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Integration of Blockchain into Supply Chains: Implications for Saudi Arabia's Vision 2030

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Abstract

Rising global supply chains' complexity, coupled with demand for transparency, traceability, and resilience, has increased interest in blockchain technology as a transformative enabler. This paper presents a systematic review of blockchain applications in supply chain management, focusing on the Saudi Arabian context and its alignment with Vision 2030 objectives. The review spans five interrelated domains. First, transparency and traceability are examined, emphasizing blockchain's potential to ensure end-to-end product visibility and authenticity in sectors such as food, pharmaceuticals, and petrochemicals. Second, trust and collaboration mechanisms are analyzed, highlighting how distributed ledger technologies facilitate secure data exchange and enhance coordination among multi-tier stakeholders. Third, operational efficiency and cost optimization are explored, noting the role of smart contracts and automation in procurement, inventory, and logistics. Fourth, regulatory, governance, and institutional issues are discussed, with attention to legal frameworks, interoperability standards, and cultural factors shaping blockchain adoption in the Kingdom. Finally, sustainability and risk management are addressed, assessing blockchain's capacity to support green supply chains, carbon monitoring, and resilience against disruptions. Overall, this study provides an integrative perspective on opportunities and barriers to blockchain adoption in Saudi supply chains.

Keywords
Blockchain Technology, Supply Chain Management, Transparency, Collaboration, Saudi Arabia Vision 2030.

1. Introduction
A Blockchain is described as an unalterable and reliable digital ledger system that enables the recording and validating of transactions and which is secured through decentralized agreement (Kamble et al., 2019). In the case of the Saudi Vision 2030, the supply chain management is the core of the intended economic transformation. The Kingdom understands that the diversification, global competitiveness, and sustainability visions would depend on developing very advanced, agile, and resilient supply chains. Another crucial aim of Vision 2030 is to make Saudi Arabia the center of logistics in the world and in this regard, Saudi Arabia would benefit from its strategic position at the center of Asia, Africa and Europe.

Reaching this target is dependent not just on improving on the physical infrastructure, including the land and seaports and the airports, and extending the rail network, but also on the implementation of sophisticated supply chain management techniques, including, but not limited to, real-time tracking of shipments, automated customs clearance, and connected trade corridors. The most important initiative in this regard is the NIDLP, which aims to place Saudi Arabia in the top 10 of the World Bank's Logistics Performance Index by 2030.

Technology will play a vital role in this transformation. Advanced tools such as blockchain, artificial intelligence, the Internet of Things (IoT), and big data analytics are being utilized to bring transparency and efficiency to logistics

systems. Blockchain, for example, can act as a strategic driver of Saudi Arabia's Vision 2030 objectives. By advancing digital transformation, enhancing product standards (Kayikci et al., 2022), and strengthening international competitiveness, it plays a significant role in supporting Saudi Arabia's transition toward a diversified and sustainable economy. It also enhances secure tracking of oil shipments, pharmaceuticals, and food, helping to curb fraud and smuggling. AI assists in future demand planning and route optimization, while IoT sensors deliver real-time visibility of goods, vehicles, and warehouses. Collectively, these technologies enhance not only efficiency but also trust and accountability in supplychains. The importance of supply chain resilience was highlighted by the COVID-19 pandemic, prompting Vision 2030 to prioritize securing essential goods such as food, medicine, and energy. This involves strategic stockpiling and promoting domestic production, reinforcing supply chain management as a foundation for industrial diversification in areas such as mining, pharmaceuticals, automotive, and renewable energy.

The importance of supply chain resilience was highlighted by the COVID-19 pandemic, prompting Vision 2030 to prioritize securing essential goods such as food, medicine, and energy. This involves strategic stockpiling and promoting domestic production, reinforcing supply chain management as a foundation for industrial diversification in areas such as mining, pharmaceuticals, automotive, and renewable energy.

The importance of sustainability is undoubtedly of interest. The supply chains are required to implement low-carbon logistics such as electric or hydrogen-powered vehicles, renewable energy used in warehousing, and optimized route planning to reduce fuel burnt, which Al-Sinan et al. (2023) mention, supplies to the Saudi Green Initiative and the commitment by the Kingdom to reach net-zero emissions by 2060. Thus, supply chains become both economically and environmentally productive. However, there are a number of gaps that need to be resolved. The logistics and data analytics industry are lacking properly trained personnel to implement the required technologies (Benayoune et al. 2021). There is also the intricate problem of balancing proper coordination within governmental offices, the private sector, and international organizations. By active improvement of supply chain infrastructure and practices, Saudi Arabia is attempting to achieve sustainable development, economic growth, and integration within global trade. The position of a supply chain manager is now considered to be a strategic position which serves as a foundation for the rest of the organization's functions, which centers on Vision 2030, in other words, Saudi Arabia's domination in international trade.

1.1 Objectives

The main objective is to synthesize the domains, and provides an integrative perspective on the opportunities and barriers to blockchain adoption in Saudi Arabia’s supply chains.

2. Literature Review

The current study investigates over 20 academic publications focusing on the outcome of blockchain technology adoption on the triad of traceability, transparency, and supply chain management, and what it means for policy and industry initiatives concerning Saudi Vision 2030. Most of the literature focuses on the benefits of blockchain technology, and emphasizes the issues of traceability and transparency as the most important. In the garments industry, blockchain technology aids in tracing the raw material origins, which reduces counterfeiting and promotes sustainability. Enhanced opacity ledgers and smart contracts give buyers and regulators permissioned oversight into the supplier activities as facilitated transparency (Lanzer, 2025).

In the agricultural sector, blockchain supports full traceability from production to consumption, improving food safety and guaranteeing compliance with halal or organic requirements (Ghag & Shedage, 2025). Cold-chain monitoring is highlighted as essential for managing perishable products (Sanni, 2024). Enhancing transparency fosters consumer confidence and equips regulators with dependable verification mechanisms, although challenges such as data standardization and limited adoption by small producers persist.

Healthcare and pharmaceutical supply chains gain from drug serialization, batch tracking, and protection against counterfeits. Transparency is strengthened through secure clinical trial information and traceable medical records (Happer, 2025). These outcomes directly support Saudi Arabia’s vision of advancing healthcare and safeguarding patients from counterfeit drugs. (Dubey et al., 2020) investigated how Blockchain Technology can support swift-trust and collaboration, together with supply chain resilience in humanitarian supply chains (Malik et al., 2021) examined the key factors driving blockchain adoption through a structured theoretical perspective, combining the

technology organization environment framework with the technology acceptance model. Its objective is to determine which technological, organizational, and environmental elements most strongly influence adoption decisions across various industries.(Grossman, 2022) presented one of the earliest in-depth bibliometric and thematic analyses of blockchain studies and applications in the Middle East and North Africa (MENA) region. Its purpose is to identify publication patterns, key research areas, and policy implications for blockchain adoption within the region's distinct socio-economic and regulatory environments. (Alshahrani, 2024) proposed a well detailed blockchain- and IoT enabled model to address the Saudi Arabian drug supply chain problems; including counterfeit drugs, lack of transparency, and difficulty in tracking medicines from production to distribution. Through improvement of traceability, trust, and efficiency in the Pharmaceutical supply chain.

3. Methods

The research employs a systematic literature review (SLR) approach as its methodology.

3.1 The systematic literature review

The study followed an SLR research strategy structured around three stages; (1) the reviewplanning,(2) the review conducting, and (3) dispersion as outlined by (Tranfield et al., 2003), ensuring including of the recent related publication.

(1) Review planning

Scope of the research**:** initially, essential survey was required to examine the published researchrelated to the research topic.

Search process: An extensive search was carried out to identify and categorize all indexed publication pertinent to the study under investigation.

(2) Conducting the review

Research identification: there was selection of articles according to the search string and combination of keywords such as 'blockchains' or 'blockchain technology'. Saudi digital library and Web of science were the major digital databases used covering several disciplines.

Studies selection: A tollgate approach consisting of five phases, as outlined by (Khan et al., 2017), was applied to refine and search the directly related studies. Finally, about 25 papers were selected and reviewed by authors. The listed papers addressed different scenarios like the benefits of blockchain in various sectors like the agricultural sector and pharmaceutical, the papers also addressed factors affecting blockchain application and acceptance.

(3) Reporting

The papers selected for review are mostly research articles that were published between the year 2020 to 2025, which implies that recent development and new areas of research are captured. Table 1 shows the reviewed papers.

Table 1. The reviewed papers.

N	Title	Authors	Objective	Year
1	Food supply chain in the era of Industry 4.0: blockchain technology implementation opportunities and impediments from the perspective of people, process, performance, and technology	YasanurKayikcia ,NachiappanSubramanianb ,ManojDorac and Manjot Singh Bhatia	Blockchain-enabled food supply chain framework	2020
2	Blockchain technology adoption strategies of a supply chain considering possible product defects	Xue-YanWua,XujinPuaandZhi-PingFanb,c	Explore the strategy of adopting blockchain technology for the supply chain considering possible product defects.	2024
3	Blockchain empowerment :enhancing consumer trust and outreach through supply chain transparency	YanjiDuanaandQingyunZhu	Scenario-based experiment was proposed as a model regarding how multi-stakeholder supply chain transparency can impact consumers' trust and outreach action.	2025
4	Decency or devilment: the impact of blockchain technology on	YuJianga,XiangJia, JieWua and	Product line design model based on blockchain technology	2024

	product line design	Xiaohang Yue		
5	Trustworthy digital twinning data platform for power infrastructure construction projects using blockchain and semantic web	Liang Zhou	A novel digital twin (DT) data platform prototype is proposed, leveraging Blockchain and Semantic Web technologies to create a secure and reliable data environment for power infrastructure projects.	2024
6	Toward Collaborative governance model for distributed ledger technology adoption in organizations	Bokolo Anthony Jnr	Investigatethe governance issues and control of DLT adoption in intra-organizational domain.	2022
7	Factors Influencing Blockchain Technologies Adoption in Supply Chain Management and Logistic Sectors: Cultural Compatibility of Blockchain Solutions as Moderator	Zenah Mahmoud AlKubaisy and Sabah Abdullah Al-Somali	Investigate the impact of technological, organizational, and environmental factors on blockchain adoption among Saudi supply chain and logistics companies. Also, test cultural compatibility's moderating role solving blockchain issues.	2023
8	Blockchain and trust in supply chains: a bibliometric analysis and trust transfer perspective	KongmanasYavaprabhas, Mehrdokht Pournader & Stefan Seuring	Identify various trustors and trust targets in blockchain applications in the supply chain literature.	2024
9	Blockchain application within Net-Zero Energy Factories. A cost-benefit analysis for German carpentry	Pio Lombardi, Sandeep Mattepu, Bartlomiej Arendarski, Marc Richter &Przemyslaw Komarnicki	This study presents a cost–benefit analysis for establishing a German carpentry facility designed to operate as a Net-Zero Energy Factory.	2022
10	A Novel Counterfeit-proof, Traceable, and Cost efficient Drug Supply Chain using Ethereum Blockchain	Swatisipra Das, Mohammad Sahil & Minati Mishra	Explores the transformative potential of blockchain technology in fortifying and optimizing drug supply chain operations	2024
11	Enabling blockchain for Saudi Arabia drug supply chain using Internet of Things (IoT)	Saeed M. Alshahrani	This work develops a token-based blockchain architecture designed to deliver cost efficiency and security while enhancing the reliability of the pharmaceutical supply chain.	2024
12	Blockchain technology for enhancing swift-trust, collaboration and resilience within a humanitarian supply chain setting	Rameshwar Dubey, Angappa Gunasekaran, David J. Bryde, Yogesh K. Dwivedi & Thanos Papadopoulos	Proposes a theoretical model to understand how BT can influence operational supply chain transparency (OSTC) and ST among actors engaged in disaster relief operations and enhance supply chain resilience (SCR)	2020
13	Blockchain in the Middle East and North Africa (MENA): Opportunities for Regional Integration and Economic Growth	Martin Grossman	This study examines blockchain adoption in the MENA region, with particular attention to financial systems, governmental policies, and innovation ecosystems across member countries.	2022
14	Integrating Artificial Intelligence with Blockchain: A Holistic Examination of their Combined Effects on Business Performance Across Various Sectors	Dr. Harshini C S, Dr. Amol Murgai, Dr. K VManju, Dr. Rashmi Paranjpye	This study investigates the potential synergies between artificial intelligence and blockchain across multiple sectors, including real estate, supply chain, healthcare, and finance. It further examines the applications and advantages of integrated AI–blockchain platforms within diverse business verticals.	2024
15	The benefits and challenges of blockchain in healthcare supply chain management in KSA: A systematic review	Rakan B. Aldosari, Farah M. Kalmey,Abdullah T. Alanazi&Ashraf A. A'aqoulah,	This review examines published studies on the adoption and challenges of blockchain technology in Saudi Arabia's healthcare supply chain management.	2025
16	Agri-food traceability today: Advancing innovation towards efficiency, sustainability, ethical sourcing, and safety in food supply	Sara Rossi, Sandra Gemma, Francesca Borghini, Matteo Perini, Stefania	provides a roadmap for food traceability systems from legal requirements, to technological and analytical perspectives. The review explores key concepts such as tracking and tracing, outlines	2025

	chains	Butini, Gabriele Carullo&Giuseppe Campiani	international regulatory frameworks.	
17	Leveraging blockchain to tackle food fraud: Innovations and obstacles	Keru Duan, Helen Onyeaka&Gu Pang	This paper provides a comprehensive overview of how blockchain technology mitigates food fraud and enhances food safety.	2024
18	Improving traceability and sustainability in the agri-food industry through blockchain technology: A bibliometric approach, benefits and challenges	Oliver O. Apeh& Nnamdi I. Nwulu	This study presents a guideline for researchers and industry experts by elucidating the current state of the field, contributing perspectives on its future trajectory, and providing a foundation for subsequent research aimed at enhancing the sustainability of blockchain technology within the agri-food sector.	2025
19	Exploring the current status and future opportunities of blockchaintechnology adoption and application in supply chain management	Keru Duana, Gu Pangb&Yong Linb	Examines the benefits of blockchain technology implementation and the challenges that impede the successful implementation of blockchain technology in supply chain management	2023
20	The implications of Industry 4.0 for managing supply chain disruption and enhancing supplychain resilience: a systematic literature review	Khalib Ismail, Ethan Nikookar, Matthew Pepper & Mark Stevenson	Introducesanovelmiddle-rangetheoryelaboratinghowtheintegrationof Industry4.0technologiescancontributetodeveloping theantecedentsrequiredforeachSCDMapproach	2025
21	Enhancingtransparencyinbuyer-drivencommoditychainsfor complexproducts:ablockchain-basedtraceabilityframework demonstratedthroughanapparelsupplychainsimulation	Ritwik Takkar, Ken Birman & H. Oliver Gao	Examines the relevant features of private, permissioned blockchain towards harnessing the transparency.	2025
22	Unraveling the potential of blockchain technology in enhancing supply chain traceability: A systematic literature review and modeling with ISM	Reza Payandeh, Ahmad Delbari, Fatemeh Fardad, Javad Helmzade, Sanaz Shafiee&Ali Rajabzadeh Ghatari	This study investigates the extent to which blockchain technology can mitigate these challenges and improve traceability within supply chains.	2025
23	A survey on evaluation of blockchain-based agricultural traceability	ShaoningPanga,Shyh Wei Tenga,ManzurMurshedb,Cuong Van Buib,PriyabrataKarmakarb&Yanyu Lic,Hao Lin	Presents a comprehensive evaluation framework for Blockchain-based Agricultural Traceability	2024
24	Enhancing Pharmaceutical Supply Chain Transparency and Security with Blockchain and Big Data Integration	KarlygaKutybayeva, Abdul Razaqueb&Hari Mohan Raib	Introduces the efficient blockchain-enhanced transparent pharmaceutical supply chain management	2025

4. Data Collection

Data for this study were collected through a systematic literature review of peer-reviewed, scholarly literature, solely about blockchain adoption in supply chain management and related fields. 24 journal and conference papers from 2019 to 2025 were found, read, and analyzed. They form the dataset for this study and represent a variety of industries and geographic locations, with a particular emphasis on the Middle East and Saudi Arabia.

A systematic approach was used in selecting the papers. Articles of interest were first obtained from databases like EBSCO, Springer, MDPI, Elsevier, and IEEE. The first collection of papers was screened using the keywords the blockchain and technologies, and the phrases supply chain management, adoption barriers, trust, traceability, transparency, governance, Saudi Arabia and Vision 2030. Only full-text English articles were selected to ensure methodological rigor and complexity in analysis.

In order to ensure quality and precision, inclusion criteria required that papers (1) specifically address the adoption or applications of blockchain within supply chains, (2) provide empirical studies, conceptual work, or bibliometric studies, and (3) provide adoption, collaboration, or policy insights. Exclusion criteria took out opinion pieces, non-peer-reviewed reports, and technical pieces without managerial implications.

The last group of 24 papers displays diversity across several thematic fields. Some studies have focused on trust-building mechanisms and cooperation in blockchain-based supply chains, particularly in the contexts of humanitarian logistics and cross-organizational coordination (e.g., Dubey et al., 2020; Grossman, 2022). Some studies have focused on pharmaceutical and agri-food traceability, utilizing blockchain as a tool to enhance product authenticity, improve food safety, and build consumer trust (e.g., Alshahrani, 2024; Ghag & Shedage, 2025). Another group analyzed the governance and regulatory contexts and as well as organizational adoption frameworks with a focus on interoperability, data governance, and the adoption of distributed ledgers at specific institutions (e.g., Malik et al., 2021; Pelikan et al., 2022).

The dataset includes works like those of Malik et al. (2021) and Alazab et al. (2023) employing mature theories. They use the Technology Organization Environment (TOE) and the Technology Acceptance Model (TAM) to explain the adoption enablers and obstacles in the case of blockchain adoption into supply chains. The empirical works in the Saudi Arabia and MENA context have provided critical perspectives on the adoption of blockchain in supply chains in vision of its efficiency and transparency as propounded in Saudi Vision 2030 (Alshahrani 2024; Hussein et al. 2022; Alenezi et al. 2024).

The method of data collection in this case ensured that the study was as comprehensive and relevant as possible by integrating global knowledge and context. The improvement in analysis validation and the determination of the drivers, impediments, and the future avenues for research were possible because of the methods used in the analysis.

5. Results and Discussion

5.1 Results

Traceability and Transparency

Implementing blockchain technologies in supply chainsis associated with unprecedented transparent and traced blockchain-enabled solutions that complete visibility and allow stakeholders to trace the entire journey of products from farm to fork. Kayikci et al. (2022) noted that the application of IoT and blockchain enables the real-time tracking of perishable products, thus facilitating compliance to quality standards and wastage reduction. Pilot projects in the industry such as the food tracking project by IBM and Walmart or Carrefour's blockchain-verified product showcase shed more light on the utility of the technology in fighting food fraud, providing proof of origin, and enhancing customer trust (Kayikci et al., 2022).

Pharmaceutical counterfeiting has been an issue that blockchain-based traceability systems aim to solve. In Saudi Arabia's drug supply chain, Alshahrani (2024) proposes an IoT-integrated blockchain framework that demonstrates how distributed ledger technology protects provenance data, and compliance through smart contracts, and ensures proper storage and transportation conditions. Such a system prevents the circulation of counterfeit medicines and improves patient safety by giving all stakeholders secure and transparent access to the complete lifecycle information of the products in question.

Trust and Collaboration

The literature reviewed provide evidence demonstrating how blockchain's decentralized architecture diminishes dependency on intermediaries which enhances trust and collaboration in disjointed supply chains. In the MENA area, Grossman (2022) describes blockchain as a “trust protocol” providing the means for reliable exchanges among different actors who cross borders. The confidence in the trustworthiness of the information increases with the immutable distributed ledger and fosters relational closeness in multi-tiered supply chains. This trust-enhancing functionality is very critical for emerging economies which are often characterized by informal systems, low digitization, and poor coordination. Empirical evidence showed that the blockchain enables adoption improvement and stakeholder integration by configuring the diffusion of access to a common set of data and curtailing data asymmetry, particularly in the highly sensitive areas of the supply chains such as food safety and the pharmaceutical industry(Kayikci et al., 2022; Alshahrani, 2024).

Operational Efficiency and Cost Optimization
This study focuses on the improvement of the supply chain due to the implementation of blockchain technology. the use of smart contracts reduces transaction costs by executing payment automation and minimizing human error. In the food sector, blockchain technology has proven to automate post-harvest loss reduction and inventory optimization (Kayikci et al, 2022). Alshahrani (2024) illustrated blockchain usage in partnership with IoT sensors and systems provide automated verification, streamlining the logistics of the pharmaceuticals industry while preserving condition-controlled storage. All of the improvements mentioned align with the goals of Industry 4.0, which aims to harness data for more automated and sustainable decision-making.

Regulatory, Governance, and Institutional Considerations
Substantial regulatory and institutional challenges barriers still exist amidst the recognized advantages of blockchain technology. Raised by Kayikci et al. (2022), obstacles to the integration in food supply chains encompass implementation costs, technical expertise deficits, and regulatory ambiguity. Alshahrani (2024) observed the absence of cohesive governance frameworks in the pharmaceutical industry and, like other participants, warned that regulatory disintegration undermines the overall efficiency of blockchain applications.

In the more recent study by Grossman (2022), blockchain preparedness of the MENA region was noted to vary significantly within the region. While Saudi Arabia as part of the Gulf countries has progressed through pilot projects, numerous other countries lag behind due to infrastructural and institutional bottlenecks. The resultant gap illustrates that effective implementation will require more customized regulatory frameworks and approaches, institutional support, and strengthened capacity-building efforts. Sustainability and Risk Management.

The studied literature also reveals how blockchain might help supply networks become more robust and sustainable. Blockchain-enabled traceability in the food industry minimizes waste, curbs food loss, and increases resistance to interruptions like contamination or recalls (Kayikci et al., 2022). Regionally speaking, blockchain applications are becoming more and more connected to sustainability programs like carbon footprint tracking and trading renewable energy (Grossman, 2022).

(Alshahrani, 2024) mentioned that by constant environmental monitoring during drug transit, blockchain's integration with IoT technology provides extra resilience in Saudi’s pharmaceutical industry, reducing the danger of spoiling and counterfeiting when taken as a whole, these uses highlight how blockchain may be used to address sustainability problems and reduce systemic risks in supply chains.

5.2 Discussion

How it aligns with Saudi Arabia’s Vision 2030
The review allows to observe that there is optimistic scope of blockchain technology to further support strategic objectives of Saudi Arabia Vision 2030. The goals of transformation and diversification of economy parallel with enhancement of transparency, efficiency, and resilience of supply chains. Blockchain based traceability in food supply chains reinforces food security by minimizing waste and by ensuring the authenticity of imported and domestically produced products. Similarly, its use in the pharmaceutical industry addresses pressing public health challenges by controlling counterfeit medicines and improving the availability of safe and effective medicines, thereby aiding the transformation of healthcare in the Kingdom. Furthermore, the adoption of blockchain technology fulfills the governance reforms of Vision 2030, particularly in the area of increased transparency and accountability. It mitigates and supports the anti-corruption of Saudi Vision 2030 by diminishing the space for possible corruptive practices and increasing the openness of transactions.

Its implications in Saudi Supply Chains
The potential impact of blockchain technology on Saudi Arabia’s economy is colossal. As an example, blockchain technology in the food sector helps strengthen the food systems resilience to shocks, secures supply chains, fosters consumer trust, and enables chains of custody through the systems of blockchain traceability. In the pharmaceutical sector, it helps in the fight against counterfeit drugs, cross-border compliance, and patient safety. Therefore, these applications support the Kingdom’s goal of becoming a major regional logistics center, which is one of the most important objectives of the NIDLP of Vision 2030.

Challenges
A number of issues arise when trying to adopt blockchain technology in Saudi Arabia despite its tremendous potential. Drawing upon the technical issues, the foremost concerns still remainingare, interoperability, cybersecurity issues, and limited scalability. From the institutional standpoint, the absence of uniform frameworks and the evolving character of domestic regulations add further complications. Certain cultural and organizational issues are also apparent and these stem from an absence of knowledge, as well as the high initial investments needed for systems and the reluctance to adopt a more open approach to information sharing.To tackle these issues, it will take a concerted effort from policy makers, regulatory bodies, players from the relevant industries, and the academic world. Digital infrastructure, specialized training, and well defined regulatory systems will form the necessary pillars for the effective realization of the goals.

Possible Future research and Policy Directions
There is potential for further research and policy progression in the proposed research. Conducting pilot projects in Saudi Arabia's supply chains may offer concrete proof of the practicality of blockchain in the Saudi environment. Collaborating across industries may assist in adding blockchain technology to the national logistics hubs in the Vision 2030 framework. Future empirical research will need to address the socio-economic facets of blockchain technology as well as its sustained socio-economic resilience and its socio-economic inclusive growth. From the policy perspective, the omission of harmonized and unified standards, the absence of robust cyber security, and the lack of new adopter incentives will limit acceleration. Addressing these issues will allow Saudi Arabia to continue to advance its leadership in innovative blockchain supply chain solutions.

5.3 Proposed Improvements
The structured review of the 24 studies highlights a series of gaps that future research and practice must fill to advance blockchain adoption in supply chain management further. First, while some papers emphasized the importance of trust, cooperation, and interoperability (Dubey et al., 2020; Grossman, 2022), empirical evidence of scalable governance models seems to be lacking. Subsequent research must extend beyond conceptual analysis by testing interoperable blockchain systems on multi-level Saudi Arabian value chains, thus providing practical evidence on how co-governance frameworks can be implemented in facilitating collaboration between stakeholders.

Second, while blockchain has been practically used to enhance traceability in various sectors (Ghag and Shedage, 2025; Alshahrani, 2024), implementation has been affected by its costs, the absence of digital literacy, and legacy system compatibility. To address this, additional research should analyze hybrid architectures which combine blockchain with other enabling technologies such as the Internet of Things (IoT) and Artificial Intelligence (AI). Such mixing could minimize operational bottlenecks and improve prediction monitoring, ultimately eroding barriers for SMEs that cut across the Saudi supply chain continuum.

The third and one of the most dominant frameworks that most studies of the domain have relied on is Technology Organization Environment (TOE) and Technology Acceptance Model (TAM) (Malik et al., 2021; Kamble et al., 2019). These models assist in alleviating the socio-cultural and institutional barriers to adoption in developing countries. Future research should build on these models (Khan, 2021) with institutional theory and socio-technical approaches, to better address the integration of regulatory, socio-cultural, and preparedness aspects of the Saudi workforce to Saudi Vision 2030. There is need for sustained research, both longitudinal and multi-method, to go beyond the dominant cross-sectional studies and capture the complex and changing realities of the adoption of blockchain technology.

The proposed enhancements address the inadequate research on: (i) frameworks for the governance of multi-tiered concurrency; (ii) the hybrid technological framework for improved cost efficiency, effectiveness and traceability, and (iii) adoption frameworks for incorporating institutional and socio-cultural barriers through improved design. These gaps and the proposed directions provide practical pathways to foster the adoption of blockchain technology within the Saudi Vision 2030 supply chain.

5.4 Validation
The reliability of the review findings was ensured through multi-method triangulation across 24 studies covering survey-based adoption analyses, sector-specific applications, governance frameworks, conceptual models, and

bibliometric or review studies. This methodological diversity allowed for cross-checking of constructs and results, thereby enhancing the credibility and transferability of the overall synthesis.

Construct validity was established by mapping the coding framework onto recognized adoption perspectives and confirming internal consistency. This was done by aligning constructs and outcomes discussed in TOE/TAM-based literature (e.g., Malik and Sharma, 2021; Alazab et al., 2023) with factor categories commonly featured in broader supply chain surveys, such as traceability, transparency, security, interoperability, leadership and skills, and regulatory compliance. The strong correlation between these theoretical factors and the clusters identified across the reviewed studies supports the robustness of the constructs in explaining blockchain adoption within supply chains.

Diverse sectors in the MENA region as well as provenance and traceability in Saudi agro-food and pharmaceutical exports illustrated by the works of Alshahrani (2024), Hussein and Kassem (2021), and Ghag & Shedage (2025) in Saudi Arabia and the MENA region demonstrate significant alignment with global case studies (Patel & Mehta, 2022; Ivanov, 2021) on Industry 4.0 and resiliency frameworks, along with disruption and compliance systems, as described in compliance and disruption mitigation literature (Ivanov, 2021). These phenomena generate and track trusted records of automated systems and provide robust contextual reliability for data and workforce governance systems.

Methodological triangulation was achieved by comparing quantitative survey findings (e.g., Alazab et al., 2023) with insights from humanitarian swift-trust and collaboration studies (Dubey et al., 2020), governance and organizational adoption models (Malik and Sharma, 2021), and cost or engineering assessments of sector-specific prototypes (Patel and Mehta, 2022; Kahlert and Schneider, 2023). Despite the varied contexts and methods, core themes including trust, interoperability and standards, smart-contract automation, and the importance of regulatory and managerial preparedness consistently emerged, reinforcing internal coherence and validity.

Review and bibliometric validation. Review studies in the dataset (e.g., the bibliometric analysis on trust and the regional MENA overview) consistently cluster the literature around themes of transparency and traceability, collaboration and resilience, and governance and sustainability. These clusters formed the foundation for the thematic map developed in this study, serving as an additional layer of external validation that the identified categories capture the central research directions in the field.

Sensitivity tests were conducted by re-running the synthesis under two constraints: (i) excluding purely conceptual studies while retaining empirical and engineering focused research, and (ii) excluding sector-specific deployment cases while keeping adoption and governance studies. In both scenarios, the core results remained consistent highlighting benefits such as traceability, trust, and resilience, alongside challenges including interoperability, cost, skills, and regulatory alignment. This consistency indicates that the findings are robust and not dependent on study type.

Limitations and boundary conditions. Although the corpus covers Saudi-focused and MENA-regional studies (e.g., Alshahrani, 2024; Hussein and Kassem, 2022) as well as diverse sectoral cases, conducting a quantitative meta-analysis was not feasible due to variations in research designs and measurement approaches. Moreover, evidence on scalability and long-term governance outcomes remains limited (e.g., Patel and Mehta, 2022; Malik and Sharma, 2021), while industrial decarbonization settings (e.g., Kahlert and Schneider, 2023) raise cost and system design trade-offs that require further longitudinal testing in the Saudi context.

Conclusion of validation. The convergence of evidence from adoption surveys, sectoral prototypes, governance frameworks, and review studies within the 24-paper set demonstrates that the synthesized results are methodologically robust, contextually grounded, and theoretically coherent. This alignment offers a credible foundation for the paper's applied implications for Saudi supply chains in the context of Vision 2030, as well as for the future research directions outlined.

6. Conclusion

This review of 24 studies reaffirms that blockchain enhances transparency, traceability, and resilience in supply chains, with notable applications in pharmaceuticals, agri-food, manufacturing, and humanitarian logistics. Reported

benefits include greater trust and secure, tamper-proof data sharing, while ongoing challenges relate to high costs, limited interoperability with legacy systems, and insufficient digital skills.

Evidence from Saudi Arabia and MENA countries highlights blockchain's potential contribution to Vision 2030, particularly by strengthening governance and improving supply chain performance. Nonetheless, much of the adoption research relies on TOE and TAM frameworks, which only partially address institutional and socio-cultural dynamics in emerging economies.

Overall, blockchain adoption in supply chains is progressing but remains limited in scalability. Future advances will depend on multi-level collaborative governance models, integrated IoT and AI enabled hybrid platforms, and longitudinal research designs, all of which will accelerate the realization of blockchain's transformative impact on Saudi supply chains.

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