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Enhancing Transparency and Efficiency in Industrial Procurement through Blockchain: A Systematic Literature Review

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Abstract*– Blockchain has emerged as a promising technology to address long-standing challenges in industrial supply chains, particularly those related to transparency, traceability, and trust among multiple stakeholders. Conventional procurement systems often rely on centralized architectures and intermediaries, resulting in data fragmentation, limited visibility, and increased operational costs. The objective of this study is to analyze the application of blockchain technology in industrial procurement processes and to assess its impact on improving reliability, efficiency, and transparency across supply chains. A systematic literature review (SLR) was conducted using the PICOC framework to define research questions and the PRISMA protocol for study selection. A total of 67 peer-reviewed articles published between 2019 and 2025 were retrieved from the SCOPUS database and classified by industry sector, identified problems, blockchain architectures, and reported outcomes. Findings show a growing research interest in blockchain-enabled procurement, with the food, agriculture, and pharmaceutical sectors exhibiting the highest adoption. Ethereum and Hyperledger are the most used platforms, often combined with hybrid on-chain/off-chain architectures to improve scalability. Reported benefits include enhanced traceability, reduced fraud and errors, improved operational efficiency, and increased automation through smart contracts. However, many implementations remain limited to pilot or controlled environments. Blockchain can significantly enhance procurement performance and supply chain reliability, but challenges related to scalability, interoperability, regulatory alignment, and high implementation costs (particularly for SME's) remain key barriers to widespread adoption.

***Keywords*-- Supply Chain, Traceability, Blockchain, Procurement, Smart Contracts.**

I. INTRODUCTION

In recent years, organizations have increasingly adopted advanced technologies to optimize their production processes and the implementation of cutting-edge technologies has contributed to improvements in operational efficiency and effectiveness across industries [1]. However, despite the widespread adoption of advanced enterprise systems such as ERP platforms and supplier management solutions structural challenges related to information traceability, transaction transparency, and trust among actors operating in highly interorganizational environments persist [2]–[4]. These challenges are particularly evident in regulated and high-impact industries such as food [5], pharmaceutical [6] and energy sectors [7], where purchasing decisions are closely linked to regulatory compliance, product safety, sustainability, and risk management. Information fragmentation, reliance on intermediaries, limited visibility into actual supplier performance, and the potential manipulation of records generate inefficiencies, increase reprocessing and auditing costs, and weaken traditional control and verification mechanisms [8]. In this context, trust among parties is often based on contracts, certifications, and ex post verification processes, which are costly and, in many cases, insufficient to ensure information integrity throughout the purchasing cycle.

Among these emerging technologies, blockchain has gained attention as a tool capable of enhancing security and transparency in various business processes [9]. Blockchain, a technology based on the consensus protocol introduced by S. Nakamoto [1], [10], relies on a distributed transaction ledger originally employed in the Bitcoin cryptocurrency. It functions as a secure digital registry in which information is organized into interconnected blocks within a network, and transaction data are protected through cryptographic mechanisms, making the system more distributed and secure [11]. Digital information related to products, processes, or services (such as timestamps, prices, and involved participants) is stored in blocks and distributed across the network, where multiple independent nodes validate transactions without prior mutual trust [12], [13]. Blockchain security relies on transaction data, cryptographic hashing, and hash linkage between blocks. This chained structure ensures immutability, as altering any block would require modifying all subsequent blocks, making the system tamper-resistant. [14].

Due to these features, blockchain is used in industrial purchasing to enable distributed records, auditability, transaction automation, and smart contracts that execute actions when conditions are met. [15]. It has also been applied to evaluate pharmaceutical traceability [6], monitor product status, and detect counterfeit medicines [16]. Similarly, blockchain has been used in food traceability to store information related to product origin [17], designation of origin [18], quality, and regulatory compliance [19]. Applications have also been reported for tracking luxury goods [20] and controlled substances [21]. Across these use cases, the primary objective is to ensure that information remains verifiable and resistant to external manipulation, thereby preserving security and trust.

Despite its association with immutability, transparency, and traceability, blockchain adoption in enterprises is constrained by legacy infrastructures and the high costs of training and technological upgrades. [12]. Furthermore, technical complexities related to privacy in public blockchain networks and the lack of interoperability among platforms limit broader deployment [22], [23]. Additional barriers include the need for standardization among stakeholders, data privacy concerns, and regulatory constraints or the absence of clear regulatory frameworks [16]. Advances in consensus mechanisms, interoperability, and regulatory clarity may mitigate current limitations, enabling broader and more sustainable adoption. Consequently, blockchain emerges as a promising tool for enhancing transparency and efficiency in procurement and strengthening supply chain performance. [17], [18].

Within this context, a knowledge gap is identified regarding comparative analyses that integrate blockchain applications in industrial purchasing procedures and systematically assess their contributions, real-world impacts, and limitations. Therefore, the objective of this study is to conduct a literature review on the adoption of blockchain technology across different industries and to analyze its applicability in improving transparency and efficiency in procurement processes. The review is conducted following the PRISMA methodology for the identification, screening, and selection of relevant studies. Blockchain applications across multiple industries are compiled, highlighting reported challenges and potential solutions, followed by a discussion of conclusions and recommendations.

II. Methodology

This study adopts a Systematic Literature Review (SLR) methodology [24], which enables the inclusion of both empirical and theoretical sources. This approach facilitates systematic extraction and synthesis of evidence regarding the applicability of blockchain technology.

A. *PICOC framework*

The PICOC framework begins with the formulation of structured research questions, broken down into key components, which enable a precise bibliographic search within the scope of specific research projects.

First, the dimensions that comprise the PICOC scheme—Population/Problem, Intervention, Comparison, Outcomes, and Context—were defined and linked to the research topic, as shown in Table 1. The context analyzed in this study is the implementation of blockchain technology in supply chain management. Accordingly, the specific aspects encompassed by each dimension were identified. The first dimension, Problem/Population (P), is directly related to the use of blockchain technology. The second dimension, Intervention (I), identifies the ways in which blockchain and smart contracts are applied in purchasing processes. The third dimension, Comparison (C), focuses on evaluating purchase order processes. The fourth dimension corresponds to Outcomes (O), which consider the effects on the level of trust and reliability. Finally, the fifth dimension, Context (C), defines the application within industrial enterprises.

Once the PICOC dimensions were associated with the research topic, the main research question (RQ) was formulated as follows: *What blockchain application methods are used to evaluate purchase order processes in industrial companies?*

Subsequently, specific research questions corresponding to each PICOC dimension were developed, as detailed in Table 2. Based on these questions, the related keywords were identified and selected, as presented in Table 3.

TABLE 1. PICOC Framework Dimensions

Population	Intervention	Comparison	Outcomes	Context
Blockchain	Methods for applying blockchain and smart contracts in procurement processes.	Evaluation of purchase order processes.	Level of trust.	Manufacturing and industrial companies.

TABLE 2. Research questions according to PICOC framework

Population	Intervention	Comparison	Outcomes	Context
What is Blockchain technology?	What methods exist in the literature?	How are these methods evaluated?	How is the reliability of blockchain analyzed?	How efficient is blockchain implementation in companies?

To address the research topic, the SCOPUS literature search engine was used, employing a set of keywords specified in Table 3. The search strategy was based on a combination of terms appearing in the title, abstract, and keywords, resulting in the following search query:

(TITLE-ABS-KEY (blockchain OR "Digital Storage" OR cryptocurrencies) AND TITLE-ABS-KEY ("Smart contracts" OR "Purchasing process" OR "Digital technology" OR interoperability) AND TITLE-ABS-KEY (pricing OR customer OR product OR amount) AND TITLE-ABS-KEY (efficiency OR security OR transparency OR "Management reduction") AND TITLE-ABS-KEY ("Process optimization" OR "Productivity" OR "flexibility" OR "Transaction registration" OR "Supply chain") AND PUBYEAR > 2018 AND PUBYEAR < 2026

B. *PRISMA protocol*

For this Systematic Literature Review (SLR), the PRISMA protocol was applied during the selection and screening stage, which was conducted in four phases. First, following an initial search in the SCOPUS database (www.scopus.com) using the search query and 1015 records were retrieved. In the first exclusion phase, 642 publications were removed based on document type, excluding works that did not constitute original studies, resulting in 373 articles. In the second phase, a language filter was applied, retaining only articles written in English or Spanish. In addition, the presence of the keyword "blockchain" was verified as an indicator of relevance to the research topic, which reduced the sample to 291 documents. The third phase involved the exclusion of inaccessible articles or those whose full content could not be retrieved, leaving 182 articles. Finally, in the fourth phase, the relevance of the remaining studies was assessed through an in-depth content analysis to ensure compliance with the inclusion and exclusion criteria specified in Table 4. This process enabled the selection of 67 articles considered appropriate for the present review. A flowchart is shown in Fig. 1.

TABLE 3. Selected keywords for PICOC framework

Population	Intervention	Comparison	Outcomes	Context
Blockchain "Digital Storage" Cryptocurrencies	Smart contracts "Purchasing process" "Digital technology" Interoperability	Pricing Customer Product Amount	Efficiency Security Transparency Management Reduction	"Process optimization" Productivity Flexibility "Transaction registration" Supply chain

TABLE 4. Elegibility criteria

IC	Inclusion criteria
IC1	The included studies are related to blockchain technology.
IC2	The studies apply and describe blockchain-based methods in purchasing processes and smart contracts.
IC3	The included studies report **quantitative results** derived from the application of the proposed methods.
IC4	The studies were conducted in **real-world industrial company environments**.
EC	**Exclusion criteria**
EC1	Publications written in languages other than **English or Spanish**.
EC2	Publications whose titles do not include the term **"blockchain"**
EC3	Publications that are **not accessible for download** through the SCOPUS database.
EC4	Studies that are **not focused on procurement or purchasing process applications** or **only focused in conceptual design.**
EC5	Studies that are **not oriented toward engineering-related disciplines**.

III. Results and Discussion

Using the PRISMA protocol, 67 studies were selected and classified by industry, problem, blockchain model, and year. Results show growing research interest in blockchain for procurement and supply chains over the last three years, reflecting its potential to improve traceability, security, and efficiency. While early studies (2019–2020) focused on security and authenticity, recent work (2023–2025) expands to whole supply chains, addressing scalability and accessibility. In addition, the distribution of blockchain studies by journal quartile shows a clear predominance of Q1 journals between 2020 and 2022, followed by increasing diversification into Q2, Q3, and Q4 journals in recent years (Fig. 2). This trend indicates that blockchain research has reached a level of scientific maturity and is now expanding across a broader range of disciplines. The growing presence in lower quartiles signals a transition from a high-impact, innovation-driven technology toward wider adoption in transversal academic fields and practical applications.

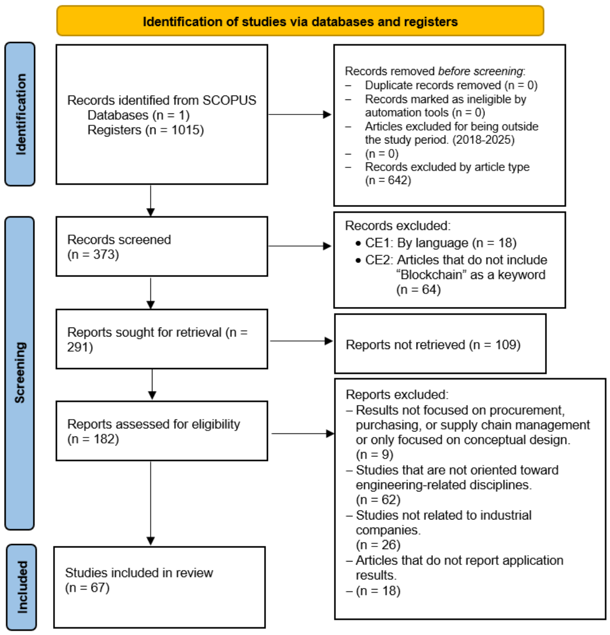

Fig. 1. PRISMA flow diagram applied to the systematic literature review.

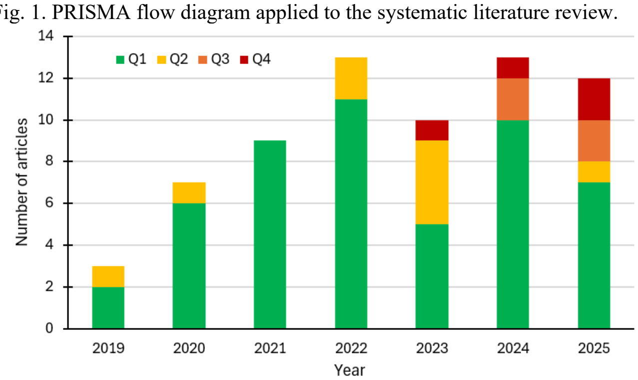

Fig. 2. Number of articles collected per year (2019–2025).

Based on the information extracted from the selected studies, the most relevant industries in the application of blockchain technology include the following:

- **Agriculture, agribusiness, and processed food:** The agricultural and agri-food sector accounts for the largest number of selected cases (33 studies), with a primary focus on traceability and food safety (Table 5 and Table 6). This predominance reflects the inherent complexity of these supply chains and their strong demand for transparency and trust mechanisms [19], [25]. A notable finding is the dominance of Ethereum as the most widely used blockchain platform, appearing in 82.3% of the analyzed studies. Ethereum stands out due to its extensive development ecosystem, the availability of tools such as Solidity, Truffle, and Ganache, and its compatibility with widely adopted standards, including ERC-1155 tokens and NFTs. In contrast, Hyperledger Fabric was employed in 29.4% of the cases, particularly in scenarios where privacy, access control, and consortium governance are critical, such as enterprise and regulated environments. Additionally, the use of Hyperledger Sawtooth was observed in 11.7% of the studies, along with supporting platforms such as IPFS (70.5%), which provide decentralized storage solutions for large data objects (e.g., certificates, genetic reports, and satellite imagery). Within this economic sector, the following positive impacts have been identified:

✓ Reduction in operational costs: up to 35% in monitoring systems, driven by the reduction of intermediaries and the automation of payment processes [25].
✓ Revenue improvement: a fruit production case reported a 34.6% increase in sales following the implementation of blockchain-based traceability [26].
✓ Coding efficiency and error reduction: the AgriBlockIoT framework achieved a 78% improvement in smart contract programming efficiency [27].
✓ Technical accuracy: agricultural price prediction models reached an accuracy of 95.3% [28].
✓ Social acceptance: high stakeholder adoption was observed across the value chain; for example, 74% of Colombian coffee sector actors supported the Ethereum-based SmartBeanFutures system [29].

TABLE 5. SUMMARY OF THE REVIEWED ARTICLES IN THE AGRICULTURE AND AGRIBUSINESS SECTORS.

Type of company	Identified problem	Blockchain architecture / Method	Year	Ref.
Agri-food industry: Agricultural supply chain	The soybean industry faces low traceability due to fragmented records, making it difficult to verify product origin and quality and to rapidly detect contamination.	The use of Ethereum-based blockchain with smart contracts improved soybean traceability by eliminating intermediaries and increased non-GMO export value by 15%, through immutable records linked to IPFS and managed by globally distributed nodes.	2019	[30]
Agri-food industry	43% of the evaluated smart contracts in agri-food supply chains exhibit vulnerabilities that compromise traceability, credibility, and food safety.	The proposed solution, developed using Ethereum, Solidity, IPFS, ReactJS, and NodeJS, reduced monitoring costs by 35% and achieved 100% traceability accuracy, demonstrating that blockchain enhances security and trust in agri-food supply chains.	2020	[25]
Agricultural industry: Supply chain	Current traceability systems in the food industry lack government regulation, private data protection, and suffer from performance bottlenecks.	Using Hyperledger Fabric, the proposed system doubled read performance, with the main layer achieving up to 50× higher throughput than the sublayer, enhancing food traceability through high privacy, operational efficiency, and decentralized regulatory control via smart contracts.	2020	[31]
Agricultural industry	Lack of transparency, data integrity, and operational efficiency.	The proposed approach employs multiple blockchain platforms, including Ethereum, Hyperledger Fabric, and Corda, along with decentralized storage systems such as IPFS to manage large-scale data efficiently.	2020	[17]
Agricultural industry	In China, fruits and vegetables account for 54.48% of agricultural production (995.03 million tons in 2019), yet traceability remains poor, leading to frequent food safety crises.	Implementing a blockchain-based system (Hyperledger Fabric) in a fruit company increased sales revenue by 34.6%, despite an 18.2% rise in costs, due to improved transparency, consumer trust, and efficient, encrypted traceability.	2021	[26]
Agri-food industry	The agri-food sector faces fraud and greenwashing in certifications; in the United States alone, misleading organic labels undermine consumer trust and food sustainability.	An Ethereum-based certification system using ERC-1155 tokens, accessible via mobile devices, was successfully implemented, preventing double-use fraud. Key impacts include improved traceability, enhanced origin transparency, and incentives for premium pricing across the supply chain.	2021	[32]
Agricultural industry	Lack of supply chain traceability	An Ethereum smart contract integrated with IPFS implements a payment-based model to prevent resource abuse, while a Hyperledger smart contract is used as a timing mechanism to control process execution.	2021	[33]
Agricultural industry	Lack of traceability and data privacy in supply chains, along with insecure agricultural price prediction from fragmented data,	The collaborative model achieved 95.3% accuracy in agricultural price prediction using genetic algorithms and the Hyperledger Sawtooth blockchain, ensuring transparency, ledger integrity, and secure stakeholder communication	2022	[28]

Type of company	Identified problem	Blockchain architecture / Method	Year	Ref.
	negatively impacts Pakistan's economy.	via smart contracts		
Agri-food industry	Food traceability in the European agri-food sector is inefficient and costly, with only 60% of companies digitally integrating key processes, limiting transparency and compliance.	The proposed system automatically generated Ethereum smart contracts for traceability, reducing human errors and development time, achieving a 78% improvement in coding efficiency and robust interoperability through the AgriBlockIoT framework and semantic web technologies.	2022	[27]
Fisheries industry (wild capture and aquaculture)	Approximately 30% of fish worldwide is mislabelled, undermining food safety and consumer trust. The fisheries sector lacks effective traceability and reliable data systems.	A blockchain-based traceability system (private Ethereum / Hyperledger Fabric) securely records each stage of the fisheries supply chain, achieving a 90% improvement in operational transparency and reducing fraud risks through smart contracts and IPFS-based distributed storage for large datasets (e.g., DNA reports and associated documents).	2022	[34]
Agricultural industry	In India, agri-food traceability suffers from limited trust, transparency, and data integration, harming food safety, productivity, and smallholder farmers' economic opportunities.	Ethereum and Hyperledger Sawtooth were analyzed; Hyperledger Sawtooth proved more efficient in terms of latency and CPU usage, while Ethereum was considered more reliable due to its wider adoption.	2023	[35]
Agriculture (Cocoa)	Lack of traceability, high certification costs, and low digital literacy among farmers.	The integration of IoT with blockchain, using platforms such as Ethereum and IPFS, enabled end-to-end tracking from cultivation to the consumer. This approach improved traceability, reduced food fraud, and increased trust between producers and consumers through secure and verifiable data.	2024	[36]
Agri-food industry: Supply chain, food production, and price management	Lack of transparency, supply chain inefficiencies, and dependence on intermediaries.	An Ethereum-based solution with smart contracts processed over 5,000 transactions efficiently through a decentralized DApp, strengthening transparency and operational security. Ethereum smart contracts were used to manage buy–sell transactions.	2024	[37]
Agricultural industry: Supply chain	Lack of traceability and transparency in the supply chain increases the risk of fraud and corruption.	Implementation with Ethereum, Solidity, Ganache, and Truffle enabled secure, accurate tracking, achieving high user satisfaction and improved real-time traceability.	2024	[38]
Agriculture (Coffee)	Lack of transparency and price volatility in coffee contracts in Colombia led to contract defaults affecting nearly one million bags in 2021, undermining sector sustainability.	An Ethereum-based system with smart contracts—using Ganache, Truffle, Hardhat, and MetaMask—was implemented. 74.07% of coffee sector stakeholders supported SmartBeanFutures, indicating improved traceability, elimination of intermediaries, and fair, sustainable pricing.	2024	[29]
Agriculture (Seed supply)	The seed supply chain is opaque and vulnerable to corruption and counterfeiting. In India, fraud has been reported where 100 kg are recorded as sold while only 50 kg are delivered to farmers.	SeedChain, implemented using Ethereum, NFTs, and IPFS, eliminated intermediaries and reduced fraud in seed distribution. The system enhanced traceability and security through smart contracts and enabled fairer transport bidding, improving process efficiency and transparency.	2024	[39]
Floral supply chain (floriculture)	The floral supply chain experiences losses due to lack of traceability and delays; the market is projected to reach USD 53.9 billion by 2032.	A system based on Ethereum, Solidity, Ganache, and IPFS automated smart contracts, reduced logistics costs, and increased traceability. In simulated scenarios, errors raised costs up to USD 19.37, highlighting that accurate sensors reduce false violations and optimize the entire supply chain.	2024	[40]
Agro-industrial food companies (edible oyster mushroom producer)	The Pleurotus ostreatus supply chain faces high spoilage, food safety risks, and poor traceability due to short shelf life, environmental sensitivity, fragmented data, and tampering vulnerability.	A permissioned Hyperledger Fabric multi-chain architecture with smart contracts, IoT (LoRa sensors), and hybrid on-chain/off-chain storage (IPFS). Deployed in a real farm, it reduced spoilage by 12.3%, increased inspection pass rate by 15.4%, and improved query efficiency and scalability versus single-chain systems.	2025	[41]
Agro-industrial food supply chain companies	While blockchain improves food traceability, existing solutions expose sensitive transactional and identity data and are vulnerable to future quantum attacks, creating a need for privacy-preserving and post-quantum-secure traceability systems.	A permissioned Hyperledger Fabric blockchain implemented via Hyperledger Composer, integrated with a modified ZK-STARK zero-knowledge proof algorithm coded in Python. Performance tests show FFT-based ZK-STARK achieves the best results (throughput 14.79 ops/s, verification time 0.029 s, proof size 0.512 KB), enhancing privacy with acceptable overhead.	2025	[42]
Halal meat industry supply chain	Existing halal meat traceability systems lack transparency and reliability, enabling fraud and mislabeling, reducing consumer trust, and complicating halal verification across supply chains.	A conceptual QR code-blockchain integrated architecture using a decentralized ledger to store immutable halal certification and traceability records, with QR codes as user interfaces for data access. Results indicate improved transparency, reduced traceability fraud, and enhanced consumer trust.	2025	[43]

For the processed food industry (13 studies), Hyperledger Fabric–based solutions dominate in corporate and enterprise settings, while Ethereum and Polygon prevail due to their lower transaction costs and open architectures (Table 6). The use of IoT, IPFS, and smart contracts is pervasive and has become a consolidated baseline architecture. Among the most representative outcomes are a 90% reduction in verification time, traceability improvements of up to 100%, and operational cost reductions exceeding 99% when migrating to platforms such as Polygon. Moreover, a paradigm shift toward more sustainable and consumer-centric systems is observed, including the integration of NFTs in premium products and the strengthening of the digital regulator's role. Overall, blockchain technology not only addresses past food safety scandals but is also emerging as a cornerstone for a safer, more trustworthy, and more efficient food industry.

TABLE 6. SUMMARY OF THE REVIEWED ARTICLES IN THE PROCESSED FOOD INDUSTRY.

Type of company	Identified problem	Blockchain architecture / Method	Year	Ref.
Food industry: Agricultural food supply chain	Long production cycles, many stakeholders, and manipulable centralized systems limit transparency, traceability, and trust in shared data.	Based on Hyperledger Fabric as a consortium blockchain, using smart contracts to manage transactions and IPFS for decentralized data storage. Experimental results showed a 90% reduction in verification time through a decentralized, tamper-resistant system.	2019	[44]
Food industry	The grain supply chain suffers from poor traceability, health risks, and data manipulation, contributing to food safety scandals in China that undermine public trust and regulatory efficiency.	A Hyperledger Fabric–based system with customized smart contracts and cloud storage improved traceability and reduced risks. Tests with companies in Shandong ensured security, interoperability, and fraud prevention across the five stages of the grain lifecycle.	2020	[45]
Food industry	The food industry faces adulterated meat scandals, poor traceability, and low consumer trust, affecting meat trade—particularly in retail and wholesale chains in countries such as China and Brazil.	A system based on Hyperledger Fabric, IoT, and an LSTM–GRU model optimized with genetic algorithms reduced RMSE to 512.21 and latency to 198 ms with 200 users, improving meat traceability and demand prediction.	2020	[46]
Food industry	Lack of transparency and traceability in India's food supply chain, along with resistance to blockchain adoption due to multiple challenges and barriers.	A blockchain-based approach (ISM framework) using a distributed ledger system, combined with IoT, was proposed to enhance traceability and transparency in agri-food supply chains.	2022	[47]
Food industry	The global food	The study validated a formal	2022	[48]

Type of company	Identified problem	Blockchain architecture / Method	Year	Ref.
	system faces severe traceability and safety failures, with millions of people affected by contaminated food. The agricultural sector requires efficient, reliable, and decentralized models.	blockchain–IoT model using VDM-SL, improving traceability, security, and automation; 100% of type and syntax errors were eliminated in evaluated processes using the VDM-SL Toolbox.		
Food industry	Failures in traceability and transparency of food products negatively impact public health. Integrating regulators into traceability systems is required to enable effective food recalls.	The TSPR system on Ethereum ensures transparent traceability and recalls; smart contracts executed correctly and reduced gas costs from USD 111.54 to USD 0.083 using Polygon EVM, enabling cost-effective adoption by manufacturers and regulators.	2022	[49]
Food supply chain, specifically focused on products certified under Protected Designation of Origin (PDO)	The agri-food sector faces limitations in transparency, trust, and efficiency. Traceability in multi-actor supply chains remains a critical challenge for ensuring safe and sustainable food.	An Ethereum-based solution using smart contracts manages traceability, complemented by a public key infrastructure (PKI) for identity and certificate validation. Certificates are stored off-chain via WalliD.	2023	[50]
Food industry	Lack of sustainability and transparency, along with the need to reduce food fraud.	A public blockchain–based solution using platforms such as Ethereum, complemented by smart contracts and associated technologies including IoT, RFID, and machine learning, was implemented to enhance traceability and sustainability across the food supply chain. According to a survey, 88% of consumers reported increased trust.	2023	[51]
Food industry (high-value products: truffles and caviar)	High-value food products (black truffles and caviar) are affected by counterfeiting; the lack of traceability and authenticity undermines consumer trust and introduces risks in the food supply chain.	An Ethereum-based solution employs composable NFTs for product traceability, integrates IPFS-based decentralized storage, and uses smart contracts to manage trade and ownership transfers.	2023	[52]
Food industry: Water bottling plant	The bottling industry lacks reliable traceability; centralized systems hinder verification of product origin and processing, as evidenced by the listeriosis outbreak in South Africa, which caused 216 deaths.	An experimental system based on a public blockchain and IPFS storage enabled real-time traceability in a bottling plant. Users accessed product histories via NFC, reducing large-scale recalls to only hundreds of units.	2024	[53]
Food industry: Fresh produce supply chain	Food systems face risks due to the lack of real-time traceability; consumers are unable to verify product origin and safety, undermining trust and increasing health risks.	The FoodChain system tracks products in real time using IoT and blockchain (Ethereum/IPFS), achieving 100% supply chain visibility and reducing fraud risks, thereby enhancing consumer trust in perishable agricultural products such as cabbage and kale.	2024	[54]
Food industry: Olive oil supply chain	Olive oil traceability is inefficient; the lack of real-time information and trust among stakeholders complicates quality management across the supply chain.	The proposed platform, based on Ethereum and IPFS, integrated IoT sensors to track strawberries in real time, improving transparency and reducing verification times by 65%, thereby enabling faster distribution and quality control decisions.	2024	[55]
Food industry: Agri-food industry – coffee supply chain	Fragmented and opaque coffee supply chains with limited end-to-end tracea-bility, manual and error-prone records, data tampering risks, insufficient real-time monitoring, and low consumer trust in ethical sourcing and origin claims.	A public Ethereum-based architecture with Solidity smart contracts deployed on the Sepolia testnet, integrating simulated IoT data (RFID, GPS, weight, environmental sensors). The system automates ownership transfers and traceability. Testing of 1000 transactions showed >95% gas fees < ETH 0.001, demonstrating cost-efficient and auditable supply chain tracking.	2025	[56]

▪ **Pharmaceutical industry:** A total of eight studies related to the pharmaceutical industry were analyzed (Table 7). Blockchain adoption contributes to combating the proliferation of counterfeit products and improving drug authenticity, with a strong focus on patient safety [11], [57]. However, one of the main challenges identified is the need for effective collaboration among supply chain stakeholders, including manufacturers, major and minor distributors, and end customers [1]. Among the most relevant findings from blockchain implementation are the following:

- ✓ Latency reduction of up to 38% (LIC-IGL).
- ✓ 70% fewer record errors (MSMAChain).
- ✓ Up to 100% accuracy in authenticity and location verification tests (Vaccine Tracker).
- ✓ Zero insertion of counterfeit drugs in simulated trials (DSCMR).

The integration of blockchain with sensors and distributed storage not only enhances traceability and security but also strengthens consumer trust and enables the automation of payments and environmental monitoring.

TABLE 7. SUMMARY OF THE REVIEWED ARTICLES IN THE PHARMACEUTICAL INDUSTRY.

Type of company	Identified problem	Blockchain architecture / Method	Year	Ref.
Pharmaceutical industry	The pharmaceutical industry loses approximately USD 200 billion annually due to counterfeit medicines; in developing countries, 1 in 10 medicines is counterfeit.	The DSCMR system, using Hyperledger Fabric with LightGBM and N-gram models, tracks and recommends medicines, achieving 100% prevention of counterfeit insertion and enhancing traceability and security.	2020	[10]
Pharmaceutical industry	The pharmaceutical industry faces fraud and counterfeit products. Current systems fail to ensure traceability and security, undermining authenticity and efficiency across multi-actor supply chains.	The LIC-IGL method, implemented using Python and machine learning, enhanced blockchain-based product authentication, reducing latency by 38% and false positive rates by 25% compared to prior approaches, using Support Vector Machines and Gaussian interpolation.	2021	[58]
Pharmaceutical industry	Conventional pharmaceutical traceability systems suffer from low transparency and fragmented data, limiting contamination detection and undermining consumer trust.	The model, based on Hyperledger Fabric and MongoDB, enables real-time traceability, identifies contamination points, and reduces recording errors by 70%, with MSMAChain supporting decentralized tracking and Ethereum enabling automated records.	2023	[59]
Pharmaceutical industry: Vaccine distribution and administration	Lack of transparency and traceability in vaccination record tracking, posing risks of counterfeit vaccines and inefficient supply chain management. QR code scanning and validation were used to ensure vaccine authenticity.	The Vaccine Tracker system, based on Ethereum and smart contracts, enabled real-time tracking of vaccine batches via QR codes and GPS, achieving 100% accuracy in authenticity and location validation during testing. Cryptographic algorithms were applied to QR codes, and blockchain supported vaccine administration processes.	2024	[60]
Pharmaceutical industry (supply chain, product management and secure payments)	Approximately 30% of medicines in developing countries are counterfeit, harming public health and causing major economic losses, along with challenges in drug quality, transport monitoring, and insecure payment processes.	An Ethereum-based solution using PoS, IPFS, smart contracts, and IoT enhances drug traceability, enables real-time quality monitoring, and supports secure automated payments.	2024	[61]
Pharmaceutical industrial supply chain	Persistent drug counterfeiting, limited traceability, and inefficiencies in transaction management	A permissioned Hyperledger Fabric blockchain using the proposed Blockchain-enabled Secured Vertical Aggregation Algorithm (BSVA) with chaincode-based	2025	[4]

Type of company	Identified problem	Blockchain architecture / Method	Year	Ref.
	within pharmaceutical supply chains, driven by centralized control, poor interoperability, and lack of real-time, trustworthy verification mechanisms.	smart contracts, certificate authority, peers, and ordering services. Experimental results show improved traceability, reduced latency, and scalability, achieving up to 250 TPS, lower transaction processing time, and superior performance over existing drug traceability methods.		
Pharmaceutical and healthcare industrial supply chain	Centralized drug traceability systems suffer from poor data integrity, vulnerability to counterfeit drugs, limited trust, and insufficient resilience against malicious nodes in distributed medical supply chains.	A permissioned Hyperledger Fabric blockchain with the BSVA algorithm improves drug traceability, reduces latency, scales to 250 TPS, and outperforms existing methods.	2025	[62]
Pharmaceutical and healthcare supply chain	High prevalence of counterfeit medical supplies and inefficiencies in last-mile delivery, driven by limited traceability, centralized control, lack of real-time monitoring, and insufficient trust among stakeholders in urban healthcare supply chains.	A permissioned Hyperledger Sawtooth blockchain using PoET consensus, integrated with IoT sensors, RFID, and ride-sharing platforms. Implemented with Python SDK, REST APIs, and off-chain storage. Experiments achieved up to 2300 TPS, counterfeit detection rates of 97–100%, average latency 2.3–3.1 s, and delivery efficiency improvements of 10–15%.	2025	[63]

▪ **Automotive and manufacturing industries:** These studies primarily focus on component traceability and record reliability, contributing to enhanced safety and reduced risks of product failures. Among the 12 identified studies (Table 8), several common challenges emerge across heavy manufacturing, automotive, and electronics industries, including:

– Counterfeiting and lack of traceability: the presence of counterfeit parts, electronic components, or the insertion of recycled or non-certified parts.

– Operational inefficiency and lack of transparency: reliance on manual processes that may lead to conflicts, delays, or human errors.

– Insecure certification and supplier reputation: limited mechanisms to reliably verify supplier credentials and compliance histories.

The automotive industry, one of the largest sectors within manufacturing, handles an enormous volume of data that continues to grow with increasing equipment complexity (e.g., onboard computers, electronic devices). Several Industry 4.0 technologies, such as the Internet of Things (IoT) and cyber–physical systems (CPS), have been integrated into automotive supply chains. In this context, blockchain technology provides critical support for information management and governance [2], [49]. An illustrative example is TruCert, a blockchain-based system that enhances operational transparency and enables end-to-end traceability of automotive components by recording original manufacturer data, thereby ensuring secure and reliable certification [22]. The most relevant impacts identified include:

- ✓ Cost reduction, particularly in certification processes; additionally, autonomous manufacturing contributes to lowering hidden operational costs.
- ✓ Energy reduction through the deployment of autonomous vehicles and IoT integration.
- ✓ Reduction of human errors and operational failures: several reviewed studies report efficiencies exceeding 80% and zero failures in traceability validation processes.
- ✓ Network performance: systems such as TrustChain achieve up to 40 transactions per second, demonstrating suitability for real-world industrial operations.

TABLE 8. SUMMARY OF THE REVIEWED ARTICLES IN THE MANUFACTURING, AUTOMOTIVE, AND RELATED INDUSTRIES.

Type of company	Identified problem	Blockchain architecture / Method	Year	Ref.
Electronics industry and integrated circuit (IC) supply chain	More than 80% of counterfeit integrated circuits (ICs) are recycled or repackaged, impacting the defense and automotive sectors and causing economic losses and critical risks.	The proposed solution, based on blockchain and Physical Unclonable Functions (PUFs), tracks IC ownership throughout the entire lifecycle at a total cost of USD 0.23 per chip, using Ethereum smart contracts.	2019	[64]
Additive manufacturing (AM) industry	In additive manufacturing, up to 90% of material can be wasted in conventional metal part production, negatively affecting traceability and intellectual property protection.	The use of Ethereum smart contracts reduced 3D-printed product certification costs to less than USD 0.15 per transaction, ensuring reliable traceability through IPFS and minimizing human intervention.	2020	[65]
Energy and technology industry	The absence of decentralized energy markets limits efficiency and privacy in peer-to-peer (P2P) energy trading, where intermediary costs are estimated to account for up to 30%.	The DeTrade platform reduced solution error to 2.1% and computation time to 58 minutes using the DACO algorithm, integrating smart contracts on Hyperledger Burrow for real-time settlement. This approach increased transaction efficiency without compromising privacy and employed tokenization backed by a real currency (EuroTokens).	2021	[66]
Automotive industry	Approximately 50% of vehicle recalls in the United States are caused by failures in critical components, negatively affecting the reputation and financial performance of the automotive sector.	The use of Ethereum smart contracts enabled transparent and traceable recall management, reducing costs to USD 5.4 per process. IPFS was integrated for report storage, improving efficiency and security across the automotive supply chain.	2021	[67]
Autonomous vehicle design and manufacturing	In the autonomous vehicle industry, excessive energy consumption and hidden costs were identified, with energy waste of 12.48% and financial losses of 11.58%.	An Ethereum smart contract solution reduced energy waste by 12.48% and hidden costs by 11.58% using the AD model with the MI indicator, supported by machine learning (SVML, K-means).	2022	[15]
Construction and project management	Conflicts and cost overruns in the construction industry arise from complex supply chains, inefficient manual tracking, and a lack of transparency among interdependent contractual parties.	An Ethereum-based consortium solution using smart contracts on the Goerli test network and Proof of Authority (PoA) consensus enhanced transparency and trust. QR codes and a Firebase-integrated application automated contract-compliant payments, reducing conflicts and ensuring immutable transaction records.	2022	[68]
Manufacturing industry	The manufacturing sector, with over 628,000 companies in the United States and 83% of global production in Asia, faces risks of counterfeiting and insecurity in critical components.	A blockchain-based system using Quorum and IPFS tracked and verified modules and ICs with an investment of only 0.002094 Ether, leveraging DApps and smart contracts to enhance traceability while reducing costs compared to public blockchains.	2022	[69]
Manufacturing industry	During the COVID-19 pandemic, the healthcare sector faced critical PPE shortages, affecting workers due to poor traceability; 50,000 kits were rejected in India alone.	An Ethereum-based blockchain system with decentralized storage achieved end-to-end traceability. Validation showed transaction costs below USD 1.7 and zero operational failures, improving security and transparency in PPE supply chains during health emergencies.	2022	[8]
Manufacturing and food industries	In manufacturing supply chains, low reliability and traceability persist, while existing reputation systems are inefficient for decentralized blockchain–IoT operations.	TrustChain, implemented on Hyperledger Fabric, enables automated and reliable reputation computation through IoT and smart contracts, achieving performance close to 40 transactions per second, with slightly higher latency than the baseline system but without compromising security.	2023	[70]
Aerospace, automotive, medical, and heavy	The automotive industry faces critical traceability challenges in complex assemblies involving	An Ethereum-based solution implementing smart contracts integrates the Bill of Assembly (BOA) framework. The BOA smart	2023	[71]

Type of company	Identified problem	Blockchain architecture / Method	Year	Ref.
machinery industries	thousands of components, increasing costs, human errors, and safety risks.	contract framework achieved 81.7% assembly efficiency by automating verification and traceability using blockchain technology, enabling secure and accurate documentation and reducing human errors.		
Automotive industry	In the automotive industry, the lack of traceability beyond tier-1 suppliers limits the certification of critical components, adversely affecting vehicle safety.	Hyperledger Besu (a permissioned Ethereum-based blockchain) was used to implement the TruCert system, which reduced the average certification cost to USD 1.23 per transaction and enabled near–real-time traceability, enhancing trust in autonomous components through digital certification and IoT sensor data.	2023	[22]
Industrial EV battery supply chain actors	Lack of decentralized, tamper-proof, and interoperable digital battery passports capable of ensuring full lifecycle traceability and quantifiable sustainability assessment across EV battery supply chains.	An Ethereum-based public blockchain using composable NFTs and a hybrid on-chain/off-chain architecture (IPFS, IPNS). Smart contracts in Solidity manage lifecycle tracking and KPI updates. Simulations show transparent traceability, automated sustainability scoring (10 KPIs), and feasible costs.	2025	[72]

▪ **Healthcare sector:** Blockchain technology addresses challenges related to transparency and authenticity in medical devices and pharmaceutical distribution. During the COVID-19 pandemic, ensuring transparent and trustworthy supply chains for medicines and personal protective equipment became critically important. A total of four representative studies in this domain were collected and are summarized in Table 9.

TABLE 9. SUMMARY OF THE REVIEWED ARTICLES IN THE HEALTHCARE SECTOR.

Type of company	Identified problem	Blockchain architecture / Method	Year	Ref.
Healthcare industry (Healthcare supply chain)	Up to 30% of medicines sold in developing countries are counterfeit, causing annual losses of USD 200 billion in the global pharmaceutical industry.	The Ethereum-based system with smart contracts enabled secure and decentralized traceability, reducing manipulation vulnerabilities. Experimental results showed low operational costs (below USD 1 per transaction) and high security, using IPFS for storage and QR-code scanning for verification.	2021	[6]
Healthcare supply chain (HCSC)	The healthcare sector wastes USD 25.7 billion annually due to supply chain inefficiencies. Contracting with Group Purchasing Organizations (GPOs) is slow, costly, and lacks transparency.	An Ethereum smart contract–based solution reduced contracting times, automated payments and traceability, and achieved transaction costs below USD 1.20 per function. The system was implemented and validated using the Remix IDE, leveraging smart contracts and decentralized storage.	2021	[73]
Healthcare industry	During the pandemic, 87% of nurses in the United States reused PPE, and only one-third of manufacturers responded to the FDA, revealing a fragmented healthcare supply chain lacking traceability, transparency, and ownership control.	The implementation of Ethereum smart contracts and NFTs (non-fungible tokens) enabled product traceability and authenticity verification. The system successfully validated deliveries, resolved disputes, and automatically executed payments. The developed software includes a DApp integrated with IPFS and demonstrated robustness against security vulnerabilities.	2022	[74]
Healthcare industry	The high cost of new medical devices—projected to reach USD 964.9 billion by 2030—drives the adoption of refurbished equipment, particularly in low- and middle-income countries.	An NFT-based system digitally certified refurbished devices, reducing counterfeiting risks and increasing buyer trust. In the United States, potential savings of up to USD 2.28 billion and 12 million pounds of waste avoided annually were estimated, using Ethereum and IPFS.	2023	[75]

The use of blockchain technology in the healthcare sector enables the resolution of critical structural challenges, such as drug counterfeiting, inefficiencies in hospital procurement, traceability of medical equipment during public health emergencies, and the validation of refurbished medical devices. Ref. [9] proposes a blockchain-based system for tracking perishable products using GPS-based tracking, IoT sensors, and verification at multiple checkpoints, complemented by digital identification technologies such as QR codes and RFID. Similarly, Ref. [21] applies Polygon (a blockchain strategy) to the cannabis oil supply chain, a regulated product that requires strict validation and certification. The flexibility offered by hybrid on-chain and off-chain data storage reduces blockchain load while ensuring the availability of critical traceability information. In parallel, the healthcare domain generates vast volumes of data related to electronic health records, medical device supply chains, remote patient monitoring, insurance claims, and the management of personal health data (PHD), among other applications [57].

▪ **Other sectors:** Blockchain technology has also been adopted in the textile [76], electronics [15], and logistics and transportation sectors [77]. Across all cases, component and product traceability emerges as a critical requirement, consistent with the previously discussed industries. In addition, smart contracts provide an effective mechanism for enforcing compliance with predefined criteria without the intervention of intermediaries, thereby reducing risks associated with corruption or manipulation [11], [50]. In e-commerce, Ethereum-based solutions reduced RFID computation times by approximately 50%. In global logistics, the UbiMS platform eliminated intermediaries, optimizing the supply chain from manufacturing to the end consumer. For the consumer goods sector, the integration of Ethereum and IPFS enabled verifiable sustainability assessments, achieving an average index score of 3.5/5. Finally, in food transportation, the combined use of artificial intelligence and blockchain reduced fraud by 80% and shortened logistics times by 25%.

TABLE 10. SUMMARY OF THE REVIEWED ARTICLES IN OTHER ECONOMIC SECTORS.

Type of company	Identified problem	Blockchain architecture / Method	Year	Ref.
Textile industry	The textile industry faces economic losses due to counterfeiting and limited traceability, accounting for 22% of product recall alerts in Europe (2010–2017).	The proposed blockchain-based system enabled end-to-end tracking of organic cotton, reducing counterfeiting risks and improving traceability through mass-balance validation and custom smart contracts.	2021	[78]
Commercial industry	Lack of transparency in manufacturing and distribution processes enables the proliferation of counterfeit products. Global trade in counterfeit goods reached USD 4.5 trillion in 2019.	The implementation of a Hyperledger Fabric–based system achieved secure traceability and anti-counterfeiting for luxury products, reaching a 99% success rate and an average latency of 4 seconds in performance tests, thereby strengthening transparency.	2022	[20]
Industry and e-commerce	Security and privacy issues related to RFID tag duplication lead to important losses; up to USD 30 billion are lost annually due to supply chain theft, particularly during wholesale product transfers.	The proposed solution halved computation time compared to previous protocols and significantly reduced messaging overhead, using Ethereum as the blockchain platform to enable efficient and secure ownership transfer in large-scale logistics chains.	2022	[79]
Multiple industries	The logistics industry faces economic losses and lack of trust among stakeholders due to poor traceability; 10% of documents contain errors, increasing legal disputes.	The UbiMS system, based on blockchain and smart contracts, enabled end-to-end product tracking from factory to consumer, eliminating intermediaries and reducing costs and lead times. It uses Ethereum software and IoT technologies to achieve transparent traceability and financial automation via digital tokens.	2023	[80]
Consumer products: Supply chain and sustainability in consumables, textiles, and plastic waste	By 2025, 2.2 billion tons of municipal solid waste and 71% non-recyclable plastic packaging will intensify pollution in a consumer products sector lacking reliable sustainability systems.	A blockchain-based solution implemented on Ethereum and IPFS enabled transparent computation of a Sustainability Index Score (SIS), averaging 3.5 out of 5. The system mitigated greenwashing, strengthened traceability with verifiable data via smart contracts.	2024	[76]

Type of company	Identified problem	Blockchain architecture / Method	Year	Ref.
Food logistics and transportation	Logistics operations face high vulnerability to fraud (80% more incidents), delivery delays (up to 24 hours), and high administrative costs, affecting global transportation and distribution.	The implementation of blockchain combined with CNN and ACO reduced delivery time by 25%, fraud incidents by 80%, and administrative costs by 25%. Ethereum smart contracts were used to record transactions, optimizing traceability, data security, and operational efficiency.	2024	[77]
Jewelry supply chain	Lack of transparency, provenance, and authenticity in the jewelry supply chain; high risk of fraud, counterfeiting, material mixing, and limited consumer trust.	The study implements a public Ethereum-based blockchain with a hybrid on-chain/off-chain architecture, using smart contracts (Solidity) and IPFS for scalable certificate storage. The system improves traceability, authenticity, and transparency, demonstrating low transaction costs (1.25×10^{-5}–2.73×10^{-5} ETH).	2025	[5]
Industrial and logistics companies	Traditional cross-border trade processes suffer from excessive documentation, lack of transparency, high transaction costs, delays, and limited trust among stakeholders, creating inefficiencies in procurement, customs clearance, and logistics coordination.	A permissioned blockchain architecture integrated with smart contracts to digitize trade documents and automate cross-border transactions. The system improves transparency, data integrity, and coordination among stakeholders, demonstrating reduced processing time, lower administrative costs, and enhanced trust compared to conventional trade workflows.	2025	[81]
Leather industry supply chain	Lack of trusted traceability and sustainability certification in the leather supply chain due to fragmented data, limited transparency, greenwashing risks, and difficulty verifying environmental and animal-welfare compliance.	A permissioned blockchain architecture integrating Ethereum smart contracts, off-chain storage, and sustainability certification data. The system records lifecycle events and certifications, improving traceability, data integrity, and trust. Experimental evaluation shows secure transactions, low operational costs, and effective verification of sustainability claims across leather products.	2025	[82]
Plastic industry: plastic resin distribution company	High import logistics costs, limited real-time visibility of container arrivals, inefficient port storage management, and low levels of direct delivery from ports to customers, reducing operational efficiency and sustainability.	A blockchain-based container tracking system integrated with IoT and cloud platforms enabled real-time ETA/ETD monitoring, reducing port storage costs by ~21% and increasing direct deliveries, improving efficiency and sustainability.	2025	[83]

Based on the reviewed studies, there are patterns in blockchain adoption across industries. As shown in Fig. 3, agriculture, processed food, and pharmaceuticals dominate due to their high traceability, security, and transparency needs and product sensitivity. In contrast, textiles, plastics, and electronics show lower adoption, while Fig. 4 highlights the diverse application areas across sectors. Relevant factors to consider include:

- Traceability: Predominantly applied in sectors such as food, agriculture, and pharmaceuticals [21], [34]
- Security and authenticity: Essential in industries such as pharmaceuticals and manufacturing, where data protection and fraud prevention are critical [6], [10].
- Operational efficiency: Particularly prominent in sectors such as logistics and automotive, where blockchain optimizes processes and reduces costs [2], [22].
- Technological integration: Compatibility with smart contracts, IoT, and decentralized storage solutions (IPFS) expands the scope of blockchain applications [9], [12], [28]
- Adoption and challenges: Despite clear benefits, barriers remain, including implementation costs [59], scalability issues, and a lack of interoperability among blockchain platforms [19].

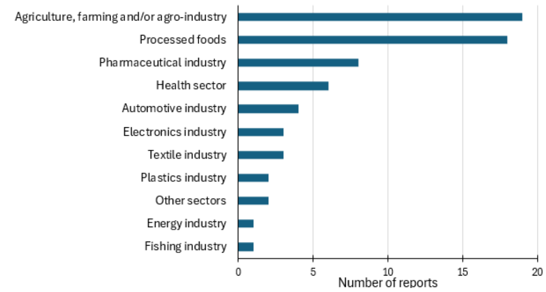

Fig. 3. Number of reported articles addressing the use of blockchain.

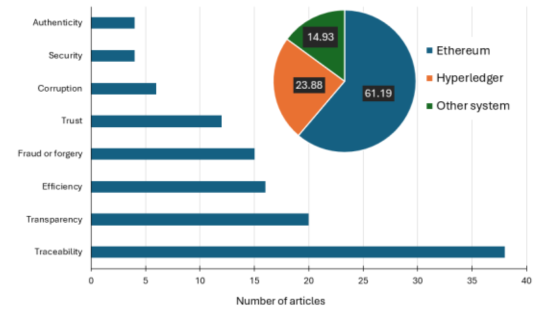

Fig. 4: Main challenges of blockchain technology. The inner section indicates the most used blockchain platforms.

Figure 4 shows that Ethereum is the dominant blockchain platform (61.19%), followed by Hyperledger (23.88%), with 14.93% using other systems. Ethereum's versatility, smart contract support, and suitability for multi-intermediary supply chains explain its widespread adoption. [16]. In contrast, Hyperledger focuses on enterprise-grade, private, and permissioned solutions [84], making it particularly suitable for industrial applications involving critical and sensitive data, such as pharmaceuticals, manufacturing, and energy. The remaining 14%, represented by other systems, suggests the presence of more specialized or emerging platforms. A recent trend is the adoption of hybrid architectures that combine decentralized off-chain storage for large datasets with on-chain blockchain storage for critical information [55]. Case studies from the agro-industrial sector in Peru [36] and Bangladesh [37] highlight opportunities to enhance blockchain implementation in supply chains, facilitating improved tracking and product traceability.

An end-to-end architecture of a blockchain-based traceability system applied to industrial supply chains is presented in Fig. 5. The model integrates data from goods production (data processing, quality control, regulatory approvals), goods specifications and logistics as structured inputs into a blockchain environment, addressing key concerns such as limited traceability, fraud, data manipulation, and lack of trust among stakeholders. Transactional, smart contract and event data are recorded through on-chain and off-chain mechanisms [26], [44], enabling secure data storage, visualization, and lifecycle tracking. As a result, the system supports complete product history [6], proof of authenticity [55], ownership transfer verification [64], and automated compliance and payment processes. Overall, the figure highlights how blockchain transforms fragmented and centralized supply chain information into a transparent, auditable, and trustworthy digital infrastructure.

Although the reviewed literature consistently reports improvements in traceability, transparency, and automation, the findings of this study reveal a structural gap between conceptual promise and practical deployment. Most blockchain implementations identified in the manuscript remain confined to pilot studies, simulations, or single-case environments, with limited evidence of long-term scalability, economic viability, or cross-organizational integration. Moreover, the predominance of platform-centric analyses

(Ethereum and Hyperledger Fabric) tends to emphasize technical capabilities while underexploring governance models, organizational readiness, and regulatory alignment, which are decisive factors in industrial procurement contexts. The lack of standardized performance metrics [76] further weakens comparative assessment across studies [14], making claims of efficiency gains or cost reductions difficult to generalize. This suggests that blockchain should not be framed as a universal solution but rather as a conditional infrastructure whose value depends on process criticality, data sensitivity, and ecosystem maturity. For industrial companies, the evidence supports targeted adoption focused on high-risk or high-value procurement processes, rather than full supply chain digitization. At the policy level, the absence of interoperable standards and enforceable smart contract regulations limits systemic impact, reinforcing the need for coordinated public frameworks that align digital innovation with industrial resilience and institutional trust [36]. Without such alignment, blockchain adoption risks remaining fragmented and experimental, failing to deliver the transformative outcomes often claimed in literature. Finally, all the benefits of blockchain are constrained by technical limitations, primary low scalability of public networks, volatile transaction costs and limited interoperability between platforms [19]. In SME companies, these limitations are amplified by restricted financial resources and limited technical capacity [17]. In Latin American contexts, additional barriers such as limited digital infrastructure, regulatory uncertainty and low levels of technological readiness restrict further adoption [18]. Therefore, the adoption of blockchain is still limited by many factors and more maturity and consolidation are required to enable wider applications.

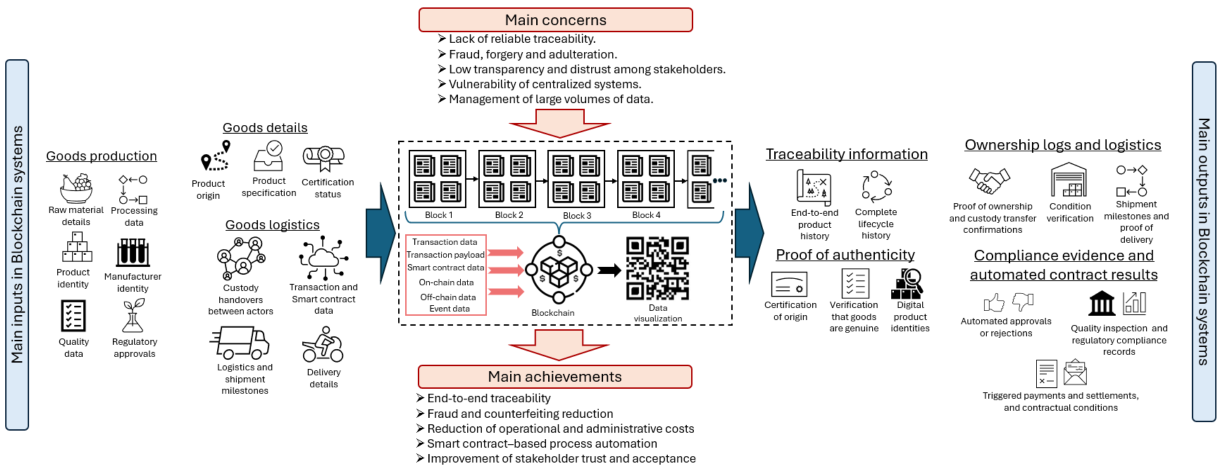

Fig. 5. Blockchain-based framework, showing main inputs and outputs, along with key concerns and achieved benefits.

IV. CONCLUSIONS

In conclusion, the findings of this study demonstrate that blockchain technology has a powerful impact on improving supply chain management. Its application enables companies to reduce costs, enhance security, and optimize process efficiency; and consequently, improves organizational performance and competitiveness. Among the industries showing the highest levels of blockchain adoption are the food, agriculture, and agrifood sectors, where traceability, security, and transparency are critical due to the nature and sensitivity of the products involved. Blockchain technology has become a fundamental resource for monitoring and verifying each stage of supply chain processes, from production to final delivery, ensuring product authenticity and preventing fraud and adulteration, particularly in the food and pharmaceutical sectors. Moreover, it fosters trust among producers, distributors, and consumers through immutable and verifiable records. Nevertheless, important challenges persist, including scalability limitations, interoperability issues, and high implementation costs, which hinder widespread adoption; especially among small and medium-sized enterprises (SMEs). Future research should focus on empirically validating these findings (indicators and verification milestone) and developing practical, scalable solutions tailored to emerging sectors, such as SMEs.

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