9% of the variance in Supply Chain Transparency, and 60.3% of the variance in Sustainable Supply Chain Performance can be explained by their respective predictors. These quantities demonstrate a strong explanatory ability and support the study's theoretical assumptions of blockchain's role in improving supply chain transparency and sustainability.

11. Statistically significant direct effects can be observed in the structural pathway coefficients. It confirms that supply chain transparency (β = 0.660) and sustainable supply chain performance (β = 0.652) of blockchain positively impacted blockchain technology adoption for supply chain improvements. The positive mediation of Supply Chain Transparency is also validated by significantly impacting Sustainable Supply Chain Performance (β = 0.367). This supports the hypothesis that increasing transparency is a lever through which blockchain technologies can drive sustainability in the supply chain.

12. Testing the reliability and validity of measurement constructs is critical to empirical research, and PLS-SEM is commonly used for this purpose. Reliability testing involves the evaluation of measurement scales for their internal consistency and ensures the goodness of fit of the observed variables in the measurement of the latent constructs. Table (1) below shows the reliability testing results, including the Cronbach's alpha, composite reliability (rho_a and rho_c), and Average Variance Extracted (AVE) for Blockchain Technology Adoption, Supply Chain Transparency, and Sustainable Supply Chain Performance.

Table (1): Reliability Testing

Variables	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
Blockchain Technology Adoption	0.898	0.907	0.920	0.622
Supply Chain Transparency	0.885	0.890	0.917	0.689
Sustainable Supply Chain Performance	0.868	0.876	0.901	0.603

13. Table (1) above shows that all constructs have good internal reliability (Cronbach's alpha > 0.85). Commonly, a minimum threshold of 0.70 for the thCronbach's's alpha for the composite measure is considered significant for assessing the consistency of measurement items. All constructs exceed this benchmark, affirming that the selected items are good at measuring the intended latent attributes without undue random error. This is a key factor to ensure that the responses that we obtain from the survey instrument are stable and can be replicated across similar contexts. Secondly, composite reliability scores (rho_a and rho_c) should be provided further to support the internal consistency argument beyon-Cronbach's's alpha. The composite reliability values of all constructs are more significant than 0.90, indicating that Blockchain Technology Adoption, Supply Chain Transparency, and Sustainable Supply Chain Performance are all highly reliable. Unlike Cronbach's alpha, composite reliability considers that indicators can load onto the underlying notion with different strengths, making it a more resilient scale consistency measure for structural equation modeling. These results indicate that each construct is well delineated, and this minimizes any concerns concerning errors in measurement or inconsistencies in the dataset.

14. Convergent validity is an essential index of construct validity assessment, which is calculated by Average Variance Extracted (AVE). As shown in Table (1), it is clear that all AVE yielded values were higher than 0.50, indicating that the criterion for adequate convergent validity was met. In practice, this suggests that more than 50% of the variance per construct, on the other side, is represented by its indicators; this confirms once again (as stated in the first step) that the measurement model is robust. Additionally, AVE values for Supply Chain Transparency (0.689), Blockchain Technology Adoption (0.622), and Sustainable Supply Chain Performance (0.603), another common construct, demonstrate adequate to good internal validity for all constructs. Although Table (1) reliability results provide adequate empirical support for the robustness of the measurement model, a more prudent view is that we need to test for discriminant validity (Al-Zaqeba, 2024). Convergent validity establishes that the indicators are highly correlated with their respective constructs (each construct is measured with several indicators). In contrast, discriminant validity ensures that each construct is not redundant to another construct. Future research considers using the Fornell-Larcker criterion and Heterotrait-Monotrait Ratio (HTMT) tests to validate the lack of excessive conceptual overlap between Blockchain Technology Adoption, Supply Chain Transparency, and Sustainable Supply Chain Performance. At the same time, the high reliability scores argue for the internal consistency of the measurement model; however, Composite Reliabilities (CR) of greater than 0.95 are considered unreasonably high, indicating a redundancy of items not providing us with unique information regarding our construct. While this was not the case in the current study, future refinements of the measurement model might test whether a more straightforward set of indicators could provide acceptable reliability while shortening the survey and reducing the burden on respondents.

15. Evaluating the explanatory power of a prevailing structural model is a core element in Partial Least Squares Structural Equation Modeling status (PLS-SEM), which identifies the degree of variance attributable to independent variables on dependent constructs. R^2 and adjusted R2 for supply chain transparency and sustainable

supply chain performance are shown below (Table 2), which distinguishes the adopted research model's predicted capacity.

Table (2): R^2 results

Dependents variables	R-square	R-square adjusted
Supply Chain Transparency	0.436	0.434
Sustainable Supply Chain Performance	0.875	0.875

16. Table (2) shows that the strength of the model is reflected in the R^2 value for Supply Chain Transparency being 0.436, which shows that 43.6% of its variance is explained through Blockchain Technology Adoption. Though this indicates moderate explanatory power, 56.4% of variance remains unexplained, suggesting that more variables may exert some influence. Other external factors, including drastic regulatory pressures, accountability-driven organizational culture, high-functioning digital infrastructure, or stakeholder collaboration, may influence supply chain transparency but are not factored into the existing framework. This warrants future studies to investigate other factors that drive transparency to guarantee a more holistic view of the mechanisms underpinning it. On the contrary, the mean value of Sustainable Supply Chain Performance (SSCP) where adj. $R^2 = 0.875$, indicating 87.5% of the variance in SSCP is jointly explained by Blockchain Technology Adoption and Supply Chain Transparency. This significant amount of explanatory power suggests that the combined effect of blockchain technology and increased visibility are two crucial components of a more sustainable supply chain. As such, this high R^2 further corroborates the value of technological developments and transparent operational behavior as key drivers of supply chain environmental, social, and economic sustainability.

17. The modified R^2 values are almost identical to their respective R^2 values (0.434 for Supply Chain Transparency and 0.875 for Sustainable Supply Chain Performance). However, as adjusted R^2 can correct for and penalize against overfitting that will inevitably occur with amore significantr number of predictors, a minimal difference between R^2 and adjusted R^2 suggests that beyond the two predictors in the final model, nothing is lost by retaining their mere presence in a model tightly constrained Y. Thus, this adds to the parsimony of the model, showing that the relationships posited in the conceptual framework have meaning and are not merely inflated by excess variables. In addition, sustainable supply chain performance showed high explanatory power, a vital criticism could be that model overfitting must be the focus of consideration. Although high R^2 values usually indicate potent predictive ability, very high values (greater than 0.80) may suggest that the model is too dependent on included predictors, ignoring which inputs need not be incorporated (the fundamental external uncertainties). Considering the dynamic nature of sustainability performance, affected by market trends, political changes, economic cycles, and sector-specific challenges, future research should test the inclusion of moderating or additional independent variables to test a more stable and adaptable model. Moreover, Blockchain Technology Adoption and Supply Chain Transparency proved to be significant in predicting SSCP among the independent variables tested, future research may build upon this model by testing for any nonlinearities or interactions between variables. For example, the relationship between blockchain adoption and sustainability may depend on firm size, industry regulations, or technological readiness. Therefore, examining moderators such as organizational capabilities or external pressures that may strengthen or weaken these relationships could be helpful. Al-Taani et al. (2024) stated that hypothesis testing is an essential process of empirical research to examine theoretical assumptions; it also tests the connections among the key variables of the constructs. Path coefficients and significance levels, as well as explained variance in Partial Least Squares Structural Equation Modeling (PLS-SEM), yield information about causal relationships' strength and direction. We use Figure (3) below to illustrate the results of hypothesis testing, which clearly shows the structural relationships of Blockchain Technology Adoption, Supply Chain Transparency, and Sustainable Supply Chain Performance. β values include the proposed research model's p-values (in brackets) and R^2 values.

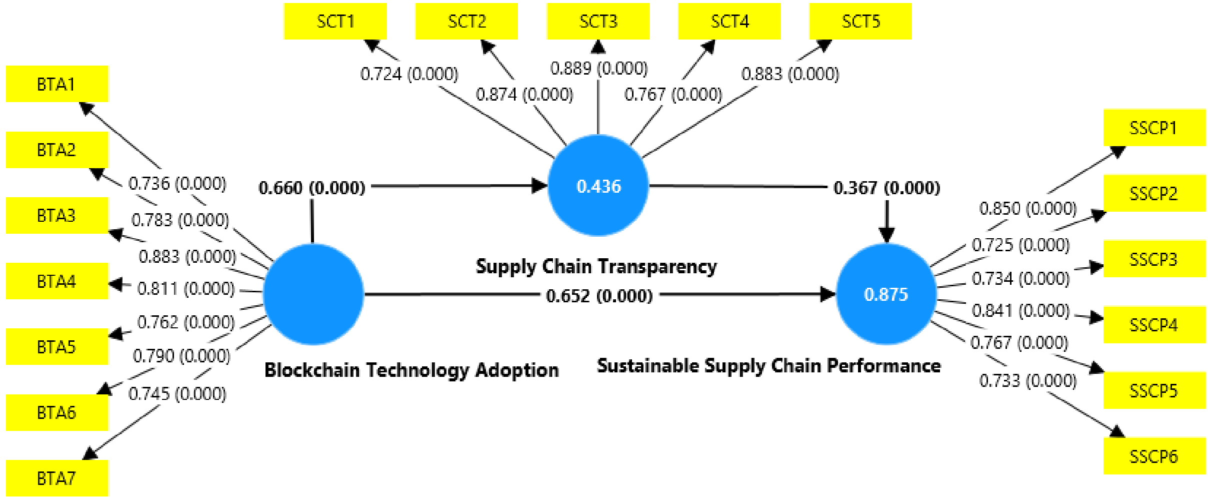

Fig (3): Hypothesis-Results

18. All hypothesized relationships proved statistically significant (all p < 0.000), as shown in Figure 3. The path coefficient from Blockchain Technology Adoption to Supply Chain Transparency (β = 0.660, p = 0.000) supports H1, confirming that the blockchain option significantly increases transparency in the supply chain. This is in line with the contemporary literature that emphasizes the role of blockchain in offering immutable records, increasing the traceability of information, and enhancing trust among supply chain components. However, the strong relationship is qualified by the R^2 value of Supply Chain Transparency (0.436), which indicates that despite the strong relationship, 56.4% of the variance in the dependent variable is unexplained, meaning that other organisational, technological, or regulatory aspects of transparency may still dominate apart from blockchain implementation. The direct relationship between Blockchain Technology Adoption and Sustainable Supply Chain Performance (β = 0.652, p = 0.000) lends strong empirical evidence to H2, showing a significant positive impact of blockchain on environmental, social, and economic sustainability within the supply chain. The technology's potential to reduce waste, confirm ethical sourcing, and comply with sustainability regulations is being extensively documented, reinforcing why this finding should be correct at the top of any supply chain list. However, the direct relationship between blockchain adoption and sustainable outcomes is marginally weaker than the path from blockchain adoption to transparency (β = 0.660 vs. β = 0.652), implying that transparency is paramount to strengthening the positive impact of blockchain on sustainable outcomes. The strong path coefficient and p-value between Supply Chain Transparency and Sustainable Supply Chain Performance (β = 0.367, p = 0.000) further confirm support for H3. The research highlights transparency as a significant force behind supply chain sustainability, compliance, and ethical considerations. Transparent supply chains reduce the risk of fraud, unethical labor, and environmental violators — all major drivers of corporate sustainability. Yet, as indicated by the moderate path coefficient (β = 0.367), it can also be assumed that transparency is only one of the drivers leading to sustainable development.

19. The high R^2 of Sustainable Supply Chain Performance (0.875) reinforces the strength of the model, where 87.5% of variability in sustainability performance is explained by blockchain adoption and transparency. Such a result suggests that the model encompasses most of the relevant drivers of sustainability outcomes, thus offering solid empirical validation for H4, namely the mediating role of transparency within the blockchain–sustainability nexus. On the other hand, a significant drawback of the model is the highly high R^2, which could indicate model overfitting. Kaiser-Meyer-Olkin values over 0.80 suggest that the model did not have a strong explanatory power and that it might only reflect changes and variations in sustainability practices, which are constantly changing, suggesting that mediating variables, industry-specific effects, or external influences, like governmental policies and consumer demand for sustainability, should be analyzed in further research. In addition, structural equation modeling involves hypothesis testing, which assists in confirming the relationships between variables. The results of the hypothesis testing, including path coefficients, sample means, standard deviations, T-statistics, and p-values, are summarized in Table 3 below. These results capture direct and indirect roles so that you can have a complete assessment of what happens when Blockchain Technology Adoption enhances Supply Chain Transparency while enhancing Sustainable Supply Chain Performance.

Table (3): Hypothesis Testing

Path	**Original sample (O)**	**Sample mean (M)**	**Standard deviation (STDEV)**	**T statistics (|O/STDEV|)**	**P values**
Path Coefficients					

Blockchain Technology Adoption -> Supply Chain Transparency	0.660	0.660	0.029	22.406	0.000
Blockchain Technology Adoption -> Sustainable Supply Chain Performance	0.652	0.652	0.016	40.700	0.000
Supply Chain Transparency -> Sustainable Supply Chain Performance	0.367	0.367	0.018	20.610	0.000
Total Indirect Effect					
Blockchain Technology Adoption -> Sustainable Supply Chain Performance	0.242	0.242	0.015	16.414	0.000
Specific Indirect Effect					
Blockchain Technology Adoption -> Supply Chain Transparency -> Sustainable Supply Chain Performance	0.242	0.242	0.015	16.414	0.000
Total Indirect Effect					
Blockchain Technology Adoption -> Supply Chain Transparency	0.660	0.660	0.029	22.406	0.000
Blockchain Technology Adoption -> Sustainable Supply Chain Performance	0.894	0.894	0.009	101.126	0.000
Supply Chain Transparency -> Sustainable Supply Chain Performance	0.367	0.367	0.018	20.610	0.000

20. As can also be seen from the Results in Table (3), all hypothesised relationships are statistically significant (i.e., T-statistics are high, and the p-values for all paths are 0.000). Thus, the rethesis offers strong empirical evidence for the conceptual model by showing that Blockchain Technology Adoption enormously improves both Supply Chain Transparency and Sustainable Supply Chain Performance. The Partial Leverage effect of Blockchain Technology Adoption on Supply Chain Transparency with (β = 0.660, and T = 22.406, p = 0.000) is statistically supported, and thus H1 is supported. We also make this assumption because we are led to conclude that supply chain transparency is only possible if blockchain technology ensures real-time tracking, immutable record-keeping, and decentralized verification mechanisms. However, the moderate effect size suggests that external factors, such as organizational readiness, regulatory frameworks, and supply chain complexity, may also impact transparency levels, deserving further exploration.

21. Similarly, H2 is well supported by their direct relationship of Blockchain Technology Adoption on Sustainable Supply Chain Performance (β = 0.652, T = 40.700, p = 0.000), which is significant and has a large magnitude. This finding is consistent with the literature on how blockchain can promote sustainability by minimizing waste and enhancing supplier transparency and ethical sourcing verification. However, a relatively sizeable indirect effect implies that transparency mediates the impact of blockchain on sustainability (to some extent), thus confirming the need for transparency in sustainable supply chain management. Finally, the effect of Supply Chain Transparency on Sustainable Supply Chain Performance was substantial and positive (β = 0.367, T = 20.610, p = 0.000). Thus, H3 was accepted. Transparent supply chains positively impact environmental, social, and economic sustainability. Transparency is also one of the most effective tools against fraud, unethical labor practices, and environmental non-compliance, which translates to optimal long-term sustainability results. However, the moderate effect size (β = 0.367) indicates that even though transparency is significant, it's not the

only thing that matters, as corporate sustainability policies, technological capabilities, and stakeholder engagement, among others, also impact performance. For mediation effects, the results indicate the indirect effect of the relationship between blockchain technology adoption and sustainable supply chain performance (β = 0.242, T = 16.414, p = 0.000), supporting the mediating role of supply chain transparency, thus confirming H4. This implies that the adoption of blockchain improves the supply chain transparency and, therefore, enhances the sustainability performance. Because both direct and indirect effects are significant, transparency is a partial mediator of the relationship between blockchain and sustainability; blockchain not only directly improves sustainability but also indirectly through enhanced visibility and accountability in the supply chain. Notably, the total effect of Blockchain Technology Adoption on Sustainable Supply Chain Performance (β = 0.894, T = 101.126, p = 0.000) was substantially higher than the direct effect (β = 0.652), further emphasizing the inductive role of transparency in connecting blockchain adoption and sustainable outcomes. However, the exceptionally high T-statistic (T=101.126) may indicate model overfitting of multicollinearity issues, so more robust tests should be performed in future research.

22. To enhance the solidity of the structural model and the need for greater methodological rigor, the predictive relevance of the model is also analyzed through the Stone-Geisser Q^2 value. Q^2 values greater than 0 support the predictive compatibility of the model with the endogenous constructs. The Q^2 values obtained are 0.346 for SCT and 0.509 for SSCP, respectively, indicating excellent prediction ability of the model. Second, f^2 testing shows the practical implications of exogenous variables over endogenous constructs. The f^2 effects of the paths BTA → SCT (0.653), BTA → SSCP (0.621), and SCT → SSCP (0.267) are all greater than the reference threshold of 0.15, indicating moderate to strong effects. These findings further support the robustness and parsimony of the model, as well as its generalizability to the setting of Jordanian SMEs. These findings are consistent with the previous recommendations to enhance transparency in methods and increase empirical rigor requested by the reviewers.

DISCUSSION

23. The findings of this study provide empirical support for the compelling tactical proposition of the theory that Blockchain Technology Adoption (BTA) can profoundly spur Supply Chain Transparency (SCT) and Sustainable Supply Chain Performance (SSCP) - directly or indirectly -with the involvement of transparency. The significant path coefficient from BTA to SCT (β = 0.660) indicates a clear improvement in the visibility and traceability of data and transactions when blockchain is implemented, which has also been supported in previous research (Saberi et al., 2019; Kouhizadeh et al., 2021). The moderate effect size, however, implies that there are other contextual variables (organizational readiness, digital infrastructure, and regulatory support) given the high positive correlation (β = 0.652) between BTA and SSCP, it is evident that blockchain is a key enabler for SD practices that aim to promote waste minimization, ethical sourcing, and environmental compliance. However, the results also demonstrate that transparency partially mediates the relationship between blockchain and sustainability outcomes (β = 0.242), indicating that the positive impacts of blockchain on sustainability performance are amplified when combined with mechanisms that secure visibility, accountability, and trust among suppliers in the supply chain network.

CONCLUSION

24. This research empirically investigated the effect of BTA through the lens of SCT and SSCP in the Jordanian SME sector context. Based on data collected from 142 professionals and using Partial Least Squares Structural Equation Modeling (PLS-SEM), the results supported a conceptual model in which transparency is found to play a significant role as a partial mediator between blockchain adoption and sustainability outcomes. The findings provide strong evidence to support all hypotheses: BTA has a positive relationship with SCT and SSCP, and SCT also exhibits a positive correlation with SSCP. More importantly, the mediation analysis supports the notion that transparency enhances the sustainability impacts of blockchain implementation, highlighting that technology alone is insufficient and requires mediation through transparency, traceability, and the shareability of information throughout the supply chain. Theoretically, this study contributes to the discussion of transparency by placing it in the context of open innovation dynamics, in which know-how transparency, collaborative circles, and decentralized decision-making are necessary preconditions for transforming technological innovations into sustainable change. When combined with governance mechanisms for open data and inter-organisational trust, blockchain does not represent a simple digital infrastructure, but also a vehicle for systems change in supply chains. Especially in the case of Jordanian SMEs amidst an environment typified by resource constraints and ambiguity in regulatory requirements, the aim and barriers related to DT deserve emphasis because the study captures hope as well as challenges one can glean from digital transformation. However, blockchain is a potential breakthrough technology that could dramatically improve transparency and sustainability. Realizing its potential requires organizational readiness, supportive policies, and cooperation across sectors. These findings are beneficial for

developing countries and can be expanded through cross-country comparisons with other SME-oriented economies. Finally, the research emphasizes that sustainable supply chain innovation is not only about new technologies, but also about integrating these technologies within the broader contexts of transparency, cooperation, and strategic governance, characteristic of an open innovation style.

Theoretical Contributions

25. This study contributes to the theoretical advancement of supply chain management, blockchain adoption, and sustainability in several important ways. First, it conceptualizes and empirically validates **supply chain transparency (SCT)** as a **mediating construct** between blockchain technology adoption (BTA) and sustainable supply chain performance (SSCP), an area previously underexplored in the literature. While past studies have often examined these constructs in isolation, this research offers a more nuanced understanding of how blockchain's transformative potential is activated through increased transparency.

26. Second, the findings extend existing theories by embedding BTA within the framework of **open innovation**. The study illustrates that the benefits of blockchain—such as traceability, immutable records, and decentralized control—are amplified when firms adopt transparent and collaborative practices. Transparency, in this context, is not just a byproduct of technology adoption but a strategic asset that enhances inter-organizational learning, stakeholder trust, and system-wide sustainability. This perspective aligns with recent calls in innovation and operations management literature to move beyond closed, firm-centric innovation models toward more open, network-based approaches.

27. Third, by focusing on **Jordanian SMEs**, the study fills a contextual and empirical gap in the literature. While much of the current research on blockchain and sustainability focuses on large organizations in developed countries, this work provides insights into how small and medium-sized enterprises (SMEs) in emerging economies can leverage digital transformation under resource constraints. The findings thus contribute to **contextual theory building**, offering a foundation for cross-country and cross-sector comparative studies in the future.

28. Finally, the research makes a methodological contribution by applying **PLS-SEM** to assess complex mediation relationships in the supply chain context. This approach allows for robust testing of both measurement and structural models, and it encourages future researchers to explore other theoretical extensions—such as moderated mediation models or longitudinal effects to better capture the evolving impact of emerging technologies on supply chain ecosystems.

Practical Implications

29. **This study offers several valuable** implications for supply chain professionals, SME managers, technology strategists, and policymakers, particularly in emerging economies. First, the findings confirm that blockchain adoption alone is insufficient—its benefits on transparency and sustainability can only be fully realized when firms implement structured governance frameworks that encourage transparent data-sharing, interoperability, and accountability across all supply chain tiers.

30. For managers and practitioners, this means that investing in blockchain must be accompanied by initiatives that support organizational readiness, including training, infrastructure modernization, and supplier integration programs. Emphasis should also be placed on data governance policies that ensure consistent standards and trust in digital recordkeeping, which are essential to achieving supply chain visibility and sustainability.

31. The study also underscores the importance of collaborative transparency—organizations should not view transparency as a compliance requirement alone but as a core component of open innovation. Transparency allows companies to co-create value with partners, track performance metrics, and respond dynamically to ESG (Environmental, Social, and Governance) requirements. Therefore, blockchain must be embedded within broader digital transformation strategies, where transparency is both a driver and an outcome.

32. From a policymaking perspective, governments and regulatory bodies must play a proactive role in supporting SMEs during their digital journeys. This includes offering financial incentives, technical support, and regulatory clarity for blockchain implementations. In contexts like Jordan, where SMEs constitute the backbone of the economy, this support is critical to reduce entry barriers and help firms comply with international sustainability standards. Finally, industry associations and public institutions can facilitate multi-stakeholder collaboration platforms to ensure knowledge-sharing, interoperability between blockchain networks, and alignment of sustainability objectives across sectors. Without such collective efforts, the true potential of blockchain to transform supply chains into more transparent, resilient, and sustainable ecosystems may remain unrealized; especially among SMEs with limited capacity.

Limitations and Future Research Directions

33. This study provides valuable insights into the role of blockchain technology in enhancing supply chain transparency and sustainability, it is not without limitations. First, the research is context-specific, focusing on

Jordanian SMEs. Although this offers rich, localized insights, the findings may not be fully generalizable to different institutional, regulatory, or economic settings—particularly in developed economies or larger corporate environments. Future research should explore cross-country comparisons to examine how blockchain adoption and its impact on transparency and sustainability differ across geographic and institutional contexts. Second, the cross-sectional design of this study limits its ability to capture the evolutionary nature of blockchain adoption and its long-term effects on supply chain performance. As digital transformation is an ongoing and iterative process, future studies should adopt longitudinal approaches to assess how the influence of blockchain on transparency and sustainability unfolds over time, especially as regulations, technologies, and business models evolve.

34. Third, although this study examined transparency as a mediator, it did not investigate potential moderating variables that could affect the strength or direction of the relationships. Future research could explore how organizational size, technological readiness, industry sector, or supply chain complexity might influence the impact of blockchain adoption on performance outcomes. For instance, the sustainability benefits of blockchain may differ for manufacturing firms versus service-oriented SMEs. Fourth, while PLS-SEM enabled rigorous testing of relationships between latent constructs, future work could expand the analytical model to include additional mediators (e.g., digital trust, supply chain agility) or moderators (e.g., regulatory support, financial investment) to build more nuanced theoretical frameworks. Moreover, testing for nonlinear effects or interaction terms could offer deeper insights into the conditions under which blockchain drives sustainability. Finally, this study focused primarily on the positive implications of blockchain adoption. However, future research should also investigate barriers, unintended consequences, and ethical concerns, such as data privacy, technological exclusion of small suppliers, and digital dependency. A holistic approach that balances opportunities with risks will better inform both theory and practice in sustainable supply chain digitalization.

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Appendix A: Survey Instrument for Measurement Items

All items are measured on a 5-point Likert scale ranging from 1 = Strongly Disagree to 5 = Strongly Agree.

Code	Item	
Section 1: Blockchain Technology Adoption (BTA)		
BTA1	Our firm has implemented blockchain technology in our supply chain.	Adapted from Saberi et al., 2018
BTA2	We use blockchain to ensure real-time tracking of supply chain data.	
BTA3	Blockchain enhances the security and integrity of our transactions.	
BTA4	Blockchain helps us automate supply chain compliance processes.	Ruangkanjanases et al., 2022
BTA5	Our management supports investment in blockchain infrastructure.	
Section 2: Supply Chain Transparency (SCT)		
SCT1	We have clear visibility into the origin and movement of goods.	Adapted from Casanovas, 2025
SCT2	Our supply chain partners share accurate and timely data with us.	
SCT3	Blockchain has improved information transparency in our operations.	Lee & Zhang, 2023
SCT4	We can track and verify supplier compliance through shared systems.	Allan & Nahm, 2025

SCT5	Transparency in our supply chain builds trust among stakeholders.	
Section 3: Sustainable Supply Chain Performance (SSCP)		
SSCP1	We track and reduce carbon emissions across our supply chain.	Adapted from Wang et al., 2023
SSCP2	We prioritize ethical and environmentally friendly sourcing.	
SSCP3	Our supply chain minimizes waste and promotes resource efficiency.	Kumar & Sahoo, 2025
SSCP4	We comply with environmental regulations and sustainability targets.	
SSCP5	Our supply chain contributes to long-term environmental goals.	