economies

Article

Exploratory Analysis of Blockchain Platforms in Supply Chain Management

Éva Réka Keresztes [1,*], Ildikó Kovács [2], Annamária Horváth [3] and Krisztina Zimányi [4]

1 Department of Methodology for Social Studies, Faculty of International Management and Business, Budapest Business School, University of Applied Sciences, 1165 Budapest, Hungary
2 Department of Marketing, Faculty of International Management and Business, Budapest Business School, University of Applied Sciences, 1165 Budapest, Hungary
3 Department of International Trade and Logistics, Faculty of International Management and Business, Budapest Business School, University of Applied Sciences, 1165 Budapest, Hungary
4 Dennis Gabor College, 1119 Budapest, Hungary
* Correspondence: keresztes.eva@uni-bge.hu

Abstract: The spread of blockchain technology is gaining ground worldwide, including in the supply chain and logistics sector. Its proliferation is expected to transform supply chains. Academic research is needed to investigate the reasons for and barriers to adoption. The objective of this study is to explore the blockchain (BC) platform and its inputs as technological solutions. In addition, the application of blockchain technology in managing supply chain (SC) business processes like shipment tracking, authenticity, and identification is also a focus of research. This research was carried out in three ways to explore the issue. Expert interviews were used to develop a research framework for the comparative analysis of BC platforms to find out the benefits and the barriers of blockchain adoption. In association with the diffusion of the technology, a qualitative comparative analysis was applied to benchmark blockchain platform providers. We analysed the blockchain-supply chain market by component, provider, type, and the conditions of usage. As part of this research, the Forbes TOP 50 companies were analysed by business area, country of origin, application area, and benefits in order to see in which area they applied blockchain technology and what improvements they have achieved. The results revealed that blockchain use in supply chains of selected industries has outstanding benefits of transparency, trustworthiness, traceability, and cost efficiencies which give businesses an advantage in terms of implementation costs, technology needs, human resources, legal environments, volatile costs, and security. In the supply chain, Hyperledger Fabric and Ethereum are the most widely used blockchain platforms. For practical implication, the application and benefits of BC in SC were analysed, and the results indicate the traceability, sustainability-related, cost, and time-saving benefits.

Keywords: blockchain; supply chain management; expert qualitative framework; qualitative comparative analysis

check for updates

Citation: Keresztes, Éva Réka, Ildikó Kovács, Annamária Horváth, and Krisztina Zimányi. 2022. Exploratory Analysis of Blockchain Platforms in Supply Chain Management. *Economies* 10: 206. https://doi.org/10.3390/economies10090206

Academic Editor: Andrea Appolloni

Received: 12 June 2022
Accepted: 20 August 2022
Published: 24 August 2022

1. Introduction

Today's economy is accelerating toward hyperconnectivity, and blockchain is the enabling technology. In a hyperconnected economy, organizational silos are evolving into ecologies of the hyperconnected enterprise, sharing economy, and distributed data (HFS Research 2020). Technologies related to Industry 4.0 can facilitate the emergence of new business models in the field of production, e-commerce, logistics, and supply chains. The application of blockchain technology is an important and increasingly used technology for the digitalisation of processes, including supply and logistics. Driven by technology solutions, the global supply chain management market is predicted to have high growth potential in the forthcoming years. Supply chain companies encounter various challenges like supply chain disruptions and shortages, customer demand for faster response times, forecasting, and the synchronization of the supply chain. There are several disruptive strategic and technological options to address these problems, including cloud computing and data storage, sensors and automatic identification, inventory and network optimization tools, robotics, and blockchain. Blockchain technology is a cutting-edge application that utilizes distributed ledger technology and provides authentic information, which generates mutual trust between multiple actors in the supply chain. Transactions are made irrevocable, which increases accuracy, and services based on the blockchain can lead to a smarter and more efficient supply chain. In a blockchain, blocks are linked together, and contain the transactions and the timestamp as well as the hash of the previous block, creating an unbreakable chain.

Digital, decentralized, and distributed ledgers such as blockchains create permanent, tamper-proof records of transactions that are logged and added chronologically (Treiblmaier 2018). Distributed ledger technology currently has a unique feature—nlike central database technologies—as it cannot be switched off, destroyed, or altered. It stores and digitises the entire process of receipts/transactions/times generated in logistics and supply chain processes on a global scale. Blockchain technology provides real-time data to inform supply chain stakeholders on the authenticity of materials, purchase orders, inventory levels, shipment receipt date, data, and related invoices.

For more than thirty years, relational database technology has played a crucial role in the lives of companies. However, cloud computing, the management of large amounts of unstructured data, and web applications are based on non-relational databases using a more flexible data model. Blockchain innovation technology is a distributed database system that allows firms and organisations to create and track transactions across a network in a near-instantaneous manner, giving them a competitive advantage (Laudon and Laudon 2020). In 2021, the blockchain market size was valued at $4.9 billion and projected to reach $67.4 billion by 2026, at a Compound Annual Growth Rate (CAGR) of 68.4% during the four-year forecast period (Markets and Markets 2021). Blockchain technologies are predicted to spread in different industries. The major driving factors contributing to the high growth rate of the blockchain market include increasing venture capital fundings and investment in blockchain technology; extensive use of blockchain solutions in banking and cybersecurity; high adoption of blockchain solutions for payment, smart contracts, and digital identities; and rising government initiatives. According to a prediction of the European Blockchain Observatory and Forum, 2022 Trend Report, the retail and E-commerce segment will grow at the highest CAGR (EU Blockchain 2022).

Due to the COVID-19 pandemic, dependency on online businesses has increased significantly worldwide. Banking, Financial Services and Insurance (BFSI), healthcare and life sciences, manufacturing, retail, transport and logistics, among others, are leveraging the internet to provide necessary services to the supply chains and consumers. Vendors have experienced a highly increased demand for a blockchain market (Markets and Markets 2021).

In the near future, blockchain technology in supply chains will have a great potential in various application areas, such as finance, cybersecurity, artificial intelligence (AI), and Internet of Things (IoT). According to Rejeb et al. (2019), the combination of IoT and blockchain technology can enhance B2B trust, value chain transparency, thereby improving the efficiency and effectiveness of business processes.

The aim of this research project is to present new trends and contexts in the field of economics–logistics by exploring the role of blockchain-based platforms in the supply chain. It also strives to map the drivers and barriers based on expert interviews, former academic research, and the comparative analysis of blockchain platforms.

2. Literature Review

This section is arranged as follows: the review of the literature discussing blockchain in supply chain management, the technology behind it, the business benefits of it, and the barriers to blockchain adoption.

2.1. Blockchain in Supply Chain Management

In supply chain-related fields, the interest in blockchain as a new technology is significant in both business and academic spheres. Its relevance to supply chain management includes providing the reliability and security of information flow, the management of complex and fragmented supply chain operations, product safety, credibility and legality issues along the supply chain stakeholder network including suppliers of upstream activities such as initial suppliers, materials suppliers, component makers, subassembly providers, and manufacturers, in addition to customers of downstream activities such as wholesalers, retailers, and end users (Bateman and Bonanni 2019; Cole et al. 2019; Dujak and Sajter 2019; Ganeriwalla et al. 2018; Horváth 2020; Seebacher and Schüritz 2017; Sheel and Nath 2019; Wang et al. 2019; Zelbst et al. 2020).

In academia, there is a growing awareness of researching blockchain integration in supply chain management (SCM) (Queiroz et al. 2020; Rodrigues et al. 2021). Treiblmaier (2018) examined the impact of blockchain on supply chain management by using a research framework based on principal-agent theory (PAT), transaction cost analysis (TCA), and resource-based view (RBV). He concluded that blockchain technology has the potential to significantly change SCM, given the huge investments by industry. Another study by Gurtu and Johny (2019) discusses the potential of blockchain technology in SCM, including the reduction of costs, the risk of banking transactions, and increased sustainability. In their paper, Hald and Kinra (2019) aim to investigate the facilitating and limiting aspects of blockchain technology (BCT) in managerial work practices of supply chain performance. They discussed four enabling and three constraining identities and found that its ability to provide data immutability makes traceability a core innovation of the technology. They concluded that blockchain is primarily seen as a way to take advantage of existing supply chain capabilities and resources. According to Qian and Papadonikolaki (2021), the application of BCT increases trust in construction supply chains. Blockchain technology has been described as a promising tool for improving knowledge sharing (KS) (Philsoophian et al. 2022) and information exchanging practices (Xue et al. 2021) in supply chains, thereby reducing information asymmetry. In their work, (Xu et al. 2021) focus on the potentially conflicting security and transparency features of using blockchain in SCM. As stated by Bag et al. (2021), there are barriers to the adoption of blockchain technology in green supply chain management (GSCM).

Results show that the current efforts of implementing BCT in SCM are focused on improving operational level capabilities rather than strategic level capabilities (Nandi et al. 2020). According to Tan et al. (2022), visibility of the blockchain can foster supply chain performance (SCP) and supply chain integration (SCI). The purpose of another research paper by Kamran et al. (2021) is to offer a reference model for global logistics operations based on blockchain technology. As for grouping blockchain technologies in supply chain and logistics, we highlight the grouping established by Petersen et al. (2018), which distinguishes (1) platforms and applications for tracking and tracing, (2) product authentication and identification, and (3) supply chain financial management. Vivaldini (2021) distinguishes macro-groups for SC blockchain functionalities such as provenance, logistics and transportation, operational, compliance and fraud, finance, and miscellaneous services.

2.2. Blockchain Technology

2.2.1. Peer-to-Peer Network Architecture

It is typical for centralized and distributed system architecture solutions to utilize client/server networks, while blockchains and decentralized applications use a peer-to-peer (P2P) network that places equal value on all nodes or computers. The benefits and limitations of blockchain technology largely stem from the features of a P2P network architecture, whose benefits are improved network efficiency as data is routed and forwarded by each node. This type of network is more resilient to failure, as the loss of single nodes does not affect the work of the entire network. If a central authority does not store or access user data, privacy is more ensured. This system is more scalable, as more participants in the network not only raise the number of clients but also the number of servers. It is more cost-effective, as costs are distributed in the network. Moreover, the underlying consensus mechanism makes data amendment or alteration less likely with peer-to-peer blockchains. The limitations of a P2P network include slower speed, and without a central authority, problem management is more challenging. It is environmentally problematic to use excessive computational power to update information on some blockchain networks that use Proof of Work (PoW) (Bybit 2022).

2.2.2. Classification of Blockchain Technologies

There are several types of blockchain technologies, and a grouping differentiates between access-based alternatives, such as public blockchain, where all transactions can be read and submitted by anyone, and private blockchain, where an invitation or permission is required to connect. In the latter case, access can be controlled either by a consortium or by an organisation (Wang et al. 2019). Hybrid blockchain can combine any of the public, private, or community/consortium blockchains to assist the progress of transactions. Concerning authorization, blockchain can be categorized as permissionless, permissioned, or hybrid based on whether prior permission is needed to participate in the blockchain network. In a permissionless blockchain identity is not tracked and managed, while in a permissioned, role-based blockchain, verifying transactions and running nodes is only allowed by authorized parties. A hybrid blockchain can combine permissionless and permissioned blockchains to facilitate inter-chain communication. In terms of core functionality and smart contract support, stateless and stateful blockchains can be distinguished. Stateless blockchain systems are primarily designed to optimize transaction performance and chain functionality, utilizing cryptographic hashes to verify transactions. Smart contracts and transaction computing capabilities are provided by stateful blockchains that support multi-faceted business logic optimizations and logic state preservation. Providing key services to participating nodes, a blockchain platform is the core of the blockchain network and consists of the following modules: Blockchain Runtime Environment, Cryptographic Services, Smart Contract Module, Blockchain Secondary Storage, Blockchain Memory Store, Consensus Protocol Module, Blockchain Services Layer, and Communication Protocol (Shrivas and Yeboah 2019). As part of this study, the blockchain platforms were mapped, identified by groups, investigated in detail based on the above-mentioned groupings, and their applications were analysed comparatively.

2.3. Benefits and Barriers of Blockchain Adoption

This work collected the advantages and disadvantages that can be shared in the various sectors and are generally valid. It is clear that the benefits affecting the entire supply chain include credibility, traceability, transparency, and food security. On the other hand, the factors preventing the spread can be found mainly at company level: they affect financial and human resources (Table 1).

In view of the growing academic and business interest in blockchain application in supply chain management, in our study we set out to answer the following research questions:

RQ1: What are the main advantages and barriers to the adoption of blockchain technology in supply chain management?

RQ2: What are the leading blockchain platforms and their potential applications in supply chain management?

Table 1. Supply chain adoption of blockchain: identification of benefits and barriers.

Drivers/Benefits	Barriers/Disadvantages
Based on a managerial expert survey, the frequency mentions of cost saving was 89%, improving traceability was 81%, enhancing transparency was 79% (Ledger Insights 2018)	Economic and social sustainability performance is negatively affected (Drljevic et al. 2022)
Increasing supply chain visibility and traceability, reducing administrative costs, counterfeiting and grey market losses through economically-sound processes managing the supply chain more effectively by recording price, location, quality, and certification information (Deloitte 2022)	The lack of measurable ROI is the top issue for 70% of organizations, while it rises to 92% for organizations at an advanced stage of development. A lack of complementary systems at partners, a lack of compliance with privacy and regulatory policies, incompatibility with legacy systems, and security concern of transactions contribute to immaturity in technology (Ledger Insights 2018)
Credibility (Drljevic et al. 2022)	Lack of information sharing, the need of ERP system (Gaur and Gaiha 2020)
An information flow, inventory flow, and financial flow are all part of a simple transaction. Improved traceability, efficiency, speed, and disruption reduction with smart contracts (Gaur and Gaiha 2020)	There is no central governance in permissionless blockchain, where trust is established by consensus verification between unknown parties. The use of blockchain technology in the supply chain sector has to prove its unique value. Concerns with data capture across wide range of untrusted parties. Full transparency or traceability can be achieved through other methods, not just blockchain technology. Developing and running costs remain unclear, with few standards now available. Blockchain's current capacity is insufficient for supply chain's future needs (McKinsey 2017).
Efficiency (Gurtu and Johny 2019)	
Implementing automated processes to replace slow, manual ones, reducing IT transaction costs associated with supply chains, while creating trust, transparency, and traceability (McKinsey 2017)	
Transparency, traceability, efficiency, information security, environmental impact (Moosavi et al. 2021)	Regulatory challenges of blockchain, blockchain governance, standardisation and certification of SC traceability processes, organizational challenges, evaluation and benchmarking, sustainability concerns, investment and operating costs, challenges associated with existing enterprise resource planning (ERP) systems, blockchain-based technologies, and those of "garbage in, garbage out" (Dasaklis et al. 2022)
The entire lifecycle of food products can be tracked, thereby improving credibility, efficiency, and safety associated with the food supply. With the use of IoT sensors and blockchain through QR codes, food production information can be digitised, traced, screening out illegal food in an easy, accessible, and traceable way, verified by consumers and producers (Dasaklis et al. 2022).	Inefficiency and delays can be caused by the involvement of a centralized agency and multiple third parties to verify and approve transactions at once. Complications linked to customers, such as a wide variety of customers, changing customer expectations, multichannel distribution to reach customers (such as E-commerce, traditional retailers, drop shipping, and third-party marketplaces), heavy demand fluctuations, cross-border sourcing of raw materials, just-in-time manufacturing, and customers expecting highly customized products contribute to the vulnerability of the system (Raja Santhi and Muthuswamy 2022)
Transparency, trust, agility, efficiency, and transaction speed are all essential, as is the ability to trace critical products (Raja Santhi and Muthuswamy 2022)	
Security, auditability, robustness, and transparency of the system (Casino et al. 2019)	
Blockchain based, real-time exchange of information is secure, verified, and trustable that makes the information accessible to all supply network members, or to anyone else (depending on the blockchain type). Through smart contract applications on the blockchain, it is possible to verify and execute agreed transactions automatically when certain requirements are met (Dujak and Sajter 2019)	Immaturity of the technology, issues with scalability, security, and privacy risks, interoperability, high energy costs, system conversions, investment cost, reluctance to change, insufficient knowledge and management support, organizational policies, and culture. Collaboration, coordination, and cooperation problems, intercultural differences, inadequate regulatory support, illegal use (Rejeb et al. 2022)
Building trust in vaccine distribution through tracing distribution steps, transparency in the supply chain will enhance efficiency by fostering mutual trust, creating a smarter and safer food system with blockchain, developing trust among partners in container logistics, verification of digital identity for supplier management (HFS Research 2020)	While public blockchain can maximize its potential in large-scale environments, there is a lack of adoption results in smaller business networks due to its unfamiliar security and data-integrity systems. Therefore, they seek to control the system through a private blockchain, while losing some transparency and incur data redundancy. In addition, skills gaps exist in blockchain development and engineering (TechTarget 2021b)

Source: Authors' own compilation.

3. Materials and Methods

To take former academic research on BC in SC as a baseline, we conducted a three-step primary research. First, we conducted two expert in-depth interviews with two platform provider managers to develop a further research framework. The sample was first drawn from the research frame of university-affiliated business leaders and experts in the logistics and supply chain management fields best suited to the research focus. In addition, we contacted international companies with Hungarian subsidiaries that use blockchain internationally to expand our pool of interviewees. Out of the 14 companies we contacted by e-mail and telephone, two responded positively to our request to participate in the interview. The in-depth interviews were conducted online with business professionals in 2021 in Hungary. The main topics of the interview protocol were the specifications of BC usage in SC, the characteristics of BC platforms, the benefits, and the barriers of the BC application.

The research was exploratory in nature, since our aim was to collect information on the basis of which further research questions could be formulated and our framework tested in a business context. We used semi-structured interviews as a data collection technique. This type of data collection method was expected to gain an input on the role of blockchain platforms in supply chains, parallel with the thorough literature review on the topic. By combining information from the two types of sources, the primary and secondary data could serve as the ground to the comparative-group analysis of different technological approaches applied in supply chain management.

Second, based on the results of the interviews and secondary research, an Expert Qualitative Framework (EQF) was developed, which provided the reference for comparing the platforms. We examined the global blockchain platforms based on former academic research and expert qualitative framework using a Qualitative Comparative Analysis approach (QCA). Within this framework, technological characteristics were identified using the information from the secondary and expert interviews, namely: Blockchain Platform, Start Year, Data Accessibility, Authorization, Smart Contract Support, Hash Function, In-Memory Data Structure, Secondary Storage, Consensus Protocol, Programming Languages, Transactions Per Second (TPS), Transaction, and other Fees.

The aim of this research step was to examine if the structure and technical conditions of the BC platforms would likely be equifinal, conjunctural, or complex. Having identified several platforms and their characteristics, we could quantify the results.

Third, focusing on the business application, a comparative analysis was structured around an interview sheet to effectively present all the information about blockchain platform user companies. It included first the name of the company, then the name, type, and general description of the blockchain technology used in the supply chain, followed by the industry/business area, appliance, and the benefit of BC usage. The purpose of the Qualitative Analysis (QA) study was elaborated, followed by a general overview of the BC usage in SC. The starting point for a detailed overview of the blockchain platform was the framework provided by the first-stage research (the expert interviews and secondary academic research). The research concept based on Expert Qualitative Framework (EQF), Qualitative Comparative Analysis (QCA), and Qualitative Analysis (QA) is visualised in Figure 1.

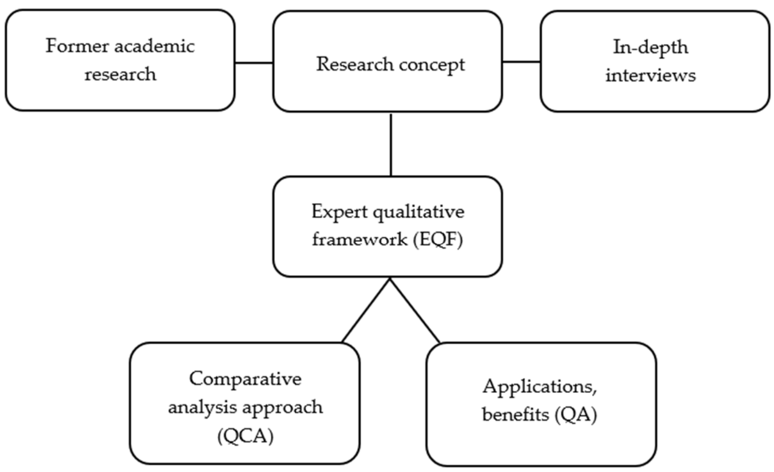

Figure 1. Research framework of exploring blockchain platforms in SCM.

4. Results

4.1. Benefits of Blockchain: Insights from Expert Interviews

The literature research has focused our attention on the blockchain solution developed by the IBM-Maersk Ltd. consortium. However, it can be said that the IBM solution was on the TOP 10 blockchain platforms list for 2020 by Enterprise Management 360, which comprises experts with international experience (Kurton 2020). In our primary research, we focused on the process of using blockchain, based on international examples. In the first step, we mapped the blockchain service providers, the conditions that are required for usage, and in which areas of business its application could bring economic benefits. In recent years, besides global companies, small, and medium-sized enterprises, a number of start-ups have emerged that are essentially dedicated to this activity. In order to ensure the effectiveness of the research, expert interviews were conducted with IT players that deliver complex solutions and are active in international business. On this basis, two blockchain platform providers, IBM Hungary Ltd. (Budapest, Hungary) and GS1 Hungary Nonprofit Ltd. (Budapest, Hungary) were selected for the inquiry.

The first company, International Business Machines (IBM), is a US-based multinational IT company, and IBM Hungary Ltd. is its Hungarian subsidiary. Today, the group is clearly at the forefront of hybrid cloud and AI developments. The first expert interview was conducted with a manager of IBM Hungary Ltd. in April 2021. IBM has chosen Hyperledger, a blockchain technology, which is an open consortium blockchain platform. The Hyperledger Foundation is the alliance where this open source blockchain technology is being developed and operated. Almost 40% of the Foundation's funding comes from IBM, in a form of a community grant.

The second enterprise, GS1 Hungary Nonprofit Company, is an international organisation with over 40 years of experience in global standards. GS1 provides standardised identification solutions for effective business communication to around 2 million companies in more than 20 sectors and nearly 150 countries through its member organisations. The use of eDelivery (a standardised messaging system developed by the EU) developed by the company can respond to the challenges of business communication. The use of blockchain technology was requested by their partners. The Integrated Delivery by Digital Assistance (IDDA) system they have developed is based on the GS1 and eDelivery standard. IDDA operates as a published system on a private blockchain, with easy data access. It has a modular architecture, processes data, and forwards it to the receiving side. It manages order messages, delivery notifications, reverse logistics, and invoices (GS1 2021; GS1 IDDA 2021). The appliance and business benefits and adoption barriers of using blockchain technology, gained from the in-depth interviews, can be found in Table 2.

Table 2. The appliance and business benefits and adoption barriers of blockchain technology.

	Benefits	Barriers
IBM Hungary Ltd.	reliability, trust, privacy, end-to-end traceability, inventory control, constant optimisation of the availability of raw materials, no downtime, no loss of capacity and deterioration in productivity indicators in the manufacturing area, without procurement anomalies, integration with ERP systems, information transparency between business units	substitute technologies are available for blockchain, the enterprise resource planning part of the companies can also extend its modules in such a way that it can handle traceability
GS1—IDDA	blockchain authenticates and accounts for message transmissions, and logs and records the transactions. It is especially effective if there is a business need to replace paper-based records, if there is no provenance of products, if standard tracking is inaccurate, if traceability is lacking, if there is no way to track suppliers, and if it is problematic to manage call-backs (in case of shipping documents by email).	compatibility problem with legacy systems, if there is no motivation on the part of companies to tackle full traceability, if there is no coercion to do so throughout the supply chain, technology is changing too fast for large companies to adapt

Source: Authors' own compilation based on the expert in-depth interviews

Figure 2 shows the main characteristics that emerge during the implementation and use of platforms, which influence their adaptability, integration into business processes, and financial implications.

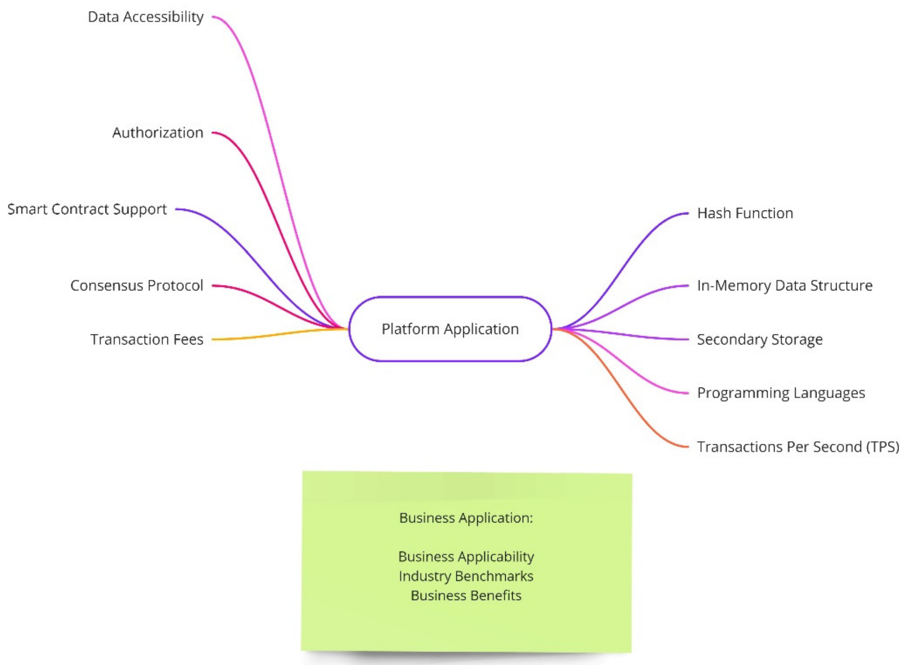

Figure 2. Framework of blockchain platform application. Source: Authors' own compilation based on the expert in-depth interviews.

4.2. Comparative Analysis of the BC Platforms

Blockchain is consensus-based, which means all nodes maintain the same ledger. The security and fault tolerance of blockchain systems can be ensured by a well-defined consensus protocol. Basically, two types of protocols can be distinguished. The first type is probabilistic-finality consensus protocol that ensures eventual consistency. Protocols PoW (Proof of Work), PoS (Proof of Stake), and DPoS (Delegated Proof of Stake) belong to this category, with a fault tolerance of 50% (Zhang and Lee 2020). An acceptable risk is building a system that requires the subversion of more than half of all organizations. PoW-based systems are most vulnerable to a 51% attack, which involves a single entity taking over a majority of the blockchain's hash rate or computing power (TechTarget 2021a). Among absolute-finality consensus protocols are PBFT (Practical Byzantine Fault Tolerance) and XRP Ledger Consensus Protocol, with a fault tolerance of 33% and 20% respectively. Power consumption is large in the case of PoW, while for PoS and DPoS it is less, and for PBFT and XPS it is negligible. The scalability of all these protocols is good, except for PBFT. Application of PoW, PoS, and DPoS is public, while DPoS and XPS is permissioned (Zhang and Lee 2020).

Shrivas et al. (2020) identified six categories of security threats to blockchain that are related to blockchain runtime environment, communication protocol, consensus protocol, smart contract, cryptography, and blockchain services. Inside these categories they distinguish 14 subcategories and 26 types of security threats.

Blockchain security risks can be mitigated by updating the software to get the latest security fixes, ensuring that blockchain and smart contract entries are monitored for security vulnerabilities, and checking that code scanning auditors and tools are familiar with blockchain technology. In addition, code for smart contracts should be scanned, and audited for errors such as misplaced cryptographic keys and security questions should be clarified by vendors and blockchain service providers. Management of cryptographic keys is best achieved using a hardware security module, and phishing and ransomware can be prevented with multifactor authentication and hardware tokens (TechTarget 2021a).

A blockchain protocol's trilemma refers to the difficulties associated with optimizing decentralization, scalability, and security at the same time. The traditional blockchain, including Bitcoin and pre-PoS/sharding Ethereum, uses full nodes of every participant to verify transactions, so it is secure and decentralized, but not scalable. Many high-TPS chains, including the DPoS types, are dependent on a small number of nodes (often 10–100) on which consensus is maintained, with users required to trust a majority of these nodes. As a result, this formation is scalable and secure, but not decentralized. Multi-chain ecosystems are decentralized and scalable, but not secure. These are essentially systems that utilize cross-chain communication protocols to establish communication between various applications running on different chains. Ethereum co-founder Vitalik Buterin (2021) suggests 'randomized sharding' as a solution for the blockchain trilemma. It is also implied that the more programming languages a system has, the more flexible and scalable it is.

Lohmer et al. (2022) identified barriers that both industry and research can address, including regulatory uncertainties, unclear governance in networks, and a lack of standards. In addition, due to legal difficulties and complex network structures, only a few use-case projects have been developed into productive applications. In their article, Johar et al. (2021) outlined nine different attacks that compromised the blockchain ledger. Wang et al. (2022) proposed a cloud service platform for an integrated energy market based on the advantages of blockchain smart contracts, such as efficiency, security, and automatic execution.

Table 3 shows the comparison of the main selected blockchain platforms. It is the technical specifications that determine the capabilities of a system, and therefore its effectiveness and business use.

4.3. Blockchain Application Benefits in Supply Chain

An organization can be listed on the Forbes Blockchain 50 list if it has blockchain-affiliation and at least $1 billion in revenue or market value. Since 2018, this prestigious list has been compiled annually. There were 169 submissions to 2022 Forbes Blockchain 50, and 16 out of the selected top 50 companies implemented blockchain technology into their supply chains (Forbes 2022a). Over $32 billion was invested in the blockchain sector in 2021 by venture capital firms. In the 2022 Forbes Blockchain 50 list, 56% of the companies applying blockchain technology are based in the United States, 24% are of Asian origin (out of which 14% Chinese), while 16% of them are from Europe (Forbes 2022b).

Among the 16 supply-chain-related cases examined, the most prominent features were tracing and tracking (9), sustainability (7), time-saving (6), cost-saving (4), and preventing counterfeiting (2). Among the business areas were manufacturing (8), retail (3), fintech and banking (3), telecom (1), and maintenance (1). Hyperledger Fabric (9) and Ethereum (3) were the most frequently mentioned platforms. As you can see in Table 4, blockchain technologies have considerably improved supply chain management for top companies.

Table 3. The main blockchain platform categories and technical specifications.

Blockchain Platform	Start Year	Data Accessibility	Authorization	Smart Contract Support	Consensus Protocol	Hash Function	In-Memory Data Structure	Secondary Storage	Programming Languages	Transactions Per Second (TPS)	Transaction Fees
Bitcoin	2009	Public	Permissionless	Stateless	PoW	SHA-256	Merkle Tree	LevelDB	C++	3–7	No fee to receive bitcoins, reasonable default fees, the average transaction fee is $1.209 per transaction.
Ripple	2012	Consortium	Permissioned	Stateless	XRP Ledger Consensus Protocol	SHA2-512	Merkle Tree, Knowledge Grap	RocksDB, NuDB	C++, JavaScript	1500	0.00001 XRP, low amount
Corda R3	2015	Consortium	Permissioned	Stateful	Validity, Uniqueness, pluggable consensus	SHA-256	Merkle tree	H2 database	Java, Kotlin	617–2780	No transaction fees
Ethereum	2015	Public	Permissionless	Stateful	Proof of Work (Ethash)	Keccak256	Trie	LevelDB, RocksDB	Go, C++, Rust, Solidity	12–25 (projected at 100,000 TPS)	The average transaction 'gas' fee is 0.0015 ETH or $1.57
IOTA	2015	Public	Permissionless	Stateless	PoW	Winternitz hash	Acyclic Directed Graph	Trytes, Balanced Trinary System	Go, C, C++, Java, JavaScript	Maximum 1000	No transaction fees
MultiChain	2015	Private	Permissioned	Stateless	PoW	SHA3-256	Merkle Tree	LevelDB	C++	1000	n/a
NEM	2015	Hybrid	Hybrid	Stateless	Proof of Importance	SHA-256d	Web, Portable or Network database	Web Database, Access database	Java, C++	n/a	0.05 XEM ($0.0023) per 10,000 XEM ($463.34) transferred, capped at 1.25 XEM ($0.0579) plus other fees occur

Table 3. *Cont.*

Blockchain Platform	Start Year	Data Accessibility	Authorization	Smart Contract Support	Consensus Protocol	Hash Function	In-Memory Data Structure	Secondary Storage	Programming Languages	Transactions Per Second (TPS)	Transaction Fees
BigChainDB	2016	Hybrid	Hybrid	Stateless	BFT	SHA3-256	Associative Array	MongoDB	Python, JavaScript, Java	1,000,000	No transaction fees
HydraChain	2016	Hybrid	Hybrid	Stateful	PBFT	SHA3-256	Merkle tree	LevelDB	Python	Up to 540 elastic capacity	Fixed token transaction fees of $0.50
Hyperledger Sawtooth	2016	Hybrid	Hybrid	Stateful	Pluggable consensus algorithms Proof of Elapsed Time (PoET), PoW, PBFT	SHA-512, SHA256	BlockCache, Radix Merkle Tree	BlockStore	Rust, Python, JavaScript, Go, C++, Java	More than 1000	n/a
Hyperledger Fabric	2016	Consortium	Permissioned	Stateful	PBFT, Raft, PoW, PoS	SHA3 SHAKE256	Bucket-tree, Merkle Tree	RocksDB	Go, JavaScript, Java	3000 (projected at 30,000 TPS)	$0.29 per virtual processor core (vpc) hour, Membership pricing
Kadena	2016	Hybrid	Hybrid	Stateful	BFT Raft, ScalableBFT	BLAKE2	Merkle	Oracle	Pact	480,000	
OpenChain	2016	Hybrid	Hybrid	Stateless	PoW	SHA-256	Associative Array	SQLite, SqlServer, MongoDb	C#	10–100	No mining fee
Quorum	2016	Consortium	Permissioned	Stateful	QuorumChain pluggable consensus (PoS, Raft, Istanbul—BFT)	Keccak256	Trie	LevelDB	Go	100–500	No transaction fees

Table 3. *Cont.*

Blockchain Platform	Start Year	Data Accessibility	Authorization	Smart Contract Support	Consensus Protocol	Hash Function	In-Memory Data Structure	Secondary Storage	Programming Languages	Transactions Per Second (TPS)	Transaction Fees
Tezos	2018	Public	Permissioned	Stateful	Proof-of-Stake	SHA-256, BLAKE2	Merkle	Distributed Database	Michelson	1000	Transaction fees based on formula
IBM MineHub	2019	Private	Permissioned	Stateful	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Nexledger Universal	2019	Consortium or private	Permissioned	Stateful	NCP (Nexledger Consensus Protocol)	Secp256k1, Keccak-256	n/a	n/a	n/a	n/a	n/a
XuperChain	2019	Public	Permissioned	Stateful	XPoS, XPoW, PoW	Sha-256	Merkle	Ciphertext storage	Solitidy, C/C++, Java	90,000	n/a
AntChain	2020	Consortium	Permissioned	Stateful	PBFT or HoneyBadger	ECC/SMX	n/a	LevelDB, RocksDB, Couch DB	Solidity, Java, C++, Golang	100,000	n/a

Source: updated and extended from Shrivas and Yeboah 2019, pp. 6–7, (columns 1–10, rows 1–16), other: Authors' own compilation (rows 17–20, columns 11–12).

Table 4. The application benefits of blockchain technologies in the supply chain management of top companies.

Company Name	Country	Industry	Blockchain Platform	Application	Benefits
A.P. Moller—Maersk	Copenhagen, Denmark	Logistics	TradeLens, Hyperledger Fabric	Containers are being tracked as they move through global seaports by the second-largest container shipper in the world and other shipping giants. Over 55 million container shipments have been tracked with Tradelens, which Maerks codeveloped with IBM in 2018.	By utilizing its proprietary TradeLens blockchain in 250 ports and on 20 ocean carriers, the company is cutting down on considerable time and paperwork. In addition, a container can now be tracked in seconds rather than hours by the sportwear company Puma, which ships out of northern Germany.
Ant Group	Hangzhou, China	International trade	AntChain	Millions of blockchain-tracked documents have been generated, including patents, vouchers, and warehouse receipts. In addition, the platform provides financing solutions. The Trusple app connects international buyers of products to six million sellers.	Tax, customs, and shipping are simplified, and banks can process payments instantly, reducing auditing costs and default risks.
Baidu	Beijing, China	Fintech	XuperChain	Developing software to track the supply chain for textile centre's $5 billion worth of synthetic fibres.	Blockchain has cut lending costs, helped reduce the supply chain's energy consumption by 17%, and could reduce carbon dioxide emissions by 15,000 tons.
BHP	Melbourne, Australia	Mining	MineHub, Hyperledger Fabric	MineHub, a blockchain-based platform for publicly available mining data, sold the first "paperless" shipment of Australian iron ore to China, recording of tests and emission data	The technology ensures that slavery and illegal deforestation are not involved in the production of the rubber in the 6000 giant truck tires it uses each year.
Boeing	Chicago, USA	Aircraft	Go Direct, Hyperledger Fabric, Hyperledger Indy	Maintains aircraft in compliance with maintenance requirements	There is a potential for savings of 25% in maintenance costs across the industry, worth billions of dollars per year.

Table 4. *Cont.*

Company Name	Country	Industry	Blockchain Platform	Application	Benefits
Breitling	Grenchen, Switzerland	Manufacturing, luxury watchmaker	Ethereum	Assuring the authenticity of products by providing a detailed product history. Breitling is also using it to tap into the resale market by providing information on previous owners and repair history.	A Swiss company is testing blockchain-based warranty claims for lost watches and letting customers quickly alert police to stolen goods via their digital wallets.
China Construction Bank	Beijing, China	Banking	Tianshu BaaS, CCB Chain, BC Trade 2.0	A blockchain-based method for transacting anything from supply chain financing to cross-border payments	It has reduced settlement time from two days to about ten minutes by enabling local CCB branches to process both halves of a trade simultaneously instead of sequentially. The platform connects 14,000 banks worldwide.
De Beers	London, Greathigh-lighted -Britain	Manufacturing diamond producer	Tracr, Ethereum	In addition to tracking a diamond's cut, colour, clarity, and karat, the platform also tracks its location in the supply chain.	An easy scan at any stage of the mining, cutting, polishing, or selling process verifies the rock's origin and authenticity, eliminating the need for time-consuming and costly mail-in verifications.
Fujitsu	Tokyo, Japan	Telecommunications and computer hardware company	Hyperledger Fabric, Besu and Cactus, plus Ethereum	The water that is normally discarded by sugar mills, distilleries, and cola makers can now be recycled or sold.	With the platform, companies can donate some of their purified water to communities in need of clean water as the water is purified, sold, and delivered
Industrial and Commercial Bank of China	Beijing, China	Banking	Emperor Seal Chain	Provides access to government transportation data through wallets owned by ICBC customers. China's new central bank digital currency can be redeemed for carbon credits issued by the transit commission as nonfungible tokens.	Eventually, securitized carbon emissions will be sold to companies to reduce carbon emissions. Qingdao, a city famous for its beer, was able to eliminate 99,000 kg of carbon in 2021.

Table 4. *Cont.*

Company Name	Country	Industry	Blockchain Platform	Application	Benefits
Nornickel	Moscow, Russia	Manufacturing, world's largest producer of palladium and refined nickel	Hyperledger Fabric	Among the metals it tokenizes as contracts are gold, silver, platinum, palladium, copper, and nickel.	Atomyze blockchain contracts allow industrial firms like Umicore, Traxys, and Glencore to track the origin and environmental credentials of their metals and adjust inventories more easily.
Oracle and Circulor	Austin, USA	Raw-materials supply-chain tracking company	Hyperledger Fabric	Cobalt and other conflict-area raw materials can be traced via a blockchain-enabled platform	The service, which is built on Oracle's blockchain, has been signed up by many of the world's largest EV manufacturers, including Volvo, Mercedes-Benz, and Polestar.
Renault	Boulogne-Billancour, France	Automaker	Hyperledger Fabric	Tracking thousands of car parts entering 16 European factories	Streamlining audits and supply-chain traceability, saving weeks of time
Samsung Group	Seoul, South Korea	Electronics, chaebol (conglomerate)	Nexledger	With a blockchain-based platform, small and midsize enterprises can request government loans easier.	By reducing paperwork and processing time to 12 days, the platform can save about 13,000 working hours annually.
Tech Mahindra, Unicef and Gavi	Pune, India	Technology arm: telecom, media and entertainment, manufacturing, retail, and energy	Hyperledger Fabric	Vaccine alliance collaborating with the World Health Organization on the Covid-19 vaccine database	The platform allows the trace of vaccines from manufacturers to recipients, so counterfeiting is prevented, and vaccines do not go to waste.
Walmart	Bentonville, USA	Food retail	Hyperledger Fabric, Walmart Blockchain	Monitoring more than a dozen kinds of risky foods	With its food safety initiatives becoming more visible to consumers, the retailer already tracks 1500 products on the blockchain, triple that from last year.

Source: Authors' own compilation based on Forbes Blockchain 50 2022 list.

Our results are aligned with those of HFS Research (2020), stating that Hyperledger Fabric and Ethereum are emerging as the leading blockchain platforms for enterprises, followed by R3 Corda, Quorum and Multichain. According to their study, major enterprise blockchain use cases were from Banking and financial services (100% = 240), Healthcare and life sciences (100% = 58), out of which 30% was supply chain related, Technology, media, and telecom (100% = 55) out of which 16% was supply chain related, Public sector (100% = 49) out of which 14% was supply chain related, Manufacturing (100% = 43), out of which 60% was supply chain related, Travel and logistics (100% = 43), out of which 49% was supply chain related, Energy and utilities (100% = 33), out of which 12% was supply chain related, and Retail and CPG (Consumer Packaged Goods) (100% = 32), out of which 66% was supply chain related (Figure 3).

Overall, across all sectors, the most popular use case for enterprise blockchain adoption was supply chain management (19%), focusing on provenance (track-and-trace). The second was document management use (16%), focusing on records management. The third was industry-specific use case (15%), including insurance claims processing, reinsurance, intercompany reconciliations, settlements, lending, and several others. Trade-related use cases (12%) focused on international trading including trade finance, as well as energy and commodity trading. Payments (8%) were followed by identity use cases (7%), including digital wallets, KYC (Know Your Customer), and other digital identity related initiatives. Customer experience use cases (6%) included loyalty management, reward points management, customer onboarding, and others. Fraud and compliance (6%) were followed by Finance and accounting (4%) (HFS Research 2020). A third of the top 50 Forbes companies developed supply chain-related blockchain applications, indicating a 13% higher share in terms of blockchain technology than in the sample of 640 blockchain engagements of HFS Research (2020).

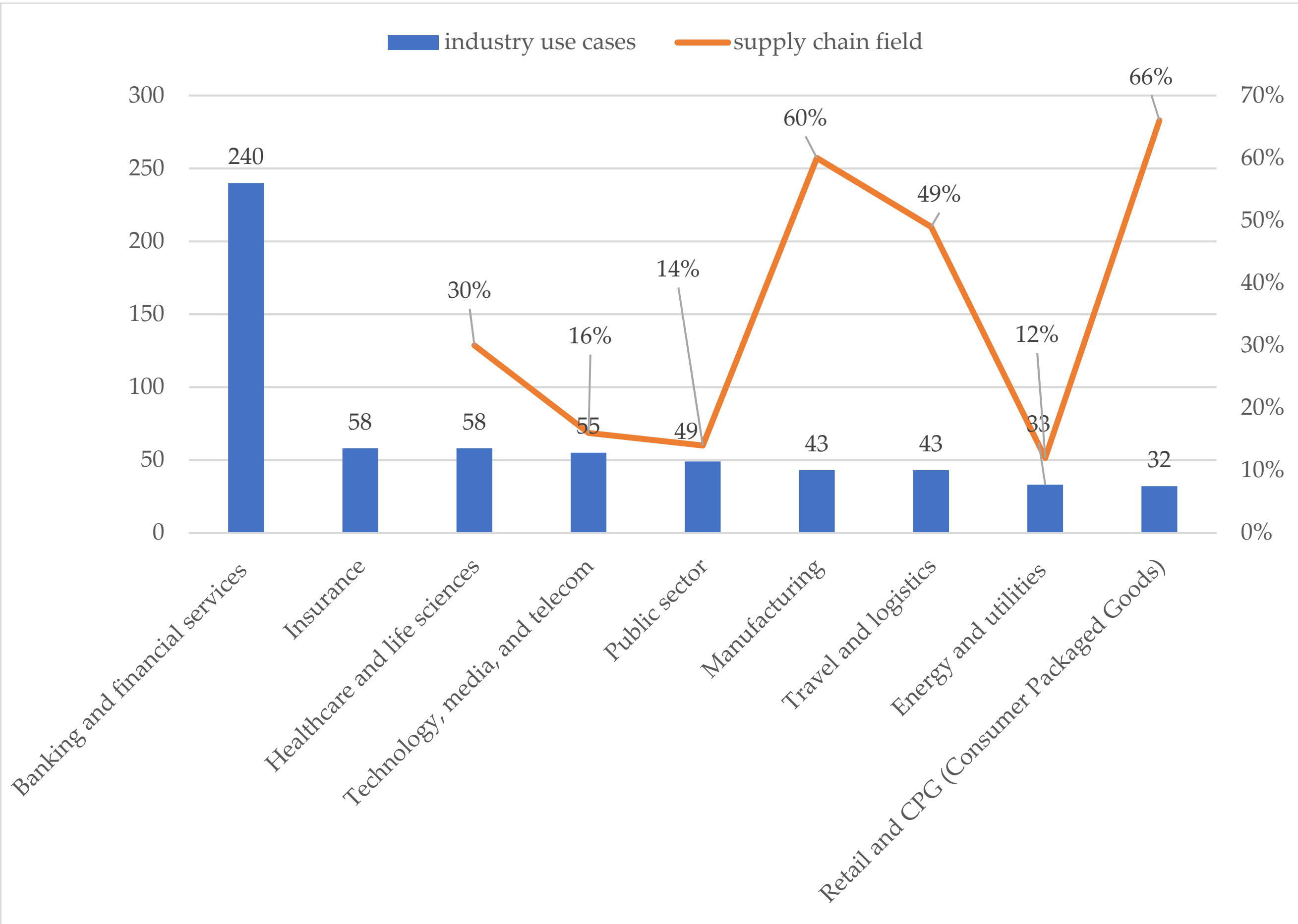

Figure 3. Industry-specific blockchain use cases and their proportion within supply chains. Source: Authors' own compilation based on HFS Research 2020, n = 640.

5. Conclusions

This research has focused on the application of blockchain technology in the supply chain/logistics sector. According to secondary research, the role of blockchain-based platforms in the supply chain needs to be considered not only from the perspective of the technical developers but also from the perspective of the user industries and companies. We have investigated two seemingly different but closely related areas on a framework based on expert interviews. The first approach was the blockchain platform itself and the technical solutions for its inputs. The second approach, on the other hand, was the business applications and benefits.

Building on previous secondary academic research and primary expert interviews, examining the advantages and disadvantages of implementation and use, we found that the main benefits were cost reduction, trusted product features such as food security, traceability, easier and faster transactions, and other operational advantages. Barriers identified include the current under-regulation of information sharing, information security, privacy, and control of blockchain transactions, as well as a lack of adequate human resources and organisational flexibility. Additional approaches to the study include the immaturity of blockchain technology and its features that are not available in current ERP systems or other systems used in the supply chain. The ERP component of the company can also extend its modules in such a way that it can handle tracking and tracing. Integration with legacy systems and into business process is also an issue.

Further limiting factors include low level of network-readiness, low prevalence, technology cost, the lack of sharing best practices, and the limited experience and expertise of human resources, especially in the case of SMEs. Blockchain technologies are not standalone systems. Although the basic blockchain is easy to set up, the integration of systems requires expertise. Other topics to be discussed also cover implementation challenges, the customisability of blockchain technology, and its impact on supply chain processes. Grouping could be used to categorise companies that see innovation in this solution and join as platform provider partners and to summarise lessons learned. The interconnectivity of the blockchain with existing IT systems and Industry 4.0 solutions is also an area for development, as is the mapping of competitors' applications. Using the framework established through expert interviews, we compared the largest global and European platform service providers and found that IBM's Hyperledger Fabric and Ethereum were the most prevalent platforms in the supply chain domain.

Based on a comparative analysis of the BC platforms, it was found that the characteristics of the platforms determine the feasibility of their SC application, and the use of different programming languages determines the integrability. Therefore, the power consumption and speed are very different. The characteristics that determine BC application and optimisation are Data Accessibility, Authorization, Smart Contract Support, Consensus Protocol, Hash Function, In-Memory Data Structure, Secondary Storage, Programming Languages, Transactions Per Second (TPS), and Transaction fees.

The security and fault tolerance of blockchain systems can be ensured by a well-defined consensus protocol. Blockchain protocols face the trilemma of optimizing decentralization, scalability, and security simultaneously. A question for fact-finding was which of the basic types of blockchain used in supply chain and logistics were dominant. The results of this study showed that in supply chain management private and consortium blockchains are dominant, and smart contract support is evident for business applications. The main business blockchain platforms, Hyperledger Fabric, supports pluggable consensus like Practical Byzantine Fault Tolerance (PBFT), Raft, PoW, and PoS, while Ethereum uses Proof of Work (Ethash).

For the largest users, business benefits (those in the supply chain) are mainly in business areas where the following factors effect usage: the nature of the products, the importance of traceability, the complexity of the product flows, the large geographic coverage, to name a few examples. Based on the qualitative analysis of business benefits, the results show the frequency of emphasising traceability and authentication, sustainability-related advantages, cost saving, time saving, and the prevention of counterfeiting. The reasons for this are complex. However, two typical conclusions are worth highlighting at this stage. The first is that this technology is used when the distribution chain is very long and involves many players, and the second is that if the product itself is special and highly prestigious, the guarantee of trust that the technology offers can be enforced. The applications are largely determined by whether there should be an expectation that full tracking is resolved. There has to be an enforcement of power, which would be required throughout the supply chain.

There can be significant differences between individual industries in terms of market structure, supply chain features, and usage benefits. Therefore, future research areas include the in-depth analysis of blockchain application in specific industries.

Author Contributions: Conceptualization, É.R.K. and I.K.; methodology, É.R.K. and I.K.; software É.R.K. and I.K.; validation, É.R.K. and I.K.; formal analysis, É.R.K., I.K., A.H. and K.Z.; investigation, É.R.K., I.K., A.H., K.Z. and É.R.K.; resources, É.R.K., I.K., A.H. and K.Z.; data curation, É.R.K., I.K., A.H. and K.Z.; writing—original draft preparation, É.R.K.; writing—review and editing, É.R.K., I.K., A.H. and K.Z.; visualization, É.R.K. and I.K.; supervision, É.R.K., I.K., A.H. and K.Z.; project administration, É.R.K., I.K., A.H. and K.Z.; funding acquisition, É.R.K., I.K., A.H. and K.Z. All authors have read and agreed to the published version of the manuscript.

Funding: The APC was funded by Budapest Business School Research Fund.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Acknowledgments: The authors would like to acknowledge support received from Katalin Kolláth.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

Bag, Surajit, Dmitriev Aleksandr Viktorovich, Atul Kumar Sahu, and Anoop Kumar Sahu. 2021. Barriers to adoption of blockchain technology in green supply chain management. *Journal of Global Operations and Strategic Sourcing* 14: 104–33. [CrossRef]

Bateman, Alexis, and Leonardo Bonanni. 2019. What Supply Chain Transparency Really Means. *Harvard Business Review*. August 20. Available online: https://hbr.org/2019/08/what-supply-chain-transparency-really-means (accessed on 20 June 2022).

Buterin, Vitalik. 2021. Why Sharding Is Great: Demystifying the Technical Properties. Available online: https://vitalik.ca/general/2021/04/07/sharding.html (accessed on 21 July 2022).

Bybit. 2022. Peer-to-Peer Blockchain Networks: The Rise of P2P Crypto Exchanges. Available online: https://learn.bybit.com/bybit-p2p-guide/peer-to-peer-blockchain-network/ (accessed on 10 July 2022).

Casino, Fran, Thomas K. Dasaklis, and Constantinos Patsakis. 2019. A systematic literature review of blockchain-based applications: Current status, classification and open issues. *Telematics and Informatics* 36: 55–81. [CrossRef]

Cole, Rosanna, Mark Stevenson, and James Aitken. 2019. Blockchain technology: Implications for operations and supply chain management. *Supply Chain Management. An International Journal* 24: 469–83. [CrossRef]

Dasaklis, Thomas K., Theodore G. Voutsinas, Giannis T. Tsoulfas, and Fran Casino. 2022. A Systematic Literature Review of Blockchain-Enabled Supply Chain Traceability Implementations. *Sustainability* 14: 2439. [CrossRef]

Deloitte. 2022. Using Blockchain to Drive Supply Chain Transparency. Future Trends in Supply Chain. Available online: https://www2.deloitte.com/us/en/pages/operations/articles/blockchain-supply-chain-innovation.html (accessed on 11 July 2022).

Drljevic, Nusi, Daniel Arias Aranda, and Vladimir Stantchev. 2022. An Integrated Adoption Model to Manage Blockchain-Driven Business Innovation in a Sustainable Way. *Sustainability* 14: 2873. [CrossRef]

Dujak, Davor, and Domagoj Sajter. 2019. Blockchain Applications in Supply Chain. In *SMART Supply Network, EcoProduction*. Edited by Arkadiusz Kawa and Anna Maryniak. Cham: Springer, pp. 21–46. [CrossRef]

EU Blockchain. 2022. Trend Report June 2022. Available online: https://www.eublockchainforum.eu/sites/default/files/reports/TrendReportJune%202022_0.pdf?utm_source=newsletter&utm_medium=email&utm_campaign=newsletter_21&utm_source=newsletter&utm_medium=email&utm_campaign=EU+Blockchain+Newsletter+July+%2321&cmid=666842d7-d071-41e4-a26b-9004b9c96703 (accessed on 5 July 2022).

Forbes. 2022a. 2022 Forbes Blockchain 50: A Closer Look. Available online: https://www.forbes.com/sites/javierpaz/2022/02/08/2022-forbes-blockchain-50-a-closer-look/?sh=36ba740566c4 (accessed on 15 July 2022).

Forbes. 2022b. Forbes Blockchain 50 2022. Available online: https://www.forbes.com/sites/michaeldelcastillo/2022/02/08/forbes-blockchain-50-2022/?sh=7ac63e8d31c6 (accessed on 15 July 2022).
Ganeriwalla, Amit, Michael Casey, Prema Shrikrishna, Jan Philipp Bender, and Stefan Gstettner. 2018. Does Your Supply Chain Need a Blockchain? BCG Publications. Available online: https://www.bcg.com/publications/2018/does-your-supply-chain-need-blockchain.aspx (accessed on 15 May 2022.).
Gaur, Vishal, and Abhinav Gaiha. 2020. Building a Transparent Supply Chain. *Harvard Business Review*. May–June. Available online: https://hbr.org/2020/05/building-a-transparent-supply-chain (accessed on 11 July 2022).
GS1. 2021. GS1 Hungary Nonprofit Ltd. Available online: https://gs1hu.org/rolunk (accessed on 5 June 2021).
GS1 IDDA. 2021. GS1 IDDA System. Available online: https://gs1hu.org/idda (accessed on 5 June 2021).
Gurtu, Amulya, and Jestin Johny. 2019. Potential of blockchain technology in supply chain management: A literature review. *International Journal of Physical Distribution & Logistics Management* 49: 881–900. [CrossRef]
Hald, Kim Sundtoft, and Aseem Kinra. 2019. How the blockchain enables and constrains supply chain performance. *International Journal of Physical Distribution & Logistics Management* 49: 376–97. [CrossRef]
Horváth, Annamária. 2020. Role of blockchain technology on supply chain. Paper presented at the Digitalization in International Trade and E-Commerce Conference, Shaoxing, China, January 10–11; Edited by Natsuda Kaoru and Amadea Bata-Balog. Budapest: Budapest Business School, pp. 76–90.
HFS Research. 2020. HFS Top 10 Enterprise Blockchain Services 2020 Excerpt for IBM. Available online: https://www.ibm.com/downloads/cas/GNR3JN1B (accessed on 20 July 2022).
Johar, Sumaira, Naveed Ahmad, Warda Asher, Haitham Cruickshank, and Amad Durrani. 2021. Research and Applied Perspective to Blockchain Technology: A Comprehensive Survey. *Applied Sciences* 11: 6252. [CrossRef]
Kamran, Rukshanda, Nasreen Khan, and Balan Sundarakani. 2021. Blockchain technology development and implementation for global logistics operations: A reference model perspective. *Journal of Global Operations and Strategic Sourcing* 14: 360–82. [CrossRef]
Kurton, Max. 2020. Top 10 Blockchain Platforms to Explore in 2020, Enterprise Management 360. Available online: https://em360tech.com/top-10/top-10-blockchain-platforms-explore-2020 (accessed on 5 June 2021).
Laudon, Kenneth C., and Jane Price Laudon. 2020. *Management Information Systems: Managing the Digital Firm*, 16th ed. New York: Pearson. ISBN 978-0-13-519179-8.
Ledger Insights. 2018. Cap Gemini: Supply Chain Blockchains Lack Clear ROI. Available online: https://www.ledgerinsights.com/cap-gemini-supply-chain-blockchain-lacks-roi/ (accessed on 12 July 2022).
Lohmer, Jacob, Elias Ribeiro da Silva, and Rainer Lasch. 2022. Blockchain Technology in Operations & Supply Chain Management: A Content Analysis. *Sustainability* 14: 6192. [CrossRef]
Markets and Markets. 2021. Blockchain Market by Component (Platforms and Services), Provider (Application, Middleware, and Infrastructure), Type (Private, Public, and Hybrid), Organization Size, Application Area, and Region (2022–2026). Available online: https://www.marketsandmarkets.com/Market-Reports/blockchain-technology-market-90100890.html (accessed on 10 July 2022).
McKinsey. 2017. Blockchain Technology for Supply Chains—A Must or a Maybe? Available online: https://www.mckinsey.com/business-functions/operations/our-insights/blockchain-technology-for-supply-chainsa-must-or-a-maybe (accessed on 12 July 2022).
Moosavi, Javid, Leila M. Naeni, Amir M. Fathollahi-Fard, and Ugo Fiore. 2021. Blockchain in supply chain management: A review, bibliometric, and network analysis. *Environmental Science and Pollution Research* 28: 1–15. [CrossRef] [PubMed]
Nandi, Madhavi Latha, Santosh Nandi, Hiram Moya, and Hale Kaynak. 2020. Blockchain technology-enabled supply chain systems and supply chain performance: A resource-based view. *Supply Chain Management. An International Journal* 25: 841–62. [CrossRef]
Petersen, Moritz, Niels Hackius, and Birgit von See. 2018. Mapping the sea of opportunities: Blockchain in supply chain and logistics. *IT Information Technology* 60: 263–71. [CrossRef]
Philsoophian, Maryam, Peyman Akhavan, and Morteza Namvar. 2022. The mediating role of blockchain technology in improvement of knowledge sharing for supply chain management. *Management Decision* 60: 784–805. [CrossRef]
Qian, Xiaoning (Alice), and Eleni Papadonikolaki. 2021. Shifting trust in construction supply chains through blockchain technology. *Engineering, Construction and Architectural Management* 28: 584–602. [CrossRef]
Queiroz, Maciel M., Renato Telles, and Silvia H. Bonilla. 2020. Blockchain and supply chain management integration: A systematic review of the literature. *Supply Chain Management. An International Journal* 25: 241–54. [CrossRef]
Raja Santhi, Abirami, and Padmakumar Muthuswamy. 2022. Influence of blockchain technology in manufacturing supply chain and logistics. *Logistics* 6: 15. [CrossRef]
Rejeb, Abderahman, John G. Keogh, and Horst Treiblmaier. 2019. Leveraging the Internet of Things and Blockchain Technology in Supply Chain Management. *Future Internet* 11: 161. [CrossRef]
Rejeb, Abderahman, Karim Rejeb, John G. Keogh, and Suhaiza Zailani. 2022. Barriers to Blockchain Adoption in the Circular Economy: A Fuzzy Delphi and Best-Worst Approach. *Sustainability* 14: 3611. [CrossRef]
Rodrigues, Eladian Batista, Wagner Luiz Lourenzani, Eduardo Guilherme Satolo, Sergio Silva Braga Júnior, Rosley Anholon, and Izabela Simon Rampasso. 2021. Blockchain in supply chain management: A grounded theory-based analysis. *Kybernetes*. *ahead-of-print*. [CrossRef]

Seebacher, Stephan, and Ronny Schüritz. 2017. Blockchain Technology as an Enabler of Service Systems: A Structured Literature Review. In *Exploring Services Science. IESS 2017. Lecture Notes in Business Information Processing*. Edited by Stefano Za, Monica Drăgoicea and Maurizio Cavallari. Cham: Springer, vol. 279. [CrossRef]

Sheel, Ashutosh, and Vishnu Nath. 2019. Effect of blockchain technology adoption on supply chain adaptability, agility, alignment and performance. *Management Research Review* 42: 1353–74. [CrossRef]

Shrivas, Mahendra Kumar, and Thomas Yeboah. 2019. The Disruptive Blockchain: Types, Platforms and Applications. *Texila International Journal of Academic Research* 3: 17–39. [CrossRef]

Shrivas, Mahendra Kumar, Thomas Yeboah, and S. Selva Brunda. 2020. The Disruptive Blockchain Security Threats and Threat Categorization. Paper presented at the First International Conference on Power, Control and Computing Technologies (ICPC2T), Raipur, India, January 3–5; pp. 327–38. [CrossRef]

Tan, Cheng Ling, Zhongkai Tei, Sook Fern Yeo, Kee-Hung Lai, Ajay Kumar, and Leanne Chung. 2022. Nexus among blockchain visibility, supply chain integration and supply chain performance in the digital transformation era. *Industrial Management & Data Systems*. *ahead-of-print*. [CrossRef]

TechTarget. 2021a. 8 Blockchain Security Risks to Weigh before Adoption. Available online: https://www.techtarget.com/searchcio/tip/8-blockchain-security-risks-to-weigh-before-adoption?utm_source=PDF&utm_medium=Pillar&utm_campaign=BlockchainforBusiness (accessed on 12 July 2022).

TechTarget. 2021b. Blockchain for Businesses: The Ultimate Enterprise Guide. Available online: https://www.techtarget.com/searchcio/Blockchain-for-businesses-The-ultimate-enterprise-guide (accessed on 12 July 2022).

Treiblmaier, Horst. 2018. The impact of the blockchain on the supply chain: A theory-based research framework and a call for action. *Supply Chain Management. An International Journal* 23: 545–59. [CrossRef]

Vivaldini, Mauro. 2021. Blockchain platforms in supply chains. *Journal of Enterprise Information Management* 34: 1769–97. [CrossRef]

Wang, Lei, Yichao Ma, Liuzhu Zhu, Xuli Wang, Hao Cong, and Tiancheng Shi. 2022. Design of integrated energy market cloud service platform based on blockchain smart contract. *International Journal of Electrical Power & Energy Systems* 135: 107515. [CrossRef]

Wang, Yingli, Jeong Hugh Han, and Paul Beynon-Davies. 2019. Understanding blockchain technology for future supply chains: A systematic literature review and research agenda. *Supply Chain Management. An International Journal* 24: 62–84, Publishing Limited. [CrossRef]

Xu, Pei, Joonghee Lee, James R. Barth, and Robert Glenn Richey. 2021. Blockchain as supply chain technology: Considering transparency and security. *International Journal of Physical Distribution & Logistics Management* 51: 305–24. [CrossRef]

Xue, Xiaofang, Junpeng Dou, and Yao Shang. 2021. Blockchain-driven supply chain decentralized operations – information sharing perspective. *Business Process Management Journal* 27: 184–203. [CrossRef]

Zelbst, Pamela J., Kenneth W. Green, Victor E. Sower, and Philip L. Bond. 2020. The impact of RFID, IIoT, and Blockchain technologies on supply chain transparency. *Journal of Manufacturing Technology Management* 31: 441–57. [CrossRef]

Zhang, Shijie, and Jong-Hyouk Lee. 2020. Analysis of the main consensus protocols of blockchain. *ICT Express* 6: 93–97. [CrossRef]