A critical analysis of the integration of blockchain and artificial intelligence for supply chain

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Abstract

The integration between blockchain and artificial intelligence (AI) has gained a lot of attention in recent years, especially since such integration can improve security, efficiency, and productivity of applications in business environments characterised by volatility, uncertainty, complexity, and ambiguity (VUCA). In particular, supply chain is one of the areas that have been shown to benefit tremendously from blockchain and AI, by enhancing information and process resilience, enabling faster and more cost-efficient delivery of products, and augmenting products' traceability, among others. This paper performs a state-of-the-art review of blockchain and AI in the field of supply chains. More specifically, we sought to answer the following three principal questions: Q1 – What are the current studies on the integration of blockchain and AI in supply chain?, Q2 – What are the current blockchain and AI use cases in supply chain?, and Q3 – What are the potential research directions for future studies involving the integration of blockchain and AI? The analysis performed in this paper has identified relevant research studies that have contributed both conceptually and empirically to the expansion and accumulation of intellectual wealth in the supply chain discipline through the integration of blockchain and AI.

Keywords: blockchain, artificial intelligence, supply chain, systematic literature review, bibliometric review, thematic analysis.

1. Introduction

Traditionally dispersed geographically, supply chains have always been difficult to manage. Supply chain complexity is caused by a variety of factors and its long-term viability necessitates effective maintenance, repair, and operations management, among others. In supply chain networks, everything from link maintenance and regulatory policies to cultural norms and human behaviour makes evaluating information and managing risk a difficult task (Ivanov, Dolgui, & Sokolov, 2019). Trust can be easily undermined by inefficient transactions, fraud, theft, and weak supply chains, which highlights the need for better information sharing and verifiability (Saberi *et al*., 2019).

In today's business environment, traceability is becoming a necessity and a competitive advantage in many supply chain industries. Without transparency in the supply chain, stakeholders cannot properly assess and validate the true value of items. The cost of dealing with intermediaries, as well as their dependability and transparency, make managing supply chain traceability even more difficult, leading to strategic and reputational competitive issues (Saberi *et al*., 2019).

There are a number of issues with today's supply chains because they rely so heavily on central, sometimes disparate, and stand-alone systems of information management, such as enterprise resource planning systems (Saberi *et al*., 2019). The single point failure of centralised information systems is a drawback of such systems, which in turn makes the entire system vulnerable to error, hacking, corruption, or attack (Dong *et al.*, 2017). Without doubt, there must be a high level of trust present for supply chain entities to entrust their sensitive and valuable data to a single organisation or broker (Abeyratne & Monfared, 2016).

In addition, there are continuous pressures on supply chain practice to recognise and certify the sustainability of supply chains. Environmental, social, and business aspects must all be considered in order to achieve sustainability, as part of the triple-bottom-line concept (Seuring *et al*., 2008). As a strategic and competitive issue, supply chain sustainability requires confirming and verifying that supply chain processes, products, and activities meet certain sustainability criteria and certifications (Grimm, Hofstetter, & Sarkis, 2016).

Existing supply chain information systems must be examined to determine if they can provide the secure, transparent, and reliable data needed to track the timely origin of goods and services. The key to resolving these difficult matters is to improve supply chain security, transparency, long-term viability, and process integrity. Blockchain technology could be the solution to this problem. New technological breakthroughs and applications based on the blockchain concept have made these objectives more attainable from an organisational, technological, and financial standpoint (Abeyratne & Monfared, 2016). With its decentralised 'trustless' database characteristics, blockchain technology can facilitate global-scale transaction and process disintermediation and decentralisation among a variety of different stakeholders (Crosby *et al*., 2016; Saberi *et al*., 2019).

As Saberi *et al.* (2019) noted, although the number of blockchain use cases has grown over time, blockchain, like any potentially disruptive system or technology, faces a number of challenges and barriers in terms of adoption and implementation by supply chain networks. Blockchain is still in its early stages of development, posing a number of challenges in terms of behavioural, organisational, technological, and policy-related issues.

Artificial intelligence (AI) promises to solve some of the above-mentioned problems. As a matter of fact, the integration of blockchain and AI is estimated to bring a number of significant various advantages, such as more robust deliverables (Odekanle *et al.*, 2022). With such integration, parties can share massive amounts of data for the purposes of analysis, learning, and decision-making without the need for a central authority or third-party intermediaries.

By automating the entire workflow, the use of AI technology in the blockchain system has the potential to redefine the supply chain. Using a combined AI and blockchain approach, useful information can be extracted from historical purchase data and other sources, allowing for the identification of data characteristics and the performance of predictive analysis tasks such as future demand and sales forecasting (Zhang *et al*., 2021).

In spite of its importance and relevance, to the best of our knowledge, there is, at the time of conducting this research, no systematic literature review of studies on the integration of blockchain and AI for supply chain. Our research contributes to the operations management field by addressing this gap through a critical evaluation of such studies. The three principal questions we aim to answer are:
Q1 – What are the current studies on the integration of blockchain and AI in supply chain?
Q2 – What are the current blockchain and AI use cases in supply chain?
Q3 – What are the potential research directions for future studies involving the integration of blockchain and AI?

As such, the aim is to not only investigate the current state of studies focusing on the integration of both technologies, but also to highlight how such integration can revolutionise "business-as-usual" practices in supply chain management. The analysis performed in this paper has identified relevant research studies that have contributed both conceptually and empirically to the expansion and accumulation of intellectual wealth in the supply chain discipline through the integration of blockchain and AI. As we will show, the majority of the literature is conceptual rather than empirical in nature, indicating that blockchain and AI integration is still in its early stages. Nonetheless, by highlighting current trends and interests in the field, it is expected that this study will assist academics, practitioners, and policymakers in understanding the current state-of-the-art on the topic and aid their decision-making to engage in empirical studies focusing on the actual deployment of AI-driven blockchain technology for supply chain and its implications for long-term performance. As a result, the current work will serve as a foundation for future research studies.

The remainder of the paper is organised as follows. In Section 2, we lay out the theoretical framework by defining our key terms, namely blockchain, artificial intelligence, and supply

chain. In section 3, we first detail the steps followed in identifying relevant studies (Section 3.1). The results of the bibliometric analysis are presented in Section 3.2 in order to obtain an overall view of the publications available in the literature on the topic. In Section 3.3, we then narrow down the pool of studies identified by means of defining inclusion and exclusion criteria. In Section 4, we discuss the identified thematic clusters, which are indicative of the current research trends on blockchain and AI integration in supply chain. Section 5 concludes the paper with final thoughts, limitations, and future research directions.

2. Theoretical Framework: Blockchain and Artificial Intelligence for Supply Chain

From the procurement stage to the product stage, the supply chain encompasses all activities involving the production of goods and the delivery of finished goods. Or, in the words of Pimenidis *et al.* (2021), "in the realm of manufacturing, a supply chain is the process of the flow of goods from the upper echelons of value creation to the end customer consumption. It is a form of symbiotic connection in which customers and suppliers work together to achieve the best interests of each other, buying, converting, distributing and selling goods and services to create specific final products and to add value to their organisations" (p. 369). In this sense then, regardless of industry, the supply chain has a complex architecture, on which a significant portion of business productivity and profits is based.

Sharing information securely, effectively, and efficiently is critical to running supply chains smoothly. A good supply chain requires efficiency and transparency at every level of the supply chain, as well as trust among stakeholders. Moreover, supply chains must become more adaptable and responsive, while also increasing their resilience and traceability, in order to be sustainable. Yet again, innovation and technology will be central to supply chain success (Baucherel, 2018). It is in this context that blockchain has emerged as a critical technology that has the potential to improve supply chain operations' flexibility and agility (Cole *et al.*, 2019). Through the use of blockchain technology, all stakeholders in the ecosystem can actively engage, share, and verify all types of information and data (Gohil & Thakker, 2021).

Satoshi Nakamoto is credited with the invention of the concept of "blockchain". In 2008, Nakamoto (2008) published a paper wherein he presented the concept of the first peer-to-peer electronic cash system aided by digital currency, dubbed as "bit-coin". Transactions are recorded as interlinked blocks that are linked to one another. In this context, the term "blockchain" refers to a chain of interconnected transactions. Blockchain enables parties who do not know each other to deal securely without the need for a centrally trusted middleman, lowering legal and transaction expenses (Pilkington, 2016). The name "distributed ledger" comes from the fact that records can be shared with different parties and maintained in multiple locations.

In other words, blockchain technology is a decentralised, distributed database of records or shared public/private digital ledgers that exists across a network and that is used to record transactions that have been executed and shared among participating agents (Crosby *et al.*, 2016). Four key characteristics of blockchain technology distinguish it from most existing

information system designs: non-localisation (decentralisation), security, auditability, and smart execution (Saberi *et al*., 2019; Steiner & Baker, 2015).

The way that the blockchain works is that a blockchain agent creates a new transaction to be added to the blockchain. This new transaction is transmitted to the network for auditing, and once it has been approved by a majority of nodes, it is added to the chain as a new block. It is further saved in several distributed nodes for security reasons. The smart contract, a key feature of blockchain technology, allows for trustworthy transactions to be executed without third-party involvement. Real-time visibility of transactions throughout the supply chain and a reduced risk of data manipulation and fraud are thus among the many advantages of blockchain technology (Cottrill, 2018; Partida, 2018).

The key properties of this technology that make it a valuable proposition to handle transactions, according to Rodríguez-Espíndola *et al.* (2020), are:

(1) Immutable: All transactions will be recorded and stored by blockchain, and each transaction will be protected against deletion, tampering, and revision. The software code in the blocks automatically records any changes as new transactions that are linked to the previous transaction.
(2) Distributed: Each of the blockchain network's participants has an identical copy of the ledger on their computer (frequently called nodes). Cash management and the parties involved in the transaction are more easily spotted as a result of the increased visibility provided by this.
(3) Decentralised: Transactions between the blockchain network entities will be easier with this property, as it eliminates the need for a central intermediary and speeds up processing time.
(4) Automated: The code running in the blockchain automatically records and cryptographically verifies each transaction, ensuring transaction authenticity. This renders the entire process incorruptible and error-free. Transaction times are reduced as a result of the automation.
(5) A single unified ledger: If a permissionless blockchain network is used and all transactions are recorded in a single immutable public ledger, grouping them together will be easier.
(6) Self-reviewing: When a transaction occurs, the blockchain automatically updates and records the information, ensuring that every node (network participant) has an up-to-date ledger copy of the information available.

AI is a way of getting a machine or programme to perform tasks that would normally be performed by human intelligence; hence, it is used to develop intelligent computers and machines that behave like humans. There are two types of AI, namely General AI and Narrow AI. Narrow AI, or AI programmes capable of solving a single problem or task, is still the prevalent type of AI today. General AI, on the other hand, which can be described as an AI programme that can solve any problem it is given, is still a work in progress.

When integrated with AI, blockchain technology can assist the supply chain in various ways. A supply chain powered by blockchain and AI could be the answer to securing the operations of a local or regional supply chain and providing the intelligence required to enhance operational efficacy (Pimenidis *et al*., 2021). It can increase data security, data efficiency, and contribute to making smart decisions (Banerjee *et al*., 2018). Blockchain securely stores a large amount of data, while AI helps analyse and produce insights from data and generates new scenarios and patterns based on data behaviour (Ahmed *et al*., 2022). In order to make supply chains more adaptable, responsive, and efficient, while also maintaining transaction transparency for the benefit of all members, blockchain and AI algorithms can help (Pimenidis *et al*., 2021). All in all, the integration between blockchain technology and AI can strengthen applications in terms of reliability, security, transparency, and trust. To the best of our knowledge, papers have looked into the use of blockchain and AI in supply chains, but they have generally treated the two technologies separately, as if they were on opposite ends of a spectrum. The current paper, on the other hand, examines the integration of the two concepts.

3. Methods and Materials

3.1 Extracting Relevant Literature

To address our research questions, a systematic literature review was carried out. To this aim, the Scopus search database, which is the abstract and citation database of Elsevier, was used as the main scientific database. Scopus is well-known and widely used for literature mapping (*e.g*., Fahimnia *et al.*, 2019). Despite the fact that there are other databases available, Scopus was chosen as one of the best options because of its consistent citation metrics and precision in locating authors and institutions (Charles, Gherman, & Emrouznejad, 2022). Scopus also provides a more comprehensive coverage of articles in Business, Economics, Management, and Social Sciences in general (Martín-Martín *et al.*, 2018). Hence, it was deemed that the works identified in the Scopus database can provide a reasonably good overview of what has been published on the topic of blockchain and artificial intelligence integration for supply chain that are relevant to this study.

Figure 1 depicts the flowchart of the approach followed in this paper. In the first phase, to conduct the search for relevant literature, we devised a set of keywords that would cover all relevant publications in the Scopus database to the greatest extent possible. The Scopus search algorithm was TITLE-ABS-KEY ("blockchain" OR "block chain") AND ("artificial intelligence" OR "machine learning" OR "neural network" OR "deep learning") AND "supply chain"). These keywords were looked up in each publication's title, abstract, and keyword list. The search returned 280 document results, all published between 2017-2022. Data were downloaded on 27 March 2022. These documents were analysed using bibliometric analysis.

The application of the above criteria for identifying relevant material was left intentionally broad, so that we could get a sense of what researchers in the field are interested in right now and in the future. Moreover, only 280 results were returned, which is a relatively low number. On the other hand, we considered excluding conference papers from our analysis because they

are frequently written to present preliminary findings and thus constitute works in progress rather than complete papers (Mubin, Arsalan, & Al Mahmud, 2018). A similar consideration was made with regards to book chapters, conference reviews, and reviews, as they serve a different purpose and do different work than journal articles. However, a decision was made not to exclude such work. The reasoning was that, because the field is still young, it is understandable that more research is ongoing rather than finished; also, that more work is conceptual or theoretical in nature rather than empirical. As a result, it would be ideal at this point to provide an overview of the entire pool of documents that we came across in order to better capture all ongoing research endeavours. The 280 records were subjected to a co-occurrence analysis using the VOSviewer software for bibliometric analysis (Section 3.2).

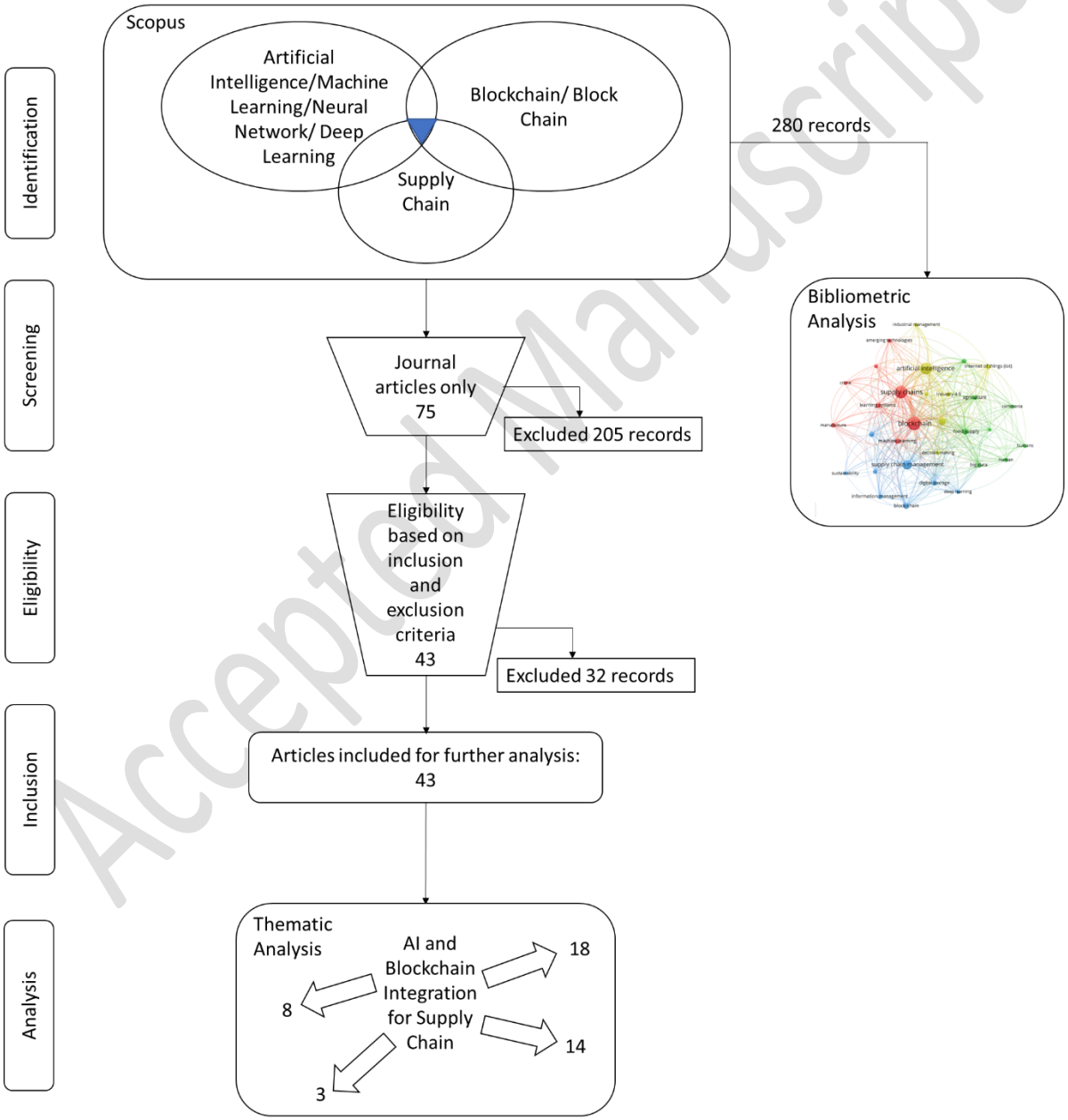

Figure 1. Flowchart of the systematic literature review with bibliometric analysis and thematic analysis.

In the subsequent phase (Section 3.3), the 280 records were screened, and only journal articles (as complete, published, and peer-reviewed research work) were selected for further analysis; this yielded 75 research articles. Then, a set of inclusion and exclusion criteria was developed, and a manual review of the 75 research articles was conducted to determine whether or not they complied with the set criteria and clearly addressed the integration of blockchain and AI for supply chain. This step resulted in a final pool of 43 research articles, which was subjected to a thematic analysis.

3.2 Bibliometric Analysis of the Results

Bibliometric analysis is a useful research technique for identifying global research trends and predicting future research directions (Liu, Zhang, & Hong, 2011). Through bibliometric analysis, this paper reveals the characteristics and trends in studies integrating blockchain and AI in the field of supply chain. The results are analysed using summary statistics.

The number of publications on blockchain and AI for supply chain has increased over time, as shown in Figure 2. It is worth noting that all 280 documents identified were published after 2017, implying that there were no publications combining the three keywords before this year, at least according to the Scopus database. Second, in recent years, there has been an increase in interest in the topic, with a peak in the year 2021 (124 records).

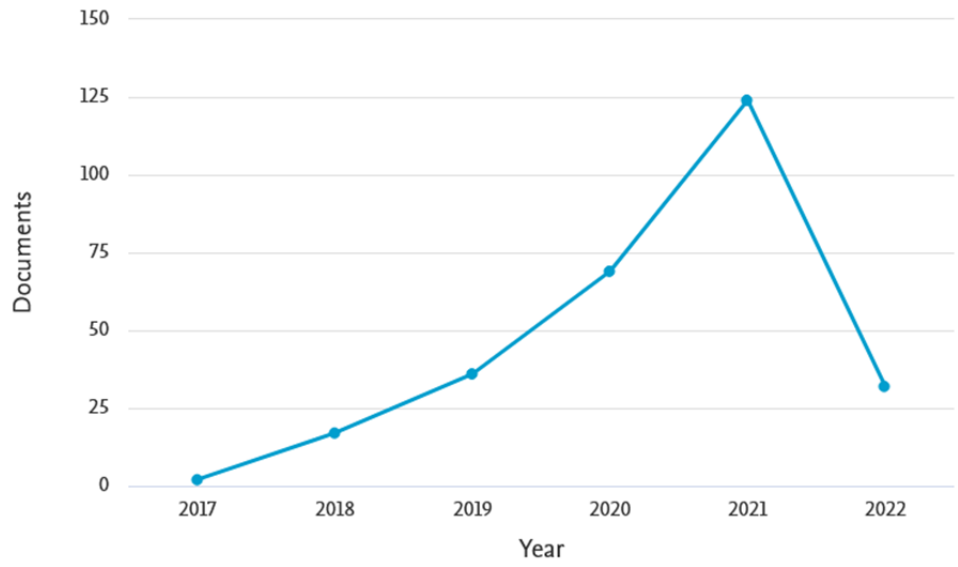

Figure 2. Annual scientific production. (Source: Scopus 2022).

Figure 3 depicts the annual document volume broken down by information source. It can be observed that top five preferred outlets for publications on blockchain and artificial intelligence for supply chain are IFIP Advances in Information and Communication Technology (17 documents), Advances in Intelligent Systems and Computing (11 documents), Communications in Computer and Information Science (10 documents), Lecture Notes in

Computer Science including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics (10 documents), and Sustainability Switzerland (9 documents).

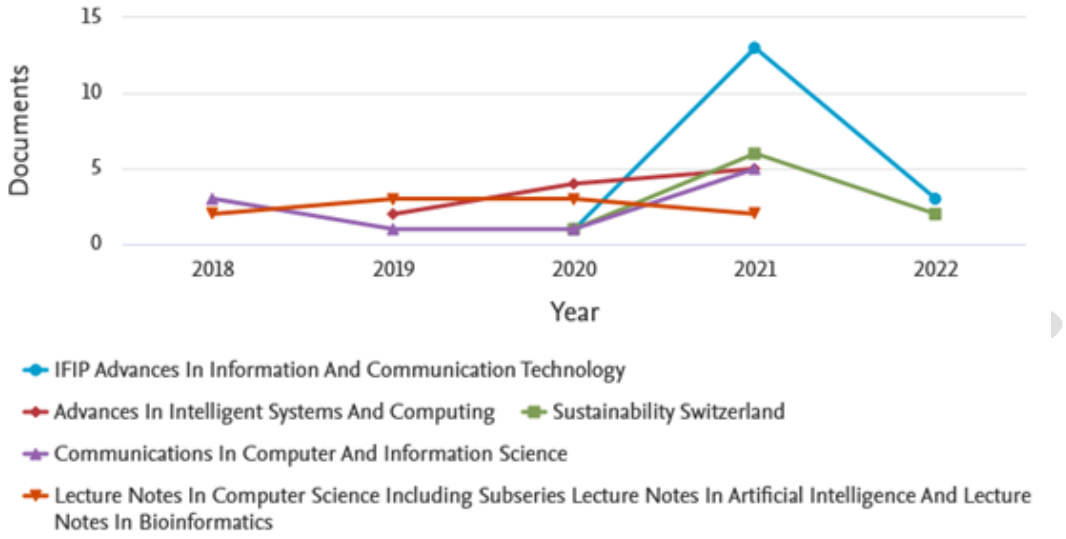

Figure 3. Documents per year per source. (Source: Scopus 2022).

Figure 4 shows the documents by affiliation, with the first 12 affiliations compared to the total number of documents. Affiliation-wise, the University of the West of England (Great Britain) leads the ranking with 5 publications and is closely followed by Hong Kong Polytechnic University (Hong Kong) and Peter the Great St. Petersburg Polytechnic University (Russia), each with 4 publications. The subsequent 9 institutions shown in the figure account for 3 publications each. It is interesting to note how these institutions reflect a mix of countries from around the world.

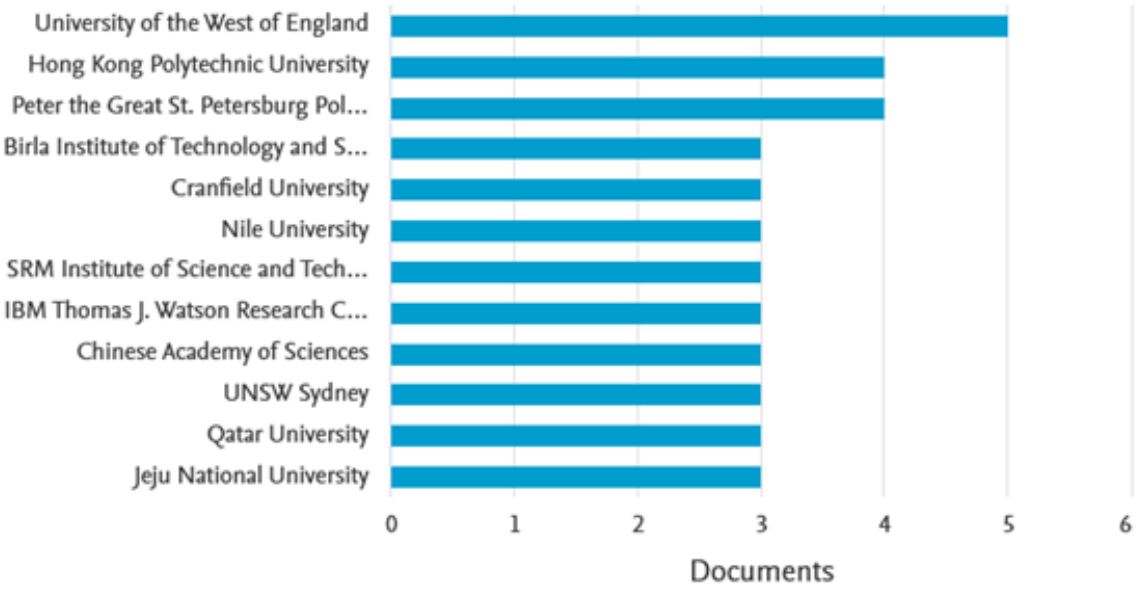

Figure 4. Documents by affiliation (Source: Scopus 2022).

Figure 5 compares the document counts for 13 countries/territories to show which have the most publications. The countries of origin were determined by the corresponding author's country. It can be easily observed that India dominates the ranking, with 51 publications, followed by China and the United States, with 38 and 34 publications, respectively. A notable observation is that these first three countries together account for almost half (*i.e.*, 44%) of the total number of publications. The fourth position is held by the United Kingdom, with 22 publications and the fifth place belongs to Australia, with 12 publications. France and Germany occupy the sixth and seventh place, respectively, both with 10 publications, followed by Hong Kong and South Korea (each with 7 publications), Italy and Taiwan (each with 6 publications) and Finland, Greece, and Iran (each with 5 publications).

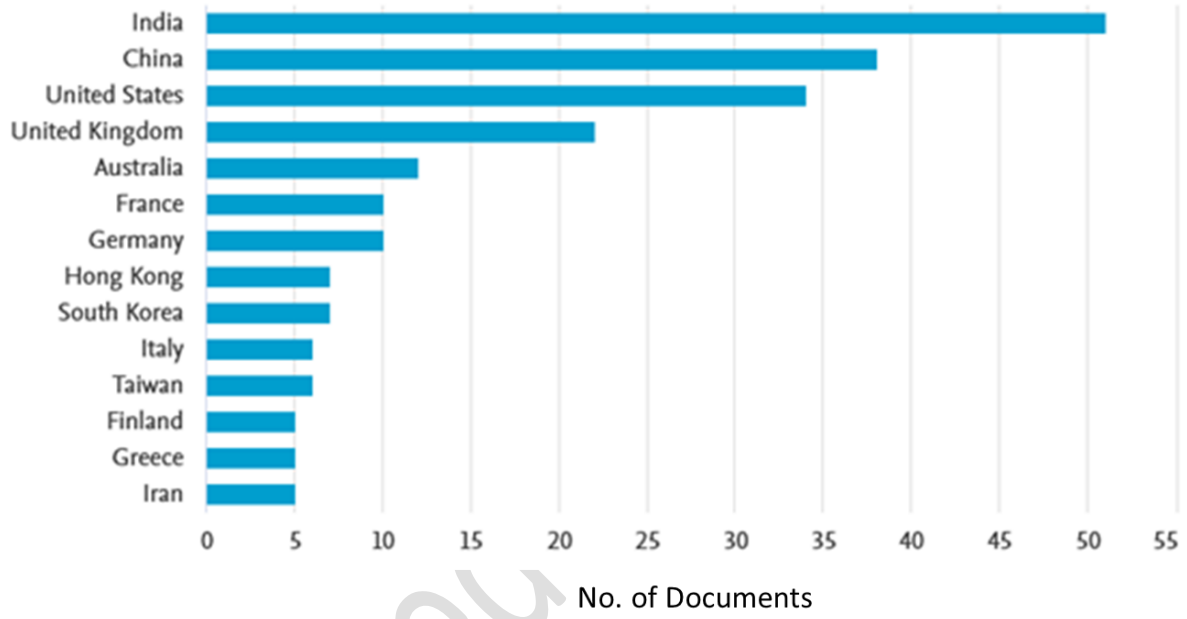

Figure 5. Documents by country or territory. (Source: Scopus 2022).

Table 1 shows the number of documents by publication type. In this regard, we can observe that conference papers predominate in the literature (86 documents, which constitute approx. 30 percent of the publications). The high number of conference papers in the literature could be attributed to the novelty of the research topic as well as the fact that the field is still in its early stages. Then there are articles (75 documents, representing approx. 27 percent of the publications). Conference reviews comprise 68 documents, or approximately 24 percent of the publications. Book chapters and reviews each have 22 documents, while books and editorials have the fewest (4 and 3 documents, respectively).

Table 1
Documents by publication type (Source: Scopus 2022)

Document type	**No. of Documents**	**%**
Conference Paper	86	30.71%
Article	75	26.79%
Conference Review	68	24.29%
Book Chapter	22	7.86%
Review	22	7.86%
Book	4	1.43%
Editorial	3	1.07%
TOTAL	**280**	**100.00%**

Finally, an analysis of published documents by subject area (Table 2) reveals that the subject area of "computer science" concentrates most of the research on the topic, with a whopping 171 documents or 29 % of the publications. This is followed by the area of "engineering", with 114 documents or approx. 19% of the publications, and the area of "decision sciences", with 67 documents or approx. 11% of the publications. The areas of "business, management, and accounting" and "social sciences" occupies the fourth position, with 47 documents, or 8% the publications.

Table 2
Documents by subject area (Source: Scopus 2022)

Subject area	**No. of Documents**	**%**
Computer Science	171	28.98%
Engineering	114	19.32%
Decision Sciences	67	11.36%
Business, Management, and Accounting	47	7.97%
Mathematics	40	6.78%
Social Sciences	36	6.10%
Environmental Science	24	4.07%
Energy	18	3.05%
Physics and Astronomy	13	2.20%
Agricultural and Biological Sciences	10	1.69%
Materials Science	10	1.69%
Chemical Engineering	9	1.53%
Medicine	9	1.53%
Earth and Planetary Sciences	8	1.36%
Economics, Econometrics, and Finance	4	0.68%
Biochemistry, Genetics, and Molecular Biology	3	0.51%

Psychology	2	0.34%
Chemistry	1	0.17%
Health Professions	1	0.17%
Immunology and Microbiology	1	0.17%
Nursing	1	0.17%
Pharmacology, Toxicology and Pharmaceutics	1	0.17%
TOTAL	590	100.00%

Note. A publication can be classified under more than one subject area.

The VOSviewer software was used to create maps of co-authorship and keyword co-occurrence based on bibliographic data. The co-authorship analysis required at least five documents per country (Figure 6); 14 of the 63 countries identified met this threshold. In this regard, Figure 6 depicts the network map of international collaboration among major countries (those with the highest total link strength) engaged in blockchain and AI for supply chain research. The colours denote the clusters to which countries are assigned according to the strength of their relationships, while the surface area of the circles indicates the number of publications secured by each country. We can see that there are a total of six clusters.

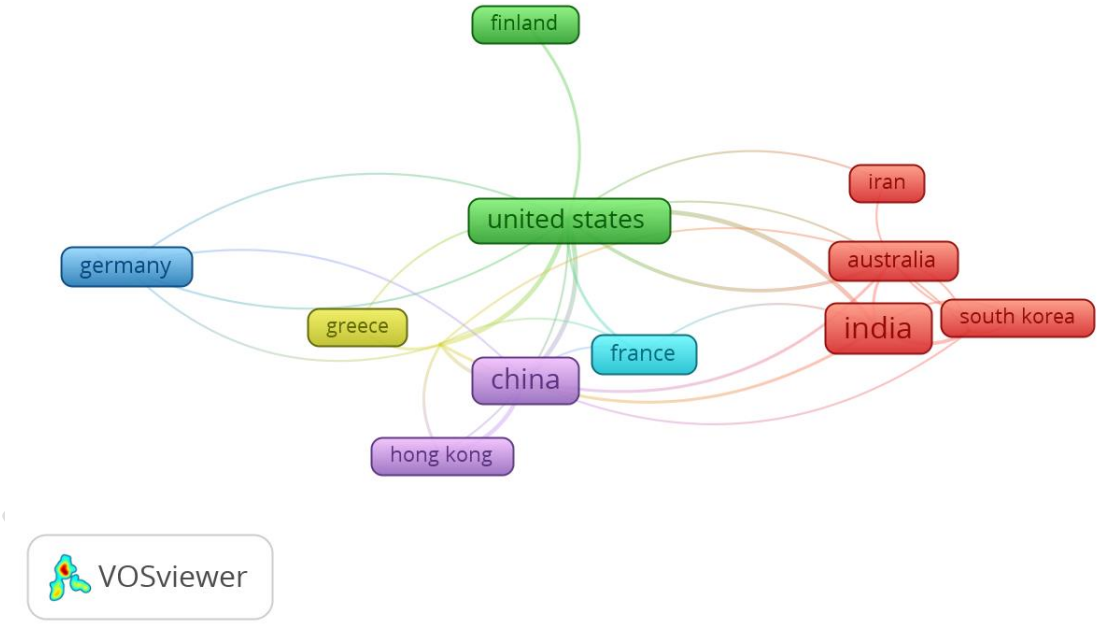

Figure 6. Co-authorship network of countries.

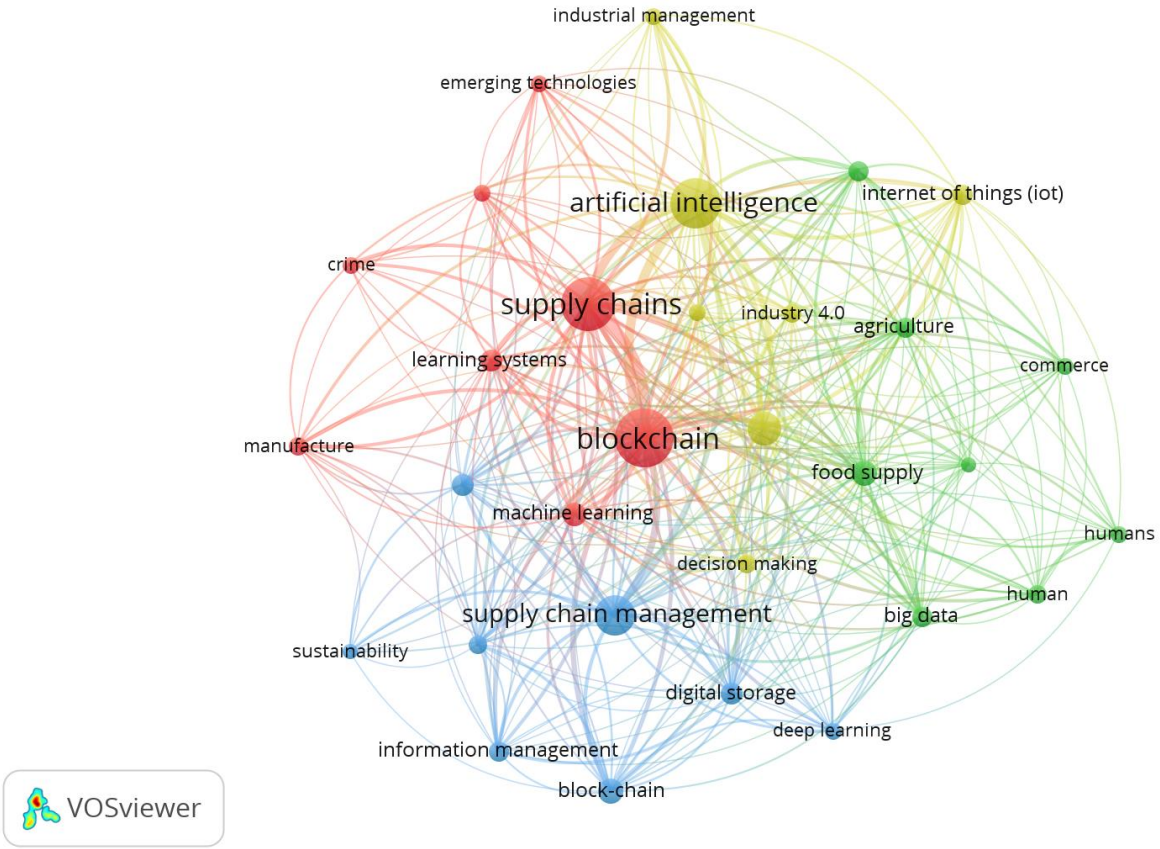

Figure 7. Network map showing the relations between various topics in the literature on blockchain and AI for supply chain (280 documents).

Using index keywords as the unit of analysis, a minimum of six occurrences per keyword and full counting as the counting method, a keyword co-occurrence analysis (Figure 7) was performed. Of the 1210 keywords, 35 met the threshold. The total strength of the co-occurrence links with other keywords was calculated for each of the 35 keywords. We chose the keywords with the most total link strength. Keywords are denoted by coloured frames, the size of which is proportional to the number of times the keyword appears in the document.

Moreover, these keywords are grouped into four clusters that seem thus to assume a prominent role vis-à-vis “food and agriculture” (green cluster), “risk, resilience, and sustainability” (blue cluster), “security and ethical governance” (red cluster), and “emerging technologies and their benefits” (yellow cluster). This is indicative of the thematic areas that have captured the interest of researchers in the area of blockchain and AI for supply chains.

3.3 Pool of research articles on the integration of blockchain and AI

After obtaining an overall view of "what is out there" in terms of existing literature on the topic, that is, the 280 records previously discussed in Section 3.2, we added, as previously mentioned, a second stage in which we narrowed our search results in order to bring additional accuracy and identify only those studies that specifically dealt with the integration of blockchain and AI

for supply chain. On this occasion, it was decided to look only at research articles in order to clearly identify complete and published research work that had also been peer-reviewed. This consideration resulted in the selection of 75 research articles for further analysis (see previous Table 1). Following that, the authors manually reviewed these 75 research articles to determine whether or not they dealt with the integration of blockchain and AI for supply chain.

Studies were considered for further analysis if they met the following criteria:

1. The articles treated the topics of "blockchain", "AI" (or any of its proxies, "machine learning", "neural network", or "deep learning"), and "supply chain" as a core question.
2. Regardless of whether the studies were literature reviews, conceptual works, empirical, case studies, or experimental, the studies clearly focused on the integration of blockchain and AI for supply chain.
3. The studies included research that was published in English, regardless of the year of publication.

Articles were excluded if:

1. The topics of "blockchain" and "AI" (or any of its proxies, "machine learning", "neural network", and "deep learning") were treated separately, with no emphasis on their integration.
2. Because the full text was not available, we were unable to verify the content.
3. The journal publication was discontinued, which also meant that the full text was no longer available (hence, we were unable to verify the content).
4. Despite being labelled as research articles, the records were discovered to be other types of publications, such as editorials.
5. The articles used the terms "blockchain" and/or "AI" (or any of its proxies, "machine learning", "neural network", or "deep learning") to analyse empirical data in the context of a supply chain, which was outside the scope of our focus.

The use of the aforementioned criteria resulted in a final pool of 43 research articles. Table 3 summarises the characteristics of the studies examined. Surprisingly, a manual content analysis of these 43 studies revealed that the previously identified thematic clusters can still be used to categorise this pool of studies. In this regard, it was discovered that 18 studies could be classified as belonging to the "Emerging Technologies and Their Benefits" cluster, 14 studies as belonging to the "Food and Agriculture" cluster, 8 studies as belonging to the "Risk, Resilience, and Sustainability" cluster, and 3 as belonging to the "Security and Ethical Governance" cluster.

-Insert Table 3 here-

It is also worth noting that the vast majority of these studies (30 articles) are conceptual in nature, followed by experimental (15 articles), literature reviews (8 articles), case studies (6 articles), and, finally, empirical studies (5 articles). Of course, with the caveat that some articles combine conceptual and literature review, conceptual and empirical, and so on (see Table 3). Such findings emphasise the still-emerging nature of studies focusing on the integration of

blockchain and AI for supply chain, indicating that more empirically completed studies are still required to fully understand what such a field has to offer from a very practical standpoint. In the next section, we proceed to interpret the identified thematic clusters. To be noted that additional searches for materials relevant to our discussion were further conducted using the referenced works of the main pool of 43 articles (snowball effect) and included herein. Section 4 thus complements the information presented in Table 3.

4. Interpreting Clusters

Cluster 1: Food and Agriculture

AI and machine learning (ML), big data analytics, cloud computing, IoT, robotics, and blockchain are examples of disruptive information and communication technologies that can help to solve problems like increasing productivity and yield, conserving water, ensuring soil and plant health, and improving environmental stewardship. According to Lezoche *et al*. (2020), these technologies "will let the agriculture to evolve in a data-driven, intelligent, agile and autonomous connected system of systems".

Apart from the sustainability benefits, AI-ML applications in particular can help to improve supply chain transparency, visibility, and product traceability (Sharma *et al*., 2020). However, all these are ongoing efforts and practitioners will need to investigate the possibilities of combining various sources of AI-ML data with blockchain technology and other technologies to a greater extent (Kamble *et al*., 2018; Sharma *et al*., 2018). Studies have started to emerge. Using RFID (Radio-Frequency IDentification) and Blockchain technology, Tian (2016), for example, gathered and transferred trusted information to reduce agri-food risk in order to build a supply chain traceability system. It is worth noting that our review revealed that building product traceability systems is one of the most common research endeavours that researchers are currently engaged in.

Smart contracts and cybersecurity are two critical applications of blockchain in the domain of agriculture. The Internet of Things enables precise sensing throughout the supply chain. With smart contracts, all transactions are documented in a distributed manner. Immutable transaction histories from raw material suppliers to consumers would aid in food quality control, increase traceability, and, ultimately, resolve food safety concerns. Blockchain-based smart contract technologies are expected to enable the agri-food supply chain's digital transformation, resulting in a "traceable, transparent, trustful, and intelligent ecosystem" (Liu, Ma, *et al*., 2021, p. 4330).

Tripoli and Schmidhuber (2018) highlighted how data generated by the IoT can be used to enhance the details of blockchain transactions. Then, the precise data provided by blockchain technology can be used to power AI applications (Rabah *et al*., 2018). Moreover, AI can enhance IoT by developing applications that use machine learning algorithms to analyse data captured by sensors in real time (Reshma & Pillai, 2018).

Sharma *et al*. (2020) performed a systematic literature review of machine learning applications in agricultural supply chains and found that all three ML algorithms, that is, supervised, unsupervised, and reinforcement learning, are used to develop sustainable agricultural supply chains. However, the study does not discuss the integration between ML algorithms and blockchain. On the other hand, Putri *et al*. (2020) noted that in the future, hyperledger blockchains can be developed and implemented using AI, allowing for the prediction, classification, and clustering of existing data and transactions based on their time period.

Although most of materials identified represent a theoretical treatment of the subject, there are a few studies that demonstrate successful integration of blockchain and AI techniques for supply chain traceability improvement, such as the study by Chen (2018). In this sense, Chen (2018) proposed a novel approach called Takagi–Sugeno Fuzzy cognitive maps artificial neural network as a traceability chain algorithm.

Cluster 2: Risk, Resilience, and Sustainability

Supply chain network complexity, combined with external factors, has resulted in supply chain disruptions over the last few years (Fan & Stevenson, 2018). Most recently, the pandemic has focused renewed attention on sustainability. As a matter of fact, no recent event has highlighted the vulnerability of supply chains as much as the COVID-19 outbreak in early 2020 (Pournader, Kach, & Talluri, 2020; Spieske & Birkel, 2021).

The medical supply chain, especially for pharmaceutical drugs, has been particularly affected. COVID-19's sudden emergence and uncontrolled global spread has exposed the inadequacies of the current healthcare systems across the world in responding to public health emergencies in a timely manner. Breakthrough technologies like blockchain and AI have emerged as viable and sustainable solutions for combating the pandemic in such circumstances (Baz *et al*., 2022) and this has evolved into a common research endeavour that has recently piqued the interest of researchers. In this context, research has emerged looking at medical supply chain and drugs and pharmaceutical supply chain management.

The COVID-19 outbreak has the potential to strain existing healthcare systems. At the moment, there is a dearth of a reliable data surveillance system capable of providing relevant healthcare organisations with real-time information about potential outbreaks. Indeed, the majority of existing Covid-19 data originates from a wide range of sources, including the general public, hospitals, and clinical laboratories, and contains a substantial amount of incorrect information that has not been thoroughly monitored (Nguyen *et al*., 2021).

Blockchain technology can assist in combating the COVID-19 pandemic by facilitating early detection of outbreaks, ensuring a secure drug supply chain and expediting drug delivery, and establishing consensus on the ordering of Covid-19 data records (Baz *et al.*, 2022). Additionally, AI-based supervised and unsupervised ML techniques enable the development of intelligent solutions for real-time epidemic outbreak monitoring, pandemic trend

forecasting, coronavirus symptom identification for treatment, and drug manufacturing support.

Nguyen *et al*. (2021) conducted a comprehensive survey on the use of blockchain and AI in the fight against the recent pandemic. The authors introduced a novel conceptual architecture that integrates blockchain and AI to combat Covid-19 and reviewed recent studies on the use of blockchain and AI to combat Covid-19 in a multitude of scenarios, including the medical supply chain.

Blockchain-based smart contracts are computer programmes that carry out the terms of a contract when certain objectives are satisfied (Griggs *et al*., 2018). Automating auditing processes, medical supply chain management, outbreak tracking, and remote patient monitoring could all be done using smart contracts based on blockchain technology (Griggs *et al*., 2018; Roosan *et al.*, 2022). Using blockchain-based smart contracts, pharmaceutical supply chains can be improved, and their quality and regulatory compliance can be verified, all while automating auditing processes (Angeles, 2018).

These combined technologies were further examined by Jabarulla and Lee (2021) to see if they could be used to help with the conventional public health strategies for combating Covid-19, such as contact tracing, outbreak estimation, coronavirus detection and analysis, as well as the management of clinical data and the supply chain, among others.

The patient-centred approach to healthcare could be reshaped by integrating blockchain and AI technology (Chen *et al*., 2019; Jabarulla & Lee, 2021; Ploug & Holm, 2020). In turn, it is possible that a patient-centred approach to dealing with the coronavirus pandemic could be useful in distributing treatment and managing pandemics (Jabarulla & Lee, 2021).

The combination of blockchain and AI technologies enables the development of an all-encompassing predictive system that could help to keep the threat of a pandemic at bay within a country's borders (Fusco *et al*., 2020). Moreover, the public surveillance system can be made more effective and robust by combining blockchain technology with AI and geographic information systems (Sharma *et al*., 2020).

Another research strand that has been gaining momentum is the use of blockchain-AI integration for circular economy and sustainability. Studies like Ebinger and Omondi's (2020) report on the current use of digital technologies (such as blockchain, cloud computing, and AI) in sustainable supply chain management provide further evidence of the progress being made in this area. A blockchain-enabled and Intelligent Agent-supported supply chain community that is intelligent and responsive, as well as secure and sustainable has been proposed by Pimenidis *et al.* (2021). Chidepatil *et al*. (2020) discussed how blockchain and multi-sensor-driven AI can transform the circular economy of plastic waste. When it comes to the protection and preservation of the global environment, including life on land, life underground, and climate change, Sivarethinamohan and Sujatha (2021) looked at how AI-driven blockchain technology could be put to use for this purpose.

Cluster 3: Security and Ethical Governance

Recent surges in security breaches and digital surveillance have highlighted the need for enhanced privacy and security, particularly with regard to users' personal data (Heister & Yuthas, 2021). Blockchain technologies enable novel methods of protecting user data through decentralised identity and other privacy mechanisms. These systems can empower users by providing tools that enable them to own and handle their data. On the other hand, AI opens up new avenues for improving system and user security.

As Heister and Yuthas (2021) highlighted, "*blockchain provides new mechanisms, such as decentralized identities and zero-knowledge proofs, that enable data to be shared in ways that maintain the privacy of the individual and allow users to maintain control over their own data. These advances can provide both increased cybersecurity and more ethical use of personal data. Blockchain participants can realize these outcomes through careful development of governance frameworks and mechanisms*". As a result, advancements in these technologies open up new avenues for the ethical use of data.

Furthermore, by improving the quality, transparency, traceability, and security of data, blockchain can improve the capabilities of other technologies and techniques such as AI and IoT in-process monitoring, trend prediction and decision-making, among others (Sun & Zhang, 2020). The combination of blockchain, AI, and supply chains may result in an improvement in information management for interconnected devices. A recent study by Unal *et al.* (2021) presented a practical approach for integrating blockchain with federated learning in order to provide private and secure big data analytics services.

One of the driving forces behind blockchain and AI in supply chains is information management. Supply chains can use blockchain technology to organise a reliable and secure digital transition in which all operations can potentially be digitised. Implementing blockchain and AI on information management tasks can result in administrative benefits such as time savings, improved information quality, and increased security. All of these developments are currently the subject of ongoing research efforts.

Cluster 4: Emerging Technologies and Their Benefits

Blockchain, AI, cloud computing, IoT, cyber-physical systems, and robotics are examples of recent technological developments (components of Industry 4.0) that enable the integration of disparate supply chain advancements into intelligent and connected Systems of Systems. These technologies have the capability for strengthening the supply chain management and will assist the relevant sectors in becoming data-driven, agile, intelligent, and automated. Table 3 showcases recent studies, with applications ranging from healthcare, business, and financial services to the automobile industry and humanitarian logistics.

Rodríguez-Espíndola *et al*. (2020), for example, argued that integrating disparate technologies is critical for the humanitarian supply chain to reap real gains. To accomplish this, the authors

proposed a framework for enhancing the flow of information, products, and financial resources in humanitarian supply chains through the integration of three emerging disruptive technologies: blockchain, AI, and 3D printing. Their analysis demonstrates that the framework has the potential to alleviate supply chain congestion, improve simultaneous collaboration among various stakeholders, reduce lead times, improve accountability, traceability, and transparency of material and financial resources, and empower victims to contribute to their own needs fulfilment.

Applications can also combine blockchain with machine learning (Ramezani & Camarinha-Matos, 2020). This combination of technologies would enable systems to improve continuously, respond more quickly and effectively to disruptions, and predict potential failures.

Given recent advancements in these fields, the adoption of smart products based on IoT and other technologies may necessitate systems with high data integrity and user privacy, which can only be furnished by blockchain technology (Chanson *et al*., 2019). Moreover, by integrating AI and blockchain with IoT sensors and edge devices, supplies chains can work toward becoming "smart supply chains".

These technologies also make intelligent transportation systems possible. Self-driving cars can use IoT sensors to constantly monitor and, in some cases, predict developments using AI, while also incorporating blockchain wallets that allow passengers to pay for rides, rentals, tolls, and other services without revealing personal information (Heister & Yuthas, 2021).

5. Conclusions and Future Research Directions

Blockchain and AI technologies are rapidly evolving, opening up new avenues for working with data that were previously unimaginable. They are setting the pace of innovation and introducing a radical shift in almost every industry. On their own, blockchain and AI are cutting-edge technologies, but when combined, they can be truly revolutionary, of course, as long as such integration is underpinned by a problem-centric thinking approach (Charles *et al*., 2022). Each of them has the potential to improve the other's capabilities, allowing for better oversight and accountability.

Although blockchain and AI have been explored in the extant literature on operations management, no state-of-the-art review of blockchain and AI integration in the field of supply chain was identified. This article is, therefore, the first to provide an overview and assessment of such studies. More specifically, we sought to answer the following three principal research questions: Q1 – What are the studies on the integration of blockchain and AI in supply chain?, Q2 – What are the blockchain and AI use cases in supply chain?, and Q3 – What are the potential research directions for future studies involving the integration of blockchain and AI?

To answer the first two questions, we queried the SCOPUS database. Our search turned up 280 results, all of which were published between 2017 and 27 March 2022. Early on, it was noted

that the majority of the material published was conceptual in nature rather than empirical. This indicated that the field of blockchain and AI convergence is still in its infancy. Given the field's nascent status, as evidenced also by the large number of publications other than completed research articles, we decided not to remove any of the materials we came across. This was done so that we could get a sense of what researchers in the field are currently interested in. A bibliometric analysis of the materials revealed four main themes that have piqued researchers' interest. These themes are "Emerging Technologies and Their Benefits", "Food and Agriculture", "Risk, Resilience, and Sustainability", and "Security and Ethical Governance", which are also indicative of the most significant use cases. Based on the findings of this study, a number of future research directions have been outlined below, which helps us to answer the third research question.

First, as previously mentioned, most of the works reviewed are conceptual rather than empirical in nature. In other words, empirical studies aimed at implementing blockchain-AI applications in real life are still lacking. This, in turn, limits the full validity of conversations on the topic. Blockchain is still in its infancy, and so is the integration of blockchain with other emerging technologies such as AI. Therefore, many flaws must be addressed before any benefits and long-term effects can be observed in practice. Empirical studies focusing on the actual deployment of AI-driven blockchain technology for supply chain and its implications on long-term performance make thus an interesting and promising future research direction.

Second, the integration between blockchain and AI can prove to be highly advantageous especially for the healthcare sector, while at the same time tackling existing ethical issues. The Covid-19 pandemic has compelled medical researchers and technologists alike to look into methods of rapidly collecting information about virus exposure and transmission while maintaining user privacy. Testing patients who may have been exposed to the virus quickly with point-of-care diagnostics has proven effective in tracing its spread and mitigating its effects. Blockchain and AI can help by collecting the data on blockchain infrastructure and then quickly analysing it using AI. Moreover, blockchain and AI can be combined with other technologies, such as cloud computing, to create more comprehensive and efficient systems. High computational power and resourceful storage are two of the most important aspects of the cloud that can aid in AI analytics. The integration of these promising technologies can be further explored in the near future to create highly advanced medical systems to combat future coronavirus-like pandemics.

Third, our analysis reveals that more studies are needed to explore the integration of blockchain and AI from an environmental sustainability, social, and economic points of view (triple bottom line perspective). In the end, blockchain and AI are merely tools, and their long-term effects are largely determined by the underlying vision and strategies that companies choose to govern their daily operations. As a result, more research is needed to optimise the range of business initiatives and strategies as well as the technology choices in order to achieve the United Nation's Sustainable Development Goals. The needs of multiple stakeholders and the complexity of multi-layered supply chains should be taken into account in future analyses.

Finally, because the integration of blockchain and AI for supply chain is still in its early stages, more cross- and inter-disciplinary empirically grounded research, particularly research approaches to study practice in truly insightful and impactful ways, is required (Charles & Gherman, 2018). As the concept of distributed ledger technologies evolves over time, new AI-based emerging technologies surface, and new sustainability debates emerge, such endeavours will necessitate the participation of a wide range of stakeholders, from researchers to practitioners and policymakers (Charles, Gherman, & Paliza, 2019).

The present paper is not without limitations. Our analysis and findings are limited to the Scopus scientific database, which was chosen for its consistent citation metrics and precision in locating authors and institutions. Despite this, the Scopus database is the largest database of peer-reviewed literature and further offers a comprehensive coverage of articles in Business, Economics, Management, and Social Sciences in general. As a result, we are confident that the works identified and included in this paper provide a reasonably good overview of what has been published on the topic of blockchain and artificial intelligence integration for supply chain, as well as current and future interests on the topic. Future studies can, of course, complement the current study by including other databases. Additionally, future studies can expand the scope of the present study by detailing the challenges and limitations of existing researches. We hope, however, that the current work serves as a foundation for future research studies.

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Table 3

Critical Taxonomy of Articles Dealing with the Integration of Blockchain and AI for Supply Chain

Authors	Journal	Article Title	Research Aim	Article Type	Topic/ Domain	Emerging Technologies Employed in Empirical/ Experimental/Case Study Analysis
Dey, S., Saha, S., Singh, A.K., McDonald-Maier, K. (2022)	Smart Cities	SmartNoshWaste: Using Blockchain, Machine Learning, Cloud Computing and QR Code to Reduce Food Waste in Decentralized Web 3.0 Enabled Smart Cities	To propose SmartNoshWaste, a multi-layered blockchain-based framework that uses cloud computing, QR codes, and reinforcement learning to reduce food waste. To demonstrate the efficacy of the proposed framework, the authors test SmartNoshWaste on real-world food data collected from the nosh app.	Conceptual & Empirical	Food & Agriculture	Blockchain, Cloud Computing, Reinforcement Learning, QR Code
Kamble, S.S., Gunasekaran, A., Parekh, H., (...), Belhadi, A., Sharma, R. (2022)	Technological Forecasting and Social Change	Digital twin for sustainable manufacturing supply chains: Current trends, future perspectives, and an implementation framework	To present a systematic literature review of 98 research papers on various digital supply chain twin dimensions with sustainable performance objectives.	Literature Review & Conceptual	Emerging Technologies & Their Benefits	-
Luo, S., Choi, T.-M. (2022)	Asia-Pacific Journal of Operational Research	Operational Research for Technology-Driven Supply Chains in the Industry 4.0 Era: Recent Development and Future Studies	To examine the OR literature on Industry 4.0 related studies.	Literature Review	Emerging Technologies & Their Benefits	-
Ahamed, N.N., Vignesh, R. (2022)	Journal of Computer Science	Smart Agriculture and Food Industry with Blockchain and Artificial Intelligence	To discuss how industry 4.0 turns into 5.0.	Conceptual	Food & Agriculture	-
Bragadeesh, S.A., Umamakeswari, A. (2022)	Computer Systems Science and Engineering	Secured vehicle life cycle tracking using blockchain and smart contract	To propose a Harmonic Optimized Gradient Descent and Łukasiewicz Fuzzy (HOGDLF) Vehicle Life Cycle Tracking in Cloud Environment.	Experimental	Emerging Technologies & Their Benefits	Blockchain, Cloud Computing

					(application to automotive industry)	
Suroso, A.I., Rifai, B., Hasanah, N. (2021)	International Journal of Information and Management Sciences	Traceability System in Hydroponic Vegetables Supply Chain Using Blockchain Technology	To design a traceability system using a rapid structured prototyping approach that combines the System Development Life Cycle (SDLC) and Prototyping methods.	Conceptual & Empirical	Food & Agriculture	Blockchain, QR Code
Eluubek kyzy, I., Song, H., Vajdi, A., Wang, Y., Zhou, J. (2021)	Expert Systems with Applications	Blockchain for consortium: A practical paradigm in agricultural supply chain system	To investigate the use of blockchain technology in the formation of consortiums.	Conceptual & Experimental	Food & Agriculture	Blockchain, Ant Colony
Martínez, J., Durán, J.M. (2021)	International Journal of Safety and Security Engineering	Software supply chain attacks, a threat to global cybersecurity: SolarWinds' case study	An exploratory review of academic literature, government information, but also articles and reports published by various cybersecurity consulting firms and software providers was conducted to analyse the SolarWinds case study.	Literature Review & Case Study	Security and Ethical Governance	-
Unal, D., Hammoudeh, M., Khan, M.A., (...), Epiphaniou, G., Hamila, R. (2021)	Computers and Security	Integration of federated machine learning and blockchain for the provision of secure big data analytics for Internet of Things	To present a practical approach for integrating Blockchain with Federated Learning in order to provide private and secure big data analytics services.	Conceptual & Experimental & Case Study (Pharmaceutical industry supply chains)	Security and Ethical Governance	Blockchain, Federated Learning, Edge Computing, IoT
Baz, M., Khatri, S., Baz, A., (...), Agrawal, A., Khan, R.A. (2021)	Computer Systems Science and Engineering	Blockchain and artificial intelligence applications to defeat COVID-19 pandemic	To explore the application of blockchain and AI in order to fight with COVID-19 epidemic scenarios.	Conceptual	Emerging Technologies & Their Benefits (application to health care)	-

Monteiro, E.S., Righi, R.D.R., Barbosa, J.L.V., Alberti, A.M. (2021)	Applied Sciences (Switzerland)	APTM: A model for pervasive traceability of agrochemicals	The agrochemical pervasive traceability model (APTM) is introduced in the paper, which combines machine learning, sensors, microcontrollers, gamification, and two blockchains.	Conceptual & Experimental	Food & Agriculture	Blockchain, IoT, Machine Learning
Khadke, S., Gupta, P., Rachakunta, S., (...), Dash, J.K., Dalapati, G.K. (2021)	Sustainability (Switzerland)	Efficient plastic recycling and remolding circular economy using the technology of trust–blockchain	The paper discusses the use of machine learning and an Auto-Regressive Integrated Moving Average in plastic production (ARIMA). It also discusses the use of blockchain technology to increase plastic recycling and the circular economy.	Conceptual	Risk, Resilience, and Sustainability	-
Wong, S., Yeung, J.K.W., Lau, Y.-Y., So, J. (2021)	Sustainability (Switzerland)	Technical sustainability of cloud-based blockchain integrated with machine learning for supply chain management	The paper proposes the design of a robust blockchain architecture based on machine learning that is implemented on a cloud infrastructure.	Conceptual & Case Study	Risk, Resilience, and Sustainability	Blockchain, Cloud Computing, Machine Learning
Liu, Y., Zhang, S., Chen, M., Wu, Y., Chen, Z. (2021)	Sustainability (Switzerland)	The sustainable development of financial topic detection and trend prediction by data mining	The paper conducts data mining on 759 papers related to blockchain technology in the financial field using Web of Science bibliometrics data.	Literature Review	Risk, Resilience, and Sustainability	-
Runzel, M.A.S., Hassler, E.E., Rogers, R.E.L., Formato, G., Cazier, J.A. (2021)	IEEE Consumer Electronics Magazine	Designing a Smart Honey Supply Chain for Sustainable Development	This article demonstrates how to build and deploy an open, image-based traceability system for sustainable development around the world. The intelligent distribution system is based on blockchain technology, pollen signature verification using machine learning algorithms, and a final customer information portal.	Conceptual	Food & Agriculture	-
Dadi, V., Nikhil, S.R., Mor, R.S., Agarwal, T., Arora, S. (2021)	Production Engineering Archives	Agri-food 4.0 and innovations: Revamping the supply chain operations	This paper presents a systematic review of the innovations in the agri-food for digital technologies such as internet-of-things, artificial intelligence, big data,	Literature Review	Food & Agriculture	-

			RFID, robotics, block-chain technology, etc.			
Lee, C.-H., Yang, H.-C., Wei, Y.-C., Hsu, W.-K. (2021)	Applied Sciences (Switzerland)	Enabling blockchain based scm systems with a real time event monitoring function for preemptive risk management	The paper combines a method of real-time event detection based on collected Twitter data with blockchain technology for event monitoring in order to improve the visibility of the supply chain system and take preemptive risk-aversion measures.	Conceptual & Experimental	Risk, Resilience, and Sustainability	Blockchain, Clustering Algorithm
Liu, Y., Ma, X., Shu, L., Hancke, G.P., Abu-Mahfouz, A.M. (2021)	IEEE Transactions on Industrial Informatics	From Industry 4.0 to Agriculture 4.0: Current Status, Enabling Technologies, and Research Challenges	The paper examines the current state of industrial agriculture, as well as the lessons learned from industrialised agricultural production patterns, industrialised agricultural production processes, and the industrialised agri-food supply chain. In addition, five emerging technologies, namely the Internet of Things, robotics, artificial intelligence, big data analytics, and blockchain, are discussed in relation to Agriculture 4.0.	Literature Review	Food & Agriculture	-
Szymonik, A. (2021)	Sustainability (Switzerland)	Impact of selected intelligent systems in logistics on the creation of a sustainable market position of manufacturing companies in Poland in the context of industry 4.0	To assess the level of intelligent system implementation in logistics among Polish manufacturing companies, as well as the impact that these systems may have on their market position.	Empirical	Emerging Technologies & Their Benefits (application to business - SMEs)	Blockchain, IoT, Cloud Computing
Bamakan, S.M.H., Faregh, N., Zareravasan, A. (2021)	Journal of Computational Design and Engineering	Di-ANFIS: An integrated blockchain-IoT-big data-enabled framework for evaluating service supply chain performance	The primary goals of this research are as follows: (1) presenting hierarchical criteria of service supply chain performance to cope with the diagnosis of the problems' root; (2) proposing a smart learning model to deal with the uncertainty conditions by a combination of neural network and fuzzy logic; and	Conceptual	Emerging Technologies & Their Benefits	Blockchain, IoT, ANFIS

			(3) introducing a distributed blockchain-based framework due to the dependence of ANFIS on big data and the lack of trust and security in the supply chain.			
Saurabh, S., Dey, K. (2021)	Journal of Cleaner Production	Blockchain technology adoption, architecture, and sustainable agri-food supply chains	To identify the determinants of blockchain integrated ICTs adoption for the supply chain actors and their propensity to embrace and use such technologies.	Conceptual & Empirical	Food & Agriculture	-
Hopkins, J.L. (2021)	Computers in Industry	An investigation into emerging industry 4.0 technologies as drivers of supply chain innovation in Australia	To use supply chain practitioners' experience to determine the current level of adoption of a number of key Industry 4.0 technologies, understand what preparatory measures firms are taking to ensure they are digitally-ready to use Industry 4.0 technologies, recognise how and where these technologies are likely to impact supply chains, and investigate whether organisational size is a factor in technology adoption.	Empirical	Emerging Technologies & Their Benefits	-
Zhang, P., Liu, X., Li, W., Yu, X. (2021)	Journal of Internet Technology	Pharmaceutical Cold Chain Management Based on Blockchain and Deep Learning	This paper proposes a pharmaceutical cold chain supervision scheme based on blockchain, cloud storage, and the Internet of Things to achieve trusted traceability of pharmaceutical products throughout their entire life cycle and ensure product safety. Then, using the high-quality and large-scale data generated by the proposed cold chain supervision system, a deep learning-based cold chain product demand forecasting scheme is built to aid in cold chain inventory management decision-making.	Conceptual & Experimental	Emerging Technologies & Their Benefits (application to pharmaceutical industry)	Blockchain, IoT, Deep Learning, Cloud Computing

Singh, P.D., Kaur, R., Dhiman, G., Bojja, G.R. (2021)	Expert Systems	BOSS: A new QoS aware blockchain assisted framework for secure and smart healthcare as a service	To establish a reliable platform for early-stage detection of COVID-19 infection by combining fog computing and artificial intelligence with smart health. To detect COVID-19 patients, a new ensemble-based classifier is proposed. This study provides a blockchain platform for analysing how unrelated cases of the COVID-19 virus can be tracked and identified using blockchain's peer-to-peer, time stamping, and shared storage benefits.	Conceptual	Emerging Technologies & Their Benefits (application to healthcare)	Blockchain, Cloud Computing, Fog Computing, IoT
Nandi, S., Hervani, A.A., Helms, M.M., Sarkis, J. (2021)	International Journal of Logistics Research and Applications	Conceptualising Circular economy performance with non-traditional valuation methods: Lessons for a post-Pandemic recovery	To conceptualise a performance measurement model (CEPMM) that is illustrated using seven COVID-19 disruption scenarios in order to provide insights that can be addressed through circular economy practices.	Conceptual	Risk, Resilience, and Sustainability	-
Dwivedi, S.K., Roy, P., Karda, C., Agrawal, S., Amin, R. (2021)	Security and Communication Networks	Blockchain-Based Internet of Things and Industrial IoT: A Comprehensive Survey	To investigate the integration of IoT and blockchain technology, as well as to provide an in-depth analysis of blockchain-enabled IoT and Industrial IoT systems.	Literature Review	Emerging Technologies & Their Benefits	-

Bechtsis, D., Tsolakis, N., Iakovou, E., Vlachos, D. (2021)	International Journal of Production Research	Data-driven secure, resilient and sustainable supply chains: gaps, opportunities, and a new generalised data sharing and data monetisation framework	The study provides a critical taxonomy of the relevant literature and identifies gaps in the following areas: (i) the impact of security on supply chain operations; (ii) cost-effective resiliency strategies and practices; and (iii) the social and labour dimensions of sustainability. The study then proposes a new generalised framework that incorporates all of the identified challenges, gaps in literature and practice, and opportunities in supply chain management research, and validates it using a real-world case study of the organic food supply chain.	Literature Review & Conceptual & Case Study	Risk, Resilience, and Sustainability	-
Wang, Y. (2021)	Wireless Communications and Mobile Computing	Research on Supply Chain Financial Risk Assessment Based on Blockchain and Fuzzy Neural Networks	This paper employs blockchain and fuzzy neural network algorithms to investigate the credit risk of SME financing from the standpoint of supply chain finance.	Experimental	Emerging Technologies & Their Benefits (application to financial sector)	Blockchain, Fuzzy Neural Networks
Chen, H., Chen, Z., Lin, F., Zhuang, P. (2021)	IEEE Access	Effective management for blockchain-based agri-food supply chains using deep reinforcement learning	The paper first proposes a blockchain-based ASC framework for product traceability, which ensures decentralised security for agri-food tracing data in ASCs. Following that, a Deep Reinforcement Learning based Supply Chain Management (DR-SCM) method is proposed to make effective decisions on the production and storage of agri-food products for profit optimisation.	Experimental	Food & Agriculture	Blockchain, Deep Reinforcement Learning
Shahbazi, Z., Byun, Y.-C. (2021)	Electronics (Switzerland)	A procedure for tracing supply chains for perishable food based on blockchain, machine learning and fuzzy logic	In this paper, a blockchain machine learning-based food traceability system (BMLFTS) is proposed to combine the new blockchain extension, Machine Learning technology, and fuzzy logic traceability system based on the shelf-life	Conceptual & Experimental & Case Study	Food & Agriculture	Blockchain, Machine Learning

			management system for manipulating perishable food.			
Sobb, T., Turnbull, B., Moustafa, N. (2020)	Electronics (Switzerland)	Supply chain 4.0: A survey of cyber security challenges, solutions and future directions	This paper describes the nature of military supply chains 4.0 and how they differ from commercial supply chains, revealing their strengths, weaknesses, dependencies, and the fundamental technologies on which they are built.	Conceptual	Security and Ethical Governance	-
Rodríguez-Espíndola, O., Chowdhury, S., Beltagui, A., Albores, P. (2020)	International Journal of Production Research	The potential of emergent disruptive technologies for humanitarian supply chains: the integration of blockchain, Artificial Intelligence and 3D printing	The literature on humanitarian supply chains looks at isolated applications of technology and lacks a framework for understanding challenges and solutions, a gap that this article aims to fill. Using a case study based on the flood of Tabasco of 2007 in Mexico, this research identifies solutions based on the use of emergent disruptive technologies.	Conceptual & Case Study	Emerging Technologies & Their Benefits (application to humanitarian logistics)	Blockchain, Artificial Intelligence, 3D Printing
Ebinger, F., Omondi, B. (2020)	Sustainability (Switzerland)	Leveraging digital approaches for transparency in sustainable supply chains: A conceptual paper	Based on the theoretical framework of Sustainable Supply Chain Transparency (SSCT) in Sustainable Supply Chain Management (SSCM), this conceptual article aims at initiating the discussion on digitalisation in SSCM.	Conceptual	Risk, Resilience, and Sustainability	-
Chidepatil, A., Bindra, P., Kulkarni, D., (...), Kshirsagar, M., Sankaran, K. (2020)	Administrative Sciences	From trash to cash: How blockchain and multi-sensor-driven artificial intelligence can transform circular economy of plastic waste?	The paper describes ongoing efforts to categorise plastics and improve the reliability of information about recycled plastics using the first-of-its-kind blockchain smart contracts powered by multi-sensor data-fusion algorithms powered by artificial intelligence.	Conceptual	Risk, Resilience, and Sustainability	Blockchain, Artificial Intelligence
Yong, B., Shen, J., Liu, X., (...), Chen, H., Zhou, Q. (2020)	International Journal of Information Management	An intelligent blockchain-based system for safe vaccine supply and supervision	The main objective of this study is to develop a “vaccine blockchain” system based on blockchain and machine learning technologies.	Conceptual & Experimental	Emerging Technologies & Their Benefits (application to health care)	Blockchain, Machine Learning

Khan, P.W., Byun, Y.-C., Park, N. (2020)	Sensors (Switzerland)	IoT-blockchain enabled optimized provenance system for food industry 4.0 using advanced deep learning	This article takes the secure IoT–blockchain data of Industry 4.0 in the food sector as a research object. It proposes a hybrid model based on recurrent neural networks using ADL techniques. As a result, it employs long short-term memory and gated recurrent units as a prediction model, as well as genetic algorithm optimisation, to optimise the hybrid model's parameters.	Conceptual & Experimental	Food & Agriculture	Blockchain, IoT, RNN, LSTM, GRU, Genetic Algorithm
Abbas, K., Afaq, M., Khan, T.A., Song, W.-C. (2020)	Electronics (Switzerland)	A blockchain and machine learning-based drug supply chain management and recommendation system for smart pharmaceutical industry	This paper proposed and implemented a novel drug supply chain management and recommendation system based on blockchain and machine learning.	Conceptual & Experimental	Emerging Technologies & Their Benefits (application to pharmaceutical industry)	Blockchain, Machine Learning
Li, Z., Guo, H., Barenji, A.V., (...), Guan, Y., Huang, G.Q. (2020)	International Journal of Production Research	A sustainable production capability evaluation mechanism based on blockchain, LSTM, analytic hierarchy process for supply chain network	The paper proposes a production capability evaluation system for supply chain networks that incorporates Internet of Things, machine learning, and blockchain technology.	Conceptual & Experimental	Emerging Technologies & Their Benefits	Blockchain, IoT, LSTM
Reyes, P.M., Visich, J.K., Jaska, P. (2020)	IEEE Engineering Management Review	Managing the Dynamics of New Technologies in the Global Supply Chain	The paper examines the effects of the following technologies on supply chains: radio frequency identification, the Internet of Things, Industry 4.0, artificial intelligence and machine learning, and blockchains.	Conceptual	Emerging Technologies & Their Benefits	-
Sgantzos, K., Grigg, I. (2019)	Future Internet	Artificial intelligence implementations on the blockchain. Use cases and future applications	The paper proposes that a blockchain can not only keep datasets on the chain for AIs to use, but it can also host an AI advanced enough to work with its own data and achieve the siren call of independently advancing knowledge—the artificial general intelligence.	Conceptual	Emerging Technologies & Their Benefits	-

Dillenberger, D.N., Novotny, P., Zhang, Q., (...), Vaculin, R., Sarpatwar, K. (2019)	IBM Journal of Research and Development	Blockchain analytics and artificial intelligence	The paper describes analytics engines that are linked to blockchains to provide user-friendly configurable dashboards, predictive models, provenance histories, and compliance checks.	Conceptual & Experimental	Emerging Technologies & Their Benefits	Blockchain, Federated Learning
Mao, D., Wang, F., Hao, Z., Li, H. (2018)	International Journal of Environmental Research and Public Health	Credit evaluation system based on blockchain for multiple stakeholders in the food supply chain	This paper proposes a blockchain-based credit evaluation system to improve the effectiveness of food supply chain supervision and management. The system also employs blockchain technology and the deep learning network LSTM to collect and analyse credit evaluations from food supply chain traders.	Experimental	Food & Agriculture	Blockchain, Machine Learning