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Blockchain Technology and Sustainability in Supply Chains and a Closer Look at Different Industries: A Mixed Method Approach

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Abstract: *Background*: This study presents a comprehensive review of blockchain technology with a sustainability orientation in supply chains and logistics. *Methods*: The publications are extracted from the Scopus and Web of Science databases, comprising 552 publications between 2017 and 2022. Several bibliometric laws and techniques, namely three-field analysis, Bradford's Law, Lotka's Law, and thematic maps, are applied in R with the bibliometrix package. Content analysis is also carried out based on 185 publications to appreciate the industry-based view of the field. *Results*: The bibliometric results indicate that this field is on the rise. Authors, sources, affiliations, countries, keywords, and their relationships are also addressed. The findings of the content analysis and thematic maps reveal that some of the most highlighted themes in the literature include traceability, COVID-19, the internet of things, and Industry 4.0. The most popular industry in this field is discovered to be food and agriculture. *Conclusions*: This paper contributes to the still relatively scarce literature on how blockchain technology fosters sustainable supply chains and logistics, providing a closer look at blockchain use, methodologies, and future directions for different industries concerning food, agriculture, fashion, textile and apparel, manufacturing, automotive, maritime and shipping, healthcare and pharmaceutical, mining and mineral, and energy.

Keywords: blockchain; sustainability; supply chains; logistics; bibliometric analysis; biblioshiny; three-field analysis; Bradford's law; Lotka's law; thematic map; content analysis

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1. Introduction

Blockchain technology (BT) has been used frequently in many industries such as healthcare systems, logistics, maritime, education, finance, education, cloud and edge computing, smart-contract transactions, governance, emissions trading, and business information [1–4]. In addition to all these industries, the importance of BT is also growing in the supply chain industry, which is the focus of our study.

Several business units, such as suppliers, manufacturers, distributors, and retailers, collaborate in the supply chain to source raw materials, convert them into finished products, or deliver products to retailers [5]. Supply chains are getting longer and more complicated as they become more global [6,7]. One of the challenges that modern supply chains typically face is sustainability, and BT is seen as essential to a company's ability to achieve supply chain sustainability [8,9]. Since the last two decades, research on supply chain management (SCM) has increasingly focused on the issue of sustainability [10]. SCM is described by Seuring and Müller [11] as the management of material and information flows, as well as the collaboration between businesses throughout the supply chain, while aiming to achieve all three facets of sustainable development: societal, environmental, and economic [12]. The main objective of sustainable supply chains is to create and maintain long-term economic, social, and environmental value for all parties involved in supplying goods and services to markets [9].

How to incorporate the sustainability idea into SCM has been a heated topic of debate in academia and practice [13]. There are still issues to be researched that academicians have called for future researchers, including how to use BT to prevent supply chain disruptions, determine the system's resilience and traceability, and ensure its sustainability [2,3]. Additionally, logistics in many industries have undergone a significant transition, particularly in light of the COVID-19 pandemic. Nitsche and Straube [14] proposed development scenarios for future logistics networks. Among these scenarios are the presence of the globalization trend, increased investment in transparency and related technologies, and increased flexibility and resilience in various logistics networks. BT is regarded as one of the key exciting technologies that will help to realize this vision. To address these calls and suggestions, this study examines the use of BT in sustainable supply chains with a mixed approach that includes bibliometric and content analysis.

To take an up-to-date picture of publications in a field in the literature, there are a variety of methods used, such as bibliometric analysis, systematic literature review, and meta-analysis. The term "bibliometrics" was first used by Pritchard [15] as a replacement for "statistical bibliography". Bibliometric analysis provides a quantitative examination of publications in the literature, and it has mainly two methods in the form of performance analysis and science mapping [16–18]. Science mapping focuses on the connections between research components, whereas performance analysis mostly provides descriptive statistics on research components [18].

Content analysis is frequently used along with bibliometric analysis in literature reviews to assess current knowledge and comprehend intellectual frameworks [19]. It is a common technique in empirical social sciences for qualitative and quantitative analysis [19,20]. According to Drisko and Maschi [21] (p. 7), content analysis is "*a family of research techniques for making systematic, credible, or valid and replicable inferences from texts and other forms of communication*". The principal aim is to derive valid conclusions about the contexts wherein texts (or other significant material) were used [22]. Content analysis is a manual or automated technique which can be explored in three ways: human-scored schema, individual word counting systems (mostly automated), and artificial intelligence-based computer systems [23,24]. Insights, topics, research diversification, research trends, and research gaps from papers grouped into clusters can be identified with the aid of content analysis [25].

For the present study, the subject of BT and sustainability in supply chains and logistics was chosen for two main reasons: (1) This study answers a call for additional research into the dynamics of the adoption of BT in sustainable supply chains and logistics. It has been suggested that the sustainability issue in the blockchain-integrated supply chain should receive more attention in future studies [3,26]. (2) To date, there is only one study [27] that provides a review of BT for sustainable supply chains using bibliometric analysis and content analysis. In comparison, the database and publications are handled more comprehensively in this study. While 146 publications between 2018 and October 2021 obtained from Scopus are discussed in [27], Web of Science (WoS) and Scopus are considered together in this study and a total of 552 studies between 2017 and September 2022 are investigated. Analyses, namely three-field analysis, Bradford's Law, Lotka's Law, and thematic maps, not covered in [27], are examined within the bibliometric analysis. Apart from the industries (food, healthcare, manufacturing, infrastructure) covered in the content analysis by Sahoo et al. [27], many more different industries, including food, agriculture, fashion, textile and apparel, manufacturing, automotive, maritime and shipping, healthcare and pharmaceutical, mining and mineral, and energy, are also identified and examined in the present study.

By carrying out a comprehensive bibliometric and content analysis of blockchain and sustainability research in supply chain and logistics, it is aimed at providing valuable insights into this emerging research field. The current study answers the following research questions (all being posed within the context of supply chains and logistics):

RQ1. *What is the status of the research on blockchain and sustainability?*

1. What is the distribution of publications over the years?
2. What are the top research components (sources, authors, affiliations, countries, keywords) in terms of production and how they are interrelated?
3. Does the research collection confirm the bibliometric laws (Bradford's Law and Lotka's Law) based on source and author productivity?
4. What are the topmost cited publications?
5. What themes have been discovered in the literature thus far and how have they changed over the years?

RQ2. *What are the industry-based insights of the research on blockchain and sustainability?*

6. What are the benefits, challenges, and uses of BT in different industries?
7. What methods and theories are used in the studies?
8. What are the open research questions for different industries?

The remainder of the current study is organized as follows: the next section includes the background of the study field. In the methodology section, information about the analyses used and the search protocol (databases, search criteria, search strings, and preparation of the collection for the analysis) are provided in detail. The results of both bibliometric and content analyses are presented in the findings section and, finally, the study is discussed and concluded in the last section.

2. Background

BT was first conceptualized in 2008 by a person (or group) named Satoshi Nakamoto, in an article titled "Bitcoin: Peer-to-Peer Electronic Cash System" [28] (p. 9). It can be characterized as a decentralized shared ledger where verified and synchronized data is stored in a peer-to-peer network using chronological, encrypted, chained blocks [29] to generate permanent and tamper-proof records [30,31]. By enabling a distributed consensus that allows every online transaction to be confirmed at any moment in the future, this technology has the potential to change the digital world [28].

The blockchain system has an accurate and verifiable record of every transaction that has ever taken place. Therefore, blockchain has the potential to improve data security, transparency, and integrity [28,32,33]. It is built on a few fundamental concepts, including decentralization, verifiability, immutability [7,34], security, chronological data, collective maintenance, and programmability [35]. Decentralization describes a network structure with a trust-based architecture that functions independently of any authority. Verifiability indicates that every participant encrypts their data using their private-public keys. Immutability means that each new block to be added to the chain carries the hash value of the preceding block and that this new block can be added to the system with consensus thanks to the consensus-based algorithm of the BT [34]. Due to the system's robust encryption, it offers security. Chronological data is ensured with blockchain. The system not only saves the data permanently, but also connects the different blocks in chronological order. The maintenance of the system is primarily carried out by collective decisions because of the distributed database nature of blockchain. Last but not least, since blocks can both store and encode data, blockchain also enables programmability [35].

It is widely acknowledged that BT is a significant advancement that, in the not-too-distant future, will fundamentally alter how organizations are organized, managed, and operated [36]. As a matter of fact, many companies have started to show great interest in this technology today. BT can be used in many areas [36], and it has gained a global attention due to its many advantages in supply chains [1,2,4].

The movement of materials cannot be done directly through a single organization. Most products pass through a number of organizations as they move between original suppliers and end customers [37]. Today, it is not possible for organizations to exist on their own, and their ultimate success is based on their ability to manage their integration and coordination abilities with other members of the supply chain [38]. In today's world, uncertainties in customer expectations, big leaps in technology, and fast internet connections have forced businesses to cross local and national borders. Therefore, with the impact of the changing environment, businesses are faced with sophisticated customers who demand greater product variety, lower cost, better quality, and faster responses. For such reasons, businesses adopt supply chain management to compete successfully [39]. SCM is an integrated system management that purchases raw materials, converts them into finished products, and distributes these products to both retailers and customers [40] while facilitating information sharing between various business units. A successful SCM depends on full-time and accurate access and sharing of information by all members [38]. Furthermore, it is influenced by customer expectations, globalization, information technologies, regulations, competition, and environment [40]. Supply chain management connects suppliers, manufacturers, distributors, and customers by using information technology to meet customer expectations efficiently and effectively [39]. The use of communication and information technology is crucial to achieving the goal of maximizing every party's overall and long-term benefits through SCM cooperation and information sharing [41]. Digitalization, particularly BT, may transform supply chain management [42]. One of the most crucial tools of Industry 4.0 is thought to be BT. Today's complicated and multi-tier supply chains can benefit from using blockchain due to its many advantages, including smart contracts, decentralization, transparency, traceability, immutability of data, and data privacy [43].

BT integration into the supply chain enables product tracking, flexibility, sustainability, traceability, and increased quality. Blockchain allows supply chains to operate more efficiently and quickly [4]. From the standpoint of sustainable supply chains, using blockchain has many advantages for businesses including cost savings, operational efficiency, transparency, and traceability [1]. Different stages of the supply chain can be tracked thanks to the blockchain system. Data recorded on a blockchain can verify that products are protected according to their specifications. For example, real-time location information is shared when the goods being transported pass through customs and ports. Supply chains can be dynamically optimized using such recorded data [6]. In addition, recently, environmental concerns, new regulations, and competitive, complex environmental regulations have led companies towards sustainable supply chain management (SSCM).

SSCM is the process of planning, organizing, coordinating, and managing supply chain to make them sustainable [10]. The sustainability of supply chains is a top issue for most businesses [9]. There has been a change from a one-dimensional view of sustainable development to a three-dimensional understanding of sustainability that incorporates environmental, social, and economic responsibilities [13,44]. The creation and preservation of long-term economic, social, and environmental value is the main objective of sustainable supply chains for all parties involved in providing goods and services to markets [9]. BT is strongly linked to the three dimensions of sustainability in the supply chain, and it has advantages for sustainability [43]. Businesses will be able to increase their social vitality, sustainable use of energy and natural resources, and environmentally friendly operations by using blockchain [7]. By effectively tracing items and keeping track of environmental compliance along the whole supply chain, BT can significantly contribute to the reduction of carbon emissions, air pollution, resource usage, and waste of energy [7,9].

3. Methodology

3.1. Analysis and Tool

This study conducts a bibliometric analysis of publications on integrating BT into sustainability-oriented supply chains and logistics. After giving a comprehensive review with bibliometric indicators, the current study also provides a closer look at different industries by conducting content analysis.

The following are the justifications for utilizing bibliometric analysis in this study, as stated in [45]:

- Unlike other methods (e.g., content analysis), bibliometric analysis is more reliable and scalable.
- Bibliometric methods can offer valuable and detailed information by providing an in-depth and thorough analysis of the numerous relationships (such as citations, keywords, and co-citations) associated with the publications under review.
- Using bibliometric approaches, researchers may easily and intuitively visualize key research areas.

Content analysis is carried out for the following reasons: first, while bibliometric analysis offers a substantial data set and enables researchers to see the overall pattern of publications for a specific subject, it is unable to provide comprehensive details about the content of the focal subject [46]. Second, combining various analysis techniques also increases the validity and strength of the findings of the study [47]. Numerous studies in the literature use mixed methods consisting of bibliometric and content analysis [27,46,48]. In this way, both quantitative and qualitative methods are used together to provide broader insights into the field. Therefore, after conducting bibliometric analysis, content analysis is carried out to appreciate the industry-based view and to provide a holistic view of the findings and gaps of the research collection.

The results of the bibliometric analysis are provided in the first section of the findings. To address the first research question (RQ1), the distribution of publications by years (RQ1.1), top research components and their relationship (three-field analysis) (RQ1.2), bibliometric laws (Bradford's and Lotka's Laws) (RQ1.3), most cited publications (RQ1.4), and thematic evolutions over the years (thematic maps) (RQ1.5) were presented under bibliometric analysis. To answer the second research question (RQ2), the results of the content analysis are provided with a closer look the benefits, challenges, and uses of BT (RQ2.1), the methods and theorems used (RQ2.2), and future directions (RQ2.3) in the reviewed studies concerning different industries.

The bibliometric analysis was conducted by using biblioshiny, a web-interface for bibliometrix package [49] in R (version 4.2.1). It is an open-source package, and it has been effectively used in various bibliometric studies so far [50–54]. Biblioshiny's menu has categories of data, filters, overview, sources, authors, documents, clustering, conceptual structure, intellectual structure, and social structure. Moral-Muñoz et al. [55] provided a comparative analysis of the software tools for the bibliometric analysis and stated that through its user interface biblioshiny, bibliometrix packages, including more extensive methods, have gained more attention recently than other tools.

3.2. Search Protocol

The information about the databases, search criteria and search terms, combining databases, and search results are provided in detail. All keyword queries were made from the databases on 21 September 2022, and the publications reached were downloaded by the authors within the same day.

3.2.1. Databases

The first step to carry out a bibliometric analysis is to select the database(s). This study considers both Scopus and WoS as databases and gives comprehensive information about merging databases, since the two top citation databases are Scopus and WoS, and they are widely used in bibliometric research [56]. Up until 2004, when the launch of Elsevier's Scopus, Amsterdam, The Netherlands, swiftly replaced WoS as the primary source of bibliometric data, WoS, owned by Clarivate Analytics, dominated the scientific community [57].

Many researchers take publications from the Scopus or/and WoS databases into consideration when performing bibliometric analysis [58]. Two independent bibliometric analyses (one from Scopus and the other from WoS) are frequently carried out when both databases are considered, and few studies merge two databases without providing information on how to perform the combination [58].

3.2.2. Search Criteria

Information on inclusion and exclusion criteria when searching is explained in this section. The language of the publications was selected as English for both databases. No exclusion was made regarding subject area, affiliation, or journal. For the document types, editorial material and book chapters were excluded and articles and conference papers were considered as in [45]. Regarding the search field, the "title, abstract, and keywords" option was selected for Scopus and "topic" corresponding to the relevant field in Scopus was chosen for WoS.

3.2.3. Search Strings

The only bibliometric study about blockchain for sustainable supply chain management has been recently conducted by Sahoo et al. [27]. The keywords of the study are as follows: "(blockchain" OR "cryptographic ledger" OR "digital ledger" OR "distributed ledger" OR "public transaction ledger") AND ("sustainable" OR "sustainability" OR "green" OR "environment*" OR "social*" OR "economic*" OR "circular economy") AND ("supply chain" OR "supply chain management" OR "logistics" OR "transport*" OR "mobility"). Some of these keywords, however, were not utilized in this study because they had little impact on search results or did not accurately capture the subject matter; for instance, the keyword "mobility" by itself does not relate to the terms supply chain and logistics.

The keywords used in searches on the databases were determined by examining previous relevant bibliometric studies too. Below are the search terms in bibliometric studies in the literature on the four keywords (blockchain, sustainability, supply chain, and logistics) discussed in the current study. Literature searches were conducted for search strings of:

- *Blockchain:* "blockchain" [52,59], ("blockchain or ethereum" OR "blockchain or distributed ledger technology" OR "blockchain or smart contracts") [60];
- *Sustainability:* (sustainab* OR triple bottom line OR TBL OR ((green OR clean) AND "production") [61], ("sustainability" OR "sustainable" OR "sustainab*") [62], ("sustainab*") [45];
- *Blockchain in supply chain and logistics:* (blockchain* AND ("supply chain*" OR logistic*)) [45], (supply chain OR logistics OR transport AND (blockchain OR block chain OR distributed ledger technology)) [63];
- *Sustainability in supply chain:* ("supply chain" OR "supply chains" OR scm OR "supply chain management") AND (sustainable OR sustainability) [64].

Search strings for the current study were finalized as follows: ("blockchain*" OR "distributed ledger technolog*" OR "smart contract*") AND ("sustainab*" OR "triple bottom line" OR "TBL") AND ("supply chain*" OR "logistic*").

3.2.4. Combining Databases and Search Results

In the keyword search results, 470 publications were found for Scopus and 454 for WoS. In Scopus, the publications were extracted in BibTeX format with all information selected. The publications obtained in WoS were exported as a plain text file with the record content "Full record and cited references" selected. To merge these datasets, codes using bibliometrix package functions, namely convert2df and mergeDbSources (see Aria and Cuccurullo [65] for details), were written in RStudio (version 4.2.1), an R IDE, and then publications with missing information about authors or abstracts were manually eliminated from the dataset.

First, the separate datasets, namely scopus.bib (Scopus dataset) and savedrecs.txt (WoS dataset), were converted into bibliographic data frames with the converting function called "convert2df". Second, using the "mergeDbSources" function, the two datasets were merged into one by removing duplicated documents from the dataset ("remove.duplicated" was set to "TRUE"). As a result, 328 duplicate documents were removed from the dataset.

Finally, the dataset was manually checked and publications with missing information were excluded from the dataset. After this cleaning procedure, a total of 552 publications were considered for the bibliometric analysis.

4. Findings

4.1. Bibliometric Analysis

4.1.1. Overview

The main information regarding the collection is given in Table 1. 552 publications have been produced on 272 different sources by 1600 different authors. The field shows an annual growth rate of 152.19%.

Table 1. Main Information.

Description	Results
Period	2017–September 2022
Publications	552
Sources	272
Annual growth rate %	152.19
Average citations per publication	19
Authors	1600
Authors of single-authored publication	40
Document types:	
article	316
article; early access	47
article; proceedings paper	3
conference paper	62
proceedings paper	40
review	72
review; early access	12

As Table 2 shows, the number of publications has been increasing over the years.

Table 2. Annual Publications.

Year	Publications
2017	2
2018	8
2019	50
2020	109
2021	179
2022	204

4.1.2. Three-Field Analysis

Three-field analysis (Sankey diagram) has been used in various bibliometric studies [53,66–69]. Sankey diagrams, which have historically been used to represent the flow of energy or materials, provide quantitative data regarding flows, linkages, and transformations [70]. The larger the size of the rectangles where the research components (keyword, country, source, institution, author, etc.) are represented, the more relationships between the components [67].

First, in this study, keywords were manually checked before analysis in order to avoid the display that may occur due to the problem of representing words with the same meaning in different terms, such as "smart city" and "smart cities" or "sustainable city" and "sustainable cities", keywords represented with different rectangles in the three-field plot in [66].

In the keywords of some studies in the dataset, it was observed that words with the same meaning were represented two or more times by different keywords (e.g., "internet of things", "IoT", and "internet of things (IoT)"). All these keywords were consistently corrected with a single keyword (for this example, all keywords were converted to "IoT"). Apart from this, the same representative keywords were decided for all studies and corrections were made to ensure that the keywords of the studies were consistent (e.g., keywords represented as "block chain" in study X, "block-chain" in study Y, "blockchain" in study Z were corrected to "blockchain" for all studies).

Sankey diagrams for the study were created by using biblioshiny's "three field plot" selecting the top 20 of each research component. Figure 1 illustrates the relationships between the author's keywords (left), authors (middle), and sources (right).

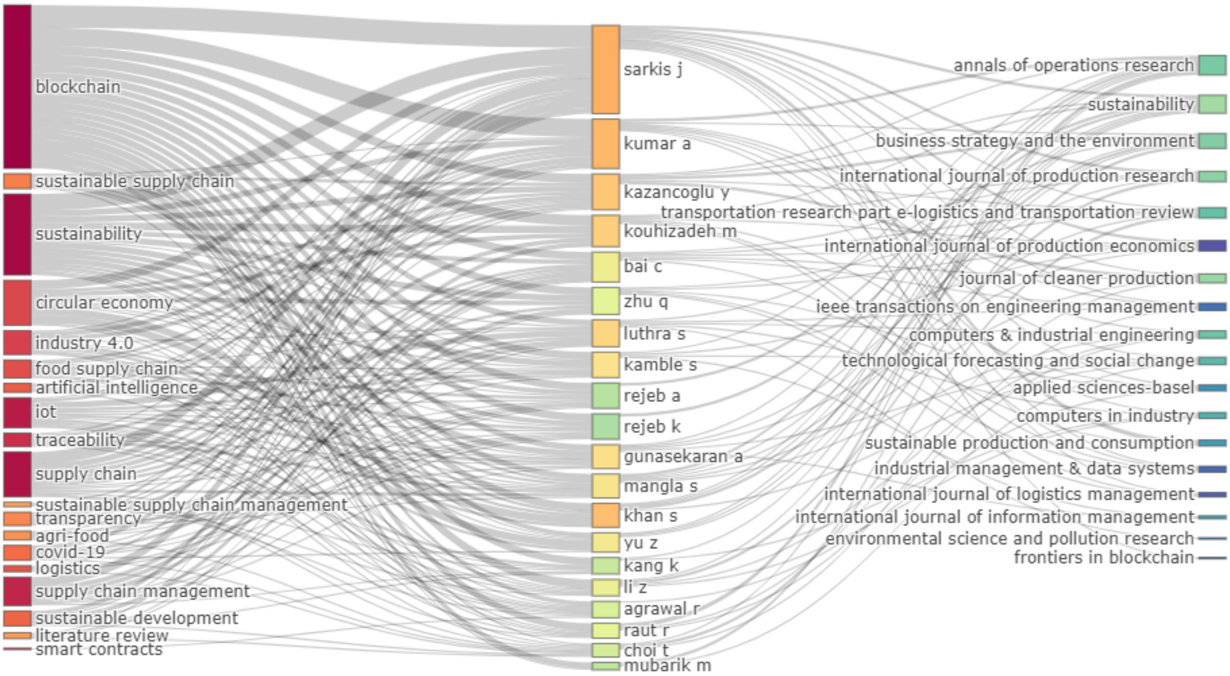


Figure 1. Three Field Plot for author's keywords, authors, and sources.

The three-field analysis of the top keywords, authors, and sources indicates that Sarkis J (Joseph Sarkis) has the most incoming (from keywords) and outgoing (to sources) flow counts. He has a strong relationship with the main research topics ("blockchain", "sustainability", and "supply chain") and many of the listed core journals. *Sustainability*, *Annals of Operations Research and Business Strategy* and *The Environment* have the most relationships in terms of incoming flow counts, demonstrating that many top authors have published their studies in these journals. Apart from the main topics, there are other top keywords that indicate relationships with top authors, such as IoT, circular economy, Industry 4.0, COVID-19, and agri-food.

The second diagram was generated for the top countries (left), affiliations (middle), and authors (right), and is given in Figure 2. Most relationships between a country and its top affiliations belong to China, followed by India. It is evident that there are many collaborations between research components. For instance, Yasar University is in Turkey and receives incoming flows from not just Turkey but also China, France, the UK, and India. The Hanken School of Economics is in Finland and has relationships with Finland, the USA, Denmark, China, and France.

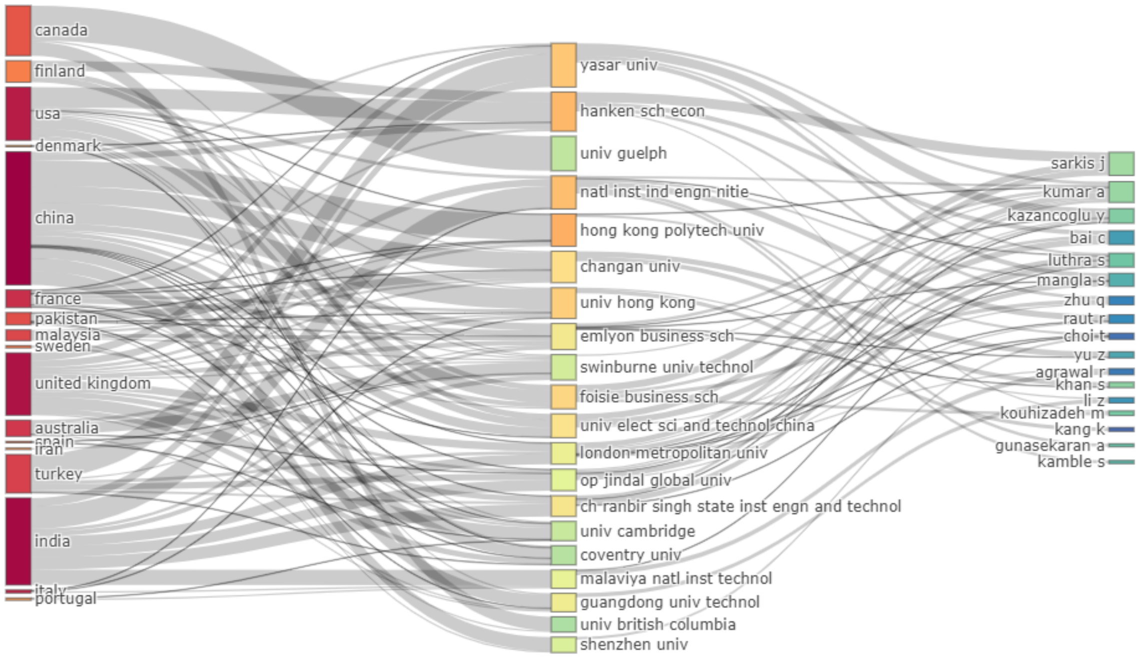


Figure 2. Three Field Plot for countries, affiliations, and authors.

4.1.3. Bradford's Law

According to Bradford's Law [71], there are few journals that publish numerous articles and many journals that publish few articles on a particular topic. To observe the core journals or to cluster the journals, Bradford's Law has been used in different bibliometric studies [69,72–74].

The distribution of the sources according to the amount of publication is shown in Figure 3 (the sources whose names are written belong to the first group). According to the results, there are 187 publications in 13 sources in the first cluster, 183 publications in 77 sources assigned to the second cluster, and 182 publications in 182 sources in the third cluster. While all the sources in the third cluster had a single publication, 14% of the articles (76 out of 552 publications) were published in a single journal (i.e., *Sustainability*).

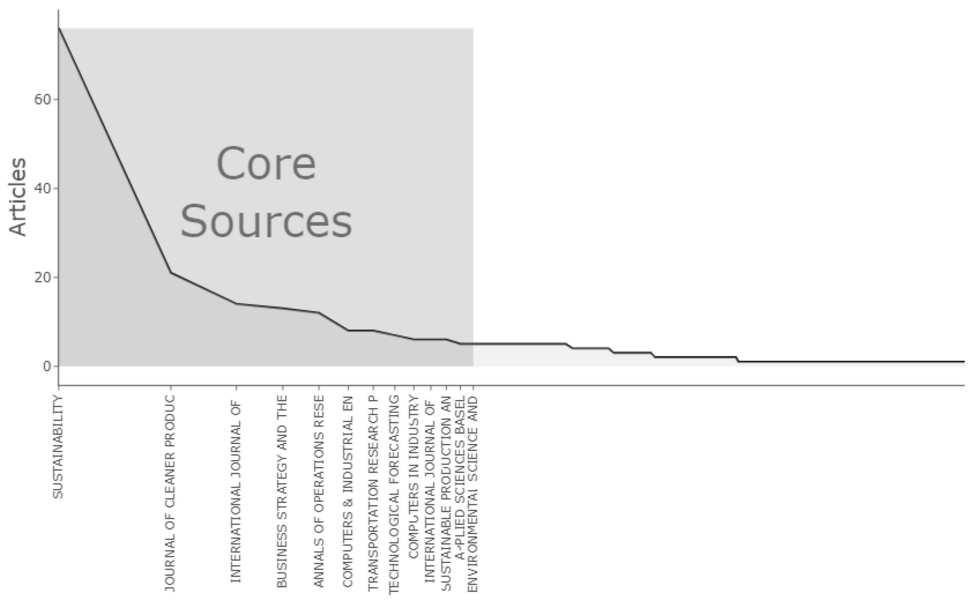


Figure 3. Source clustering through Bradford's Law.

Mathematical compliance with the rule was calculated according to Kumar and Mohindra [72]. The calculation was made for the 1:n:n^2 rule and the error rate was found. By this rule, the relationship of each cluster in the study is 13:77:182 (272 sources in total) and the mean Bradford multiplier is 4.14 (average (77/13, 182/77)). The error calculation is as follows:

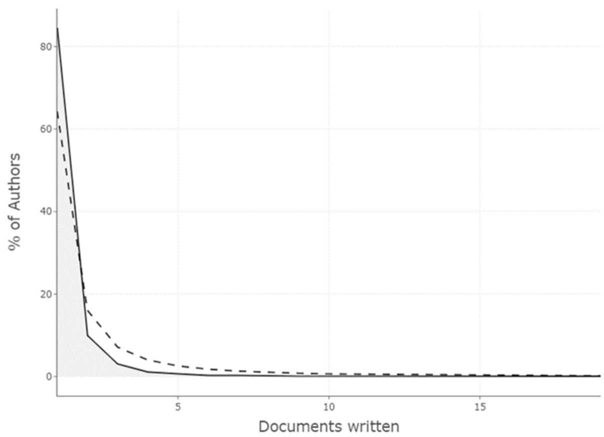
$$13{:}13 \times 4.14{:}13 \times 4.14^2 = 13{:}53.86{:}223.18 \quad (1)$$

$$\%\ \text{error} = ((13 + 53.86 + 223.18) - 272)/272 \times 100 = 6.63\% \quad (2)$$

The data confirms Bradford's Law as the percentage of error is not too high [72].

4.1.4. Lotka's Law

Lotka's Law is one of the laws that have been applied in bibliometric studies, just like Bradford's Law [72,74]. Lotka's Law (the inverse square law of scientific productivity) [75] seeks to identify researchers who produce more frequently in a certain field of expertise. Authors' productivity is illustrated in Figure 4a. 84.5% of the authors published just one article, whereas the most productive author (Joseph Sarkis) had 19 publications (0.1%).



(**a**)

Publications (X)	Authors (Y)	Authors (Expected, n = 3.088)
1	1352	1352
2	159	159
3	48	45.46
4	17	18.70
5	10	9.39
6	4	5.35
7	4	3.32
8	2	2.20
9	1	1.53
10	1	1.10
17	1	0.21
19	1	0.15

(**b**)

Figure 4. Author Productivity through Lotka's Law (**a**) The number of publications and the number of authors in the collection are illustrated; (**b**) The number of publications (X), the number of authors (Y), and the expected number of authors calculated through the law are given.

All calculations were made according to Kumar and Mohindra [72] and the data is given in Figure 4b. The formula for Lotka's Law is given by the expression:

$$X^n Y = C \quad (3)$$

The values of 1 for X and 1352 for Y were given, and C was found to be 1352. Then, by giving the values X = 2, Y = 159, and C = 1352, n was calculated as 3.088. The number of authors was calculated using the n = 3.088 value. According to the results, it is seen that the expected number of authors was consistent with the number of authors (Y). Therefore, Lotka's Law applies to this study.

4.1.5. Most Impactful Publications

The top five most cited studies are given in Table 3. The most cited publication belongs to Saberi et al. [76]. In the study, an overview of BT, its use in the supply chain, and the challenges it faces were discussed. The second most cited study [77] examined how blockchain can impact key supply chain management goals such as sustainability, cost, and speed. While underlining the potential future direction of blockchain application and technology, Hughes et al. [78] emphasized the numerous obstacles to blockchain adoption. Included in addition were several instances of supply chain and logistics businesses that stand to gain a lot from BT. Kamble et al. [79] discovered the drivers of blockchain adoption in agriculture supply chains and explored their relationships. Traceability, auditability, immutability, and provenance were found to be the top four drivers of BT adoption. In another study, Kamble et al. [80] conducted a literature review and suggested a framework that recognizes supply chain resources and visibility as the primary driving forces behind building data analytics capabilities and attaining sustainable performance in agri-food supply chains.

Table 3. Top Five Most Cited Publications.

Author	Title	Total Citations
Saberi et al. [76]	Blockchain technology and its relationships to sustainable supply chain management	988 (Scopus) 829 (WoS)
Kshetri [77]	Blockchain's roles in meeting key supply chain management objectives	732 (Scopus)
Hughes et al. [78]	Blockchain research, practice and policy: Applications, benefits, limitations, emerging research themes and research agenda	287 (Scopus)
Kamble et al. [79]	Modeling the blockchain enabled traceability in agriculture supply chain	270 (Scopus)
Kamble et al. [80]	Achieving sustainable performance in a data-driven agriculture supply chain: A review for research and applications	255 (Scopus)

4.1.6. Thematic Evolution

A group of keywords can be treated as a concise summary of a particular research theme and two parameters, density and centrality, apply to any research topic [81]. The degree of interconnection between all keywords is determined by density, while the degree of interconnection with other themes is measured by centrality [81]. A thematic map (strategic diagram) is illustrated as divided into four areas based on the themes' density and centrality [82]. The four quadrants have different aspects [81–83]:

- *Niche themes (upper-left quadrant; high density and low centrality):* They are often referred to as "highly developed and isolated themes". The connections between themes are strong internally but weak outside. They are just marginally relevant to the field.
- *Motor themes (upper-right quadrant; high density and high centrality):* This quadrant addresses well-developed themes crucial to the structure of a research area.
- *Emerging or declining themes (lower-left quadrant; low density and low centrality):* This quadrant demonstrates weakly developed and peripheral themes.
- *Basic themes (lower-right quadrant; low density and high centrality):* Although they are poorly developed, the themes in the lower-right quadrant are crucial for a research topic. Therefore, this quadrant gathers "general, basic, and transversal" themes.

There isn't a single, conclusive response to the problem of what themes could persist in the future. Cahlik [81] stated that themes that were prevalent in earlier periods have a good likelihood of remaining in later ones. In addition, engaging development of a theme may provide a greater chance of permanence than simple dynamics, and if they are not considered to be interesting by researchers, many of the themes from the fourth quadrant may disappear from the field in the next period [81].

Thematic maps or thematic evolutions of different years have been applied in many bibliometric studies [48,68,69,84]. For the analysis, first, some text preprocessing methods were applied by preparing and using a dictionary in the "Text Editing" area of the biblioshiny program to eliminate keywords about search strings, such as blockchain, smart contracts, sustainability, sustainable supply chain, supply chain, and logistics, as these keywords stand out in the analysis as expected and provide no useful information and insights about the themes.

To understand the evolution of the themes in the corpus, the author's keywords were used to generate the thematic maps. To maintain the readability of the maps and give insightful information, the following parameters were selected (number of words = 200, minimum cluster frequency = 5, number of labels for each cluster = 2, and the other parameters were default) [68]. The time zones were set for 2020 and 2021. This is due to several factors, including the recent sharp rise in article production in the last two years, the goal to maintain a constant quantity of articles over time, and the need to highlight recent trends.

Evolutions of the themes for the years 2017–2022 and their relationships are shown in Figure 5. The themes are given for the years 2017 to 2020 on the left, the year 2021 in the middle, and the year 2022 on the right. It is observed that *IoT*, *traceability*, and *Industry 4.0* have been studied for all time periods. Other themes that have been developed in 2022, are, for instance, circular economy and multi-tier supply chain. It is observed that the *food supply chain* theme has a connection with *COVID-19*, and *circular economy* has relationships with *digital technologies*, *COVID-19*, and *Industry 4.0*. Themes for each period are illustrated as thematic maps to deepen the analysis.

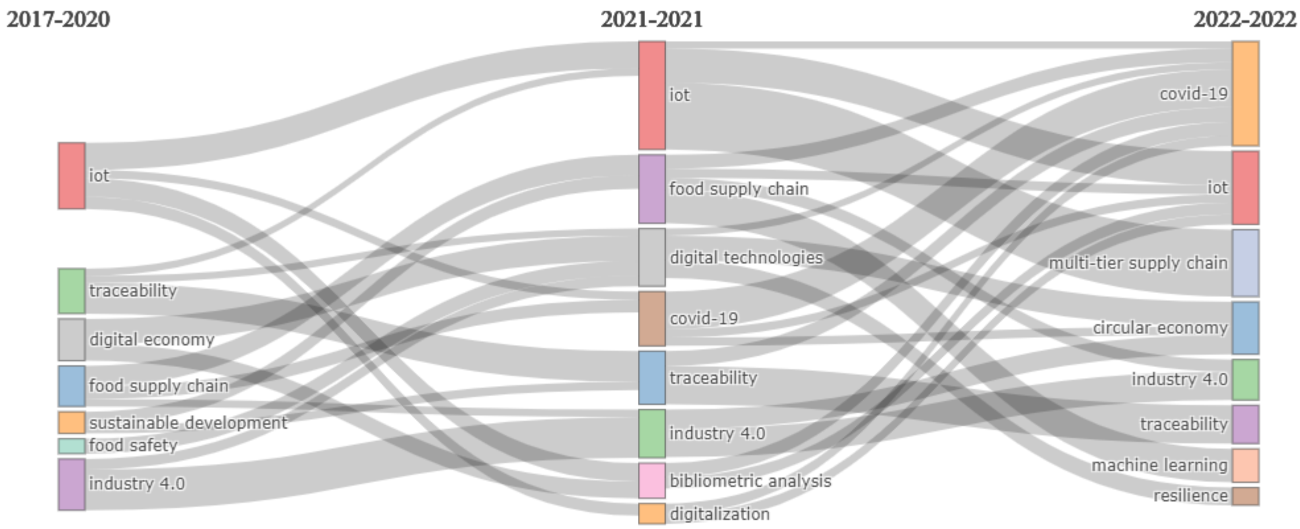


Figure 5. Thematic Evolution Map (2017–2022).

The thematic map for 2017 and 2020 (Figure 6) has twelve thematic clusters, namely, food safety, cost saving, food supply chain, traceability, sustainable development, environmental sustainability, data science, IoT, Industry 4.0, supply chain performance, digital economy, and peer-to-peer. The food safety cluster, labelled by food safety, China, and Evoo (Extra Virgin Olive Oil) and the cost saving cluster are in the niche themes quadrant, indicating marginal relevance to the field. The well-developed and crucial topics of the research field, motor themes, consist of three clusters: food supply chain, traceability, and sustainable development. Basic themes have three clusters as IoT (IoT, artificial intelligence, smart city), Industry 4.0 (Industry 4.0, circular economy, fashion), and supply chain performance (supply chain performance, supply chain visibility, and information transparency). Digital economy appears to be an emerging theme, whereas the peer-to-peer topic seems to be a declining theme. Environmental sustainability and data science are sandwiched between niche and emerging themes.

The next period's map, the thematic map for 2021 (Figure 7), has nine thematic clusters, namely, *digital technologies*, *bibliometric analysis*, *food supply chain*, *digitalization*, *IoT*, *Industry 4.0*, *traceability*, *COVID-19*, and *Tradelens* (developed jointly by IBM and GTD Solution, TradeLens is an open supply chain platform powered by blockchain technology (www.tradelens.com (accessed on 5 November 2022)). *Tradelens* seems to be a declining theme, whereas *COVID-19* can be an emerging theme with higher centrality. Although *traceability* is a motor theme for the 2017–2020 period, it is placed between quadrants 3 and 4, namely basic and emerging themes for the 2021 map. *IoT* and *Industry 4.0* are basic themes that almost become motor themes with more development. *Digitalization* and *food supply chain* are motor themes; both the number of studies in these domains are substantial and there are close internal relationships with thematic areas. *Digital technologies* and *bibliometric analysis* are located in the second quadrant (niche themes).

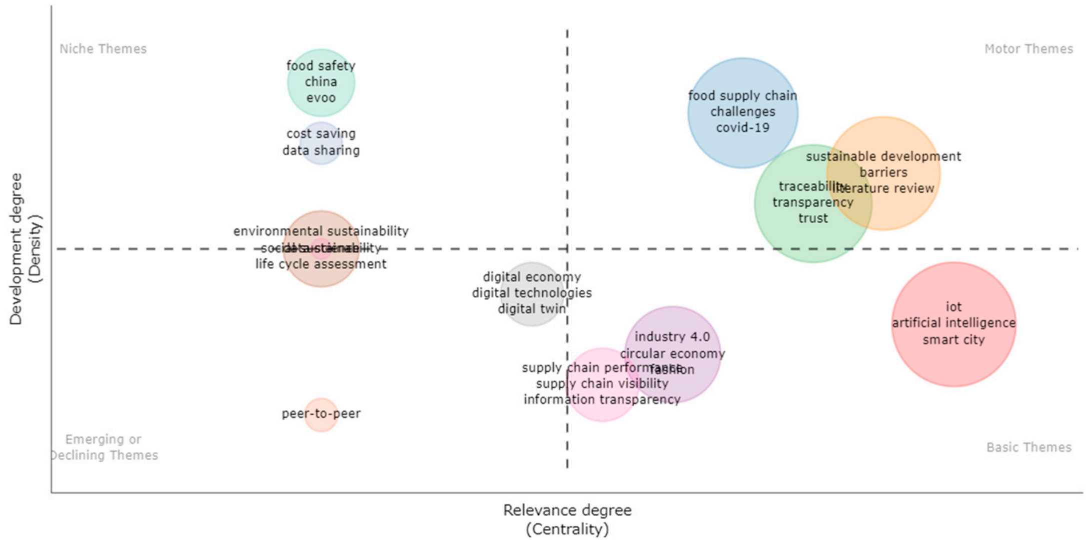


Figure 6. Thematic Map (2017–2020).

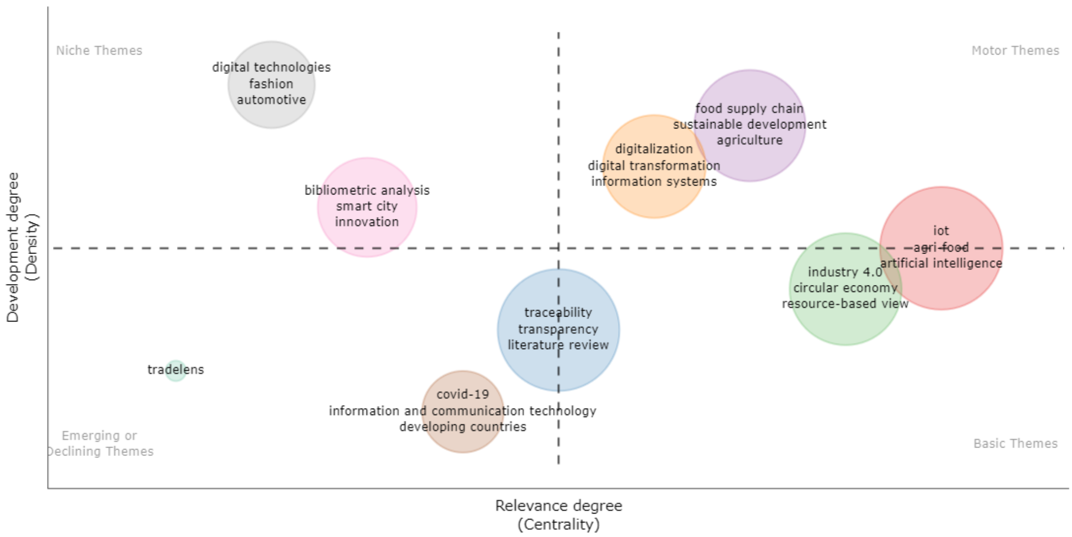


Figure 7. Thematic Map (2021).

The current year's map, the thematic map for 2021 (Figure 8), has ten thematic clusters, namely IoT, circular economy, Industry 4.0, traceability, COVID-19, resilience, carbon emission, environmental, machine learning, multi-tier supply chain, and game theory. Machine learning and environmental are located as niche themes. Traceability is sandwiched between niche and motor themes, indicating that it has gained density and move upward compared to the 2021 map. It is seen that new themes have emerged, such as multi-tier supply chain, game theory, and carbon emission. COVID-19 and Industry 4.0 have gained more centrality and density, as a result, they have become motor themes. IoT, circular economy, and resilience are in basic themes.

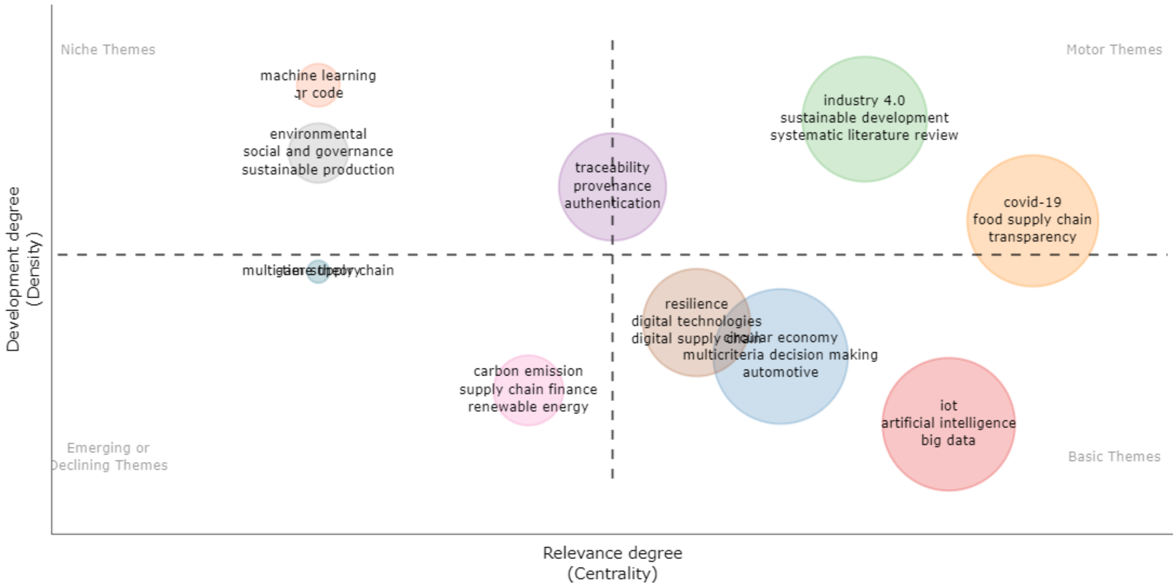


Figure 8. Thematic Map (2022).

4.2. Content Analysis

The literature review team, consisting of two Ph.D. candidates, rigorously reviewed the abstracts, findings, discussions, and conclusions of the 552 publications and manually clustered them by industry, considering some inclusion and exclusion criteria. The article was supposed to be about blockchain adoption in industries within sustainable supply chain systems to meet the initial inclusion requirement. As an exclusion criterion, some publications that did not mention a specific industry for blockchain adoption in the supply chain were not included in the sample. This led to 185 publications and eight industry clusters examining the benefits, challenges, and use of BT in a sustainable supply chain system based on specific industries as well as discussing methods and theories used, and future directions in the reviewed studies.

The industry with the most publications is found to be *food and agriculture* when the distribution of publications by industries is examined (Table 4). The three industries with the least number of publications are *energy, mining and mineral*, and *healthcare and pharmaceutical*.

Table 4. Distribution of Publications by Industries.

Industry	Number of Publications
Food and Agriculture	115
Fashion, Textile, and Apparel	18
Manufacturing	12
Maritime and Shipping	10
Automotive	9
Healthcare and Pharmaceutical	8
Mining and Mineral	7
Energy	6
Total	**185**

Other than these industries, there are niche applications in different supply chains based on blockchain use, such as oil and gas [85], aircraft [86], airports [87], autonomous vehicle [88], defence [89,90], forestry [91], trucking [92], tourism [93], and telecom [94]. Due to the low number of studies related to these industries, they were not evaluated under content analysis.

4.2.1. The Uses, Benefits and Challenges of Blockchain Technology

Food and Agriculture Industries

Agriculture and food supply chains (FSCs) are essential for the sustainability of human activities [77,95,96]. Major changes are now needed in the agrifood industry to encourage sustainability, reduce waste, and motivate a shift toward sustainable, healthy diets [97]. Traditional agricultural business models endured a tremendous transformation during the preceding three industrial revolutions [98,99] after facing several challenges such as counterparty and financing risk, low customer confidence [100], lack of a strong method for integrating various information systems, lack of prompt and clear information regarding temperature and status of the products, controlling high communication costs [101], inconsistent product quality, lost data [102], and a surplus of manually processed papers [101,103].

The fourth industrial revolution has significantly accelerated the development of agricultural sustainability [98,104–106]. Nowadays, agriculture businesses have no option but to adapt to the new system in the practices of the increasingly digitalized and globalized world [107,108]. To assure economic, social, and environmental sustainability, modern agriculture needs to incorporate technologies like machine learning, big data analytics, cloud computing, the IoT, blockchain, and other developments (e.g., smart sensors, robotics, digital twins, and cyber-physical systems) more synergistically [99,109,110]. With less human participation and more accurate data, these cutting-edge digital technologies enable the development of interconnected, data-driven, intelligent, agile, and autonomous systems for entire supply chain processes [98,101,104,105,111,112]. Blockchain has also started to be used in sustainable e-agriculture applications [113] and it fosters cooperation in the e-agriculture supply chains [31,106,114].

Food supply chain systems also share the same characteristics as agriculture supply chains. Flour milling, milk processing, meat processing, the canning industry and the production of dried and canned fruit, vegetables, and seeds, fishing, manufacturing of sugar and confectionery, chocolate and desserts, and production of spices are the traditional industries that make up the food industry [115]. Consumers and stakeholders are becoming increasingly concerned about the reliability, safety, quality, and distribution—which must adhere to sustainability standards—of food information due to the lack of transparency and traceability in FSCs [116,117]. For FSCs to address societal, economic, and environmental demands, managing sustainability is a critical strategy [118,119]. FSCs are quickly getting more and more complex in today's globalizing environment [96,110,118,120]. Recently, due to several terrible events such as environmental deterioration, climate change, population growth, resource scarcity, and food waste caused by the COVID-19 pandemic have further increased the problems in sustainable FSCs on a global scale [99,110,121–127]. These problems have a lot to gain from blockchain technology's distributed ledger, transparency, traceability, and other aspects [128,129]. To ensure food safety and reduce harmful environmental impacts, it is necessary to move towards resilient and sustainable food systems [126,130] with the help of BT.

BT can offer many benefits for agriculture and FSCs. Real-time farm management, high levels of automation, and data-driven intelligent decision-making in an industrial agriculture ecosystem will dramatically increase agri-food supply chain efficiency, food safety, and resource utilization [98]. Numerous rules, governmental laws, and specifications can be handled easily to create food security through the blockchain [131–133].

BT has the potential to increase supply chain transparency, allowing to produce high-quality food with minimal negative social and environmental effects particularly in the agri-food industry [134,135]. In this way, high-quality products can be discovered and marketed to the rest of the world [101]. In addition, blockchain-based food monitoring systems aid in preventing inflated price increases [125]. Once customers' trust is gained through blockchain, their satisfaction level can be positively impacted [136] and, in the long run, they can be loyal to the company [137,138].

BT has the potential to increase existing food production in a cost-effective and sustainable manner [126,139]. It can provide shorter transit distances, quicker payment settlements [102], and the avoidance of food waste [102,103,105,140]. Through the realization of information's traceability, security, and non-manipulation, which are particularly helpful in the agri-food sector, BT can promote sustainability [31,141,142]. Environmental preservation, pollution control [143], water conservation, the health of the soil and plant insurance [110] are other benefits of BT.

Blockchain offers chances to find and utilize synergies between various actors [144]. It improves supply chain coordination by giving warehouse managers more information [145], and combines many sources of information for more effective logistical management [145,146]. Blockchain implies novel business models [147] where each agricultural step will be automatically linked into the supply chain up to the final customer [80,104]. Furthermore, blockchain offers the potential for guaranteeing equitable value distribution and fair supply chain procedures, which can be helpful for organizations like social enterprises, NGOs, and fair trade agencies that wish to demonstrate to their clients that they are committed to sustainability [148].

With the help of data integration, suppliers and buyers can communicate directly without the need for intermediaries [128,149], and, through the elimination of intermediaries in the agri-food supply chain [122,150], farmer income may be increased. By tracking the source of food, blockchain helps build trust between producers and consumers [151,152], forecast demand [135], increase awareness, and help the transition to a more sustainable food system [126].

Improved visibility and traceability, as well as the immutability of records, are also recognized as advantages of BT [98,126,129,153–156] that may be helpful for regulators in assisting with the identification and reduction of possible food fraud cases [110,123,149,157,158], and counterfeiting [102,135,159] especially for society in less developed nations and rural areas [108,149]. One of the basic human rights is a healthy diet. However, as a result of increasing population and urbanization, the land allocated for agriculture has decreased [160]. In traditional supply chains, it has become challenging to obtain healthy foods and consume foods devoid of toxic chemicals. For example, daily reports of numerous instances of food fraud, contamination, and adulteration from various regions of India point to the urgent requirement for an improved decentralized supply chain paradigm [102]. Therefore, it is necessary to take advantage of BT in modern supply chains to prevent potential food fraud. With the help of BT, bacterial contamination or inferior food can be identified quickly [122,161]. For preventing fraud efforts, several businesses have begun to adopt blockchain in the real world. For example, IBM and Walmart have established a partnership by creating a blockchain-based platform to determine whether food fraud incidents may be identified or diminished [110]. Similarly, Alibaba's Food Trust frameworks have also tried to integrate BT into the food cold chain for perishable foods to boost food safety [142]. In addition, Walmart and Kroger were among the first businesses to integrate BT into their supply chains, and the outcomes of this implementation have demonstrated that this technology also saves time in terms of routing and sourcing [162].

In conclusion, the "farm to fork" concept is highlighted using BT [105,109,163–166]. Namely, BT has made it possible to track the crop through every stage, from production to harvest. For instance, during the production stage, data from the blockchain system will be used to protect product details such as production area, planting and harvest dates, fertilizer status, chemicals and pesticides used [80], agricultural permits, and food safety certificates [146]. After all, before the product reaches the fork, it is put through several inspections. Governmental agencies and food safety inspectors schedule field visits to farms and facilities. If specifications are met, products can be digitally signed by relevant organizations and governmental bodies following an inspection [146].

On the other hand, in some cases, various obstacles may be encountered that may prevent the use of BT. The biggest barriers preventing food businesses from implementing BT are the lack of the necessary technical skills, education, and training resources [99,167], regulatory and governmental issues [168], low technological readiness levels [169], high investment cost, technological immaturity, lack of awareness and customer acceptance, resistance from old business models, and a lack of common frameworks architecture [118]. In terms of technical problems, BT has scalability issues [98,170,171] due to the heavy computing required. Ethereum can only process 15 transactions per second, which is a very low rate when compared to other financial authorities, demonstrating the scalability concerns with blockchain [172]. Although one of the most cutting-edge methods in the food sector is BT, the design and development of the suggested systems take a lot of time and effort [95]. BT depends on internet availability and infrastructure capacity, so especially for small and medium-sized enterprises, lack of internet connectivity makes it difficult to integrate into their business [122,173,174]. Since the adoption of blockchain is frequently extremely expensive [175], the investment costs to be incurred in the integration process may be more challenging [176]. The importance of infrastructure improvement that enables better and more efficient physical connectivity between related parties [177]. Moreover, there are still issues with security, technical, legislative, infrastructural, institutional, and other crucial factors and developing appropriate IoT solutions to address complex and unique issues in the agriculture sector is suggested [79,178,179]. In terms of regulative issues, the implementation of BT reduces stakeholder control over agricultural production processes and operations. Therefore, the adoption of BT finds significant resistance from managers and decision-makers, especially on sustainability-related issues [31].

While researching agriculture and FSCs, some industries have been studied in detail in the literature. As such, cocoa [180], cheese [154], cotton [145], wine [181,182], halal food [131], organic tea [149,183], crystal sugar [130], smart honey [158], perishable foods [133,142], dairy products [102,154,184], seafood [117,185,186], and olive oil [187,188] are among the main industries studied.

It is necessary to specify the integration of BT into the system. In the reviewed studies, the use of BT is generally explained by developing a model architecture [102,153,174,187,189–191]. Mostly, there are various layers in the developed architectures. For example, according to Vo et al. [189], there are four layers in the BT-based structure that make up their architecture: the business layer, the traceability layer, the blockchain layer, and the application layer. Each layer serves a different purpose, and smart contracts can be useful in these layers. The blockchain smart contract allows for the real-time capture of feedback data regarding different ties, which can further optimize the control of agricultural production and provide the basis for maximizing its benefits [128,141,192]. In the proposed architectures, the blockchain-based supply chain system is generally integrated with the IoT technology. IoT and blockchain-enabled systems are essential for FSCs to adopt cost-effective methods [163,190,193]. Combining specific technologies, such as using IoT devices or RFID tags to smart contracts, can enhance the benefits of blockchains [103,153]. Platforms built on BT and IoT enhance supply chain visibility, improve contract execution, and boost the authenticity of product source data [96,100,103,194]. With the help of the IoT devices placed on the objects in the chain, the humidity and temperature of the crops can be measured, and the location of the products can be easily monitored using the QR codes placed [101,125,188,195], and fine-grained sensing can be available throughout the whole supply chain [98]. In this way, the consumer can view the whole life cycle of the product, and they may see how the price is handled in each of the transactions [125]. Another framework suggests smart packaging. With the help of blockchain and radio-frequency identification tags, during the whole chain foods' information can be tracked and smart packages' color change once the food spoils [196]. Among the blockchain systems used in research projects, the Ethereum platform is the most widely used alternative [95].

Fashion, Textile and Apparel Industries

The increased production of goods that directly cause environmental or societal issues is considered a significant problem in fast fashion [197]. In addition, as in other industries, COVID-19 has had a significant impact on the fashion industry, both in terms of supply and demand dynamics, as store closures or revenues decrease [198]. The fashion industry should drive digital innovation such as BT and create smart solutions, as part of the United Nations' Sustainable Development Goals [199].

Similar and related to the fashion industry, social, environmental, and sustainability concerns are common in the textile and apparel industry, which emphasizes the need for efficient traceability solutions [200]. The following benefits of using BT in the textile and apparel industry's supply chain are particularly noteworthy: transparency, tracking, sustainability, combating slavery, and brand protection [201]. Blockchain traceability data can also improve the life cycle assessment of textile products. Data from blockchain traceability might help characterize and understand a product's impacts, and also inform product eco-design and boost transparency regarding the effects of a product's life cycle [202].

The integration of technologies, such as smart contracts, 3D printing, QR-codes and AI with BT in the fashion industry can assist in achieving all objectives linked to maintaining the required ethical, social, and environmental standards [198,203]. As information about the fashion product, including the brand, the ingredients, the producer, and even the customer, is verified and stored, the items' usage history can be readily followed and validated, and with the help of BT, these used products can be cleaned and sterilized, then sold, rented, or donated to extending their useful life [197]. With no geographical restrictions, BT records every transaction involving clothing along the value chain. There is no requirement for third-party operators since value chain participants may decentralize access and disseminate information from any place [203].

Using blockchain in the global fashion industry can also affect the triple bottom line, which includes the planet, people, and profit [203]. Since the fashion industry depends on global supply chains for its operations, which are highly fragmented and have serious transparency and traceability issues, more and more businesses in these industries are being asked to demonstrate their commitment to sustainability in order to combat these issues [204]. Blockchain's significance in sustainability is evident [205] and the success of sustainable supply chains can be attained by using BT [198]. This technology can also promote sustainability from a consumer perspective. Accessing product information that might support ethical purchasing habits or guarantee product originality is challenging for customers [206]. Consumers are more encouraged and more likely to purchase sustainable goods and fashion brands when they have access to more reliable and clear guidance about the social and environmental effects of the clothing [202,207,208]. Using blockchain in supply chains can also help prevent inappropriate use of labor, as all information is open and cannot be covered up, and consumers become aware of the working conditions workers are exposed to [201]. All parties might make use of the special chance, flexibility, and power to track back their supplier networks and build an open and sustainable supply chain using the blockchain-based traceability system [206].

Blockchain's role in fostering responsible management as well as how companies' messages of responsible management contribute to sustainability in luxury fashion supply chains were also explored [209]. Most executives have a positive opinion of blockchain's ability to enhance responsible management in the supply chain for luxury fashion. BT can help managers increase consumer engagement and avoid greenwashing in the supply chain and stop the counterfeiting of goods sold by third parties that do not own a certain brand [201].

Three sustainability goals that companies focus their efforts on while using BT investigated in the fashion supply chain and product safety, brand authenticity and strategic positioning are found [210]. It is advised that supply chain companies take the blockchain into account as a significant strategic resource that may be used with other digital technologies to provide them with an advantage over rivals. Considering the blockchain implementation intentions of the supplier companies, "relative advantage, compatibility, perceived trust, top management considerations, absorptive capacity, information sharing and collaborative culture, and trading partners' influence" were found to have an impact [211].

With all these benefits, there are some obstacles to the acceptance and use of BT in the fashion sector, such as a bottleneck of digitization, a lack of industry knowledge, immutability, the network's poor scalability, interoperability, transaction speed, some security and privacy issues, block capacity, and power consumption [203,204]. Companies with a highly fragmented supply chain will need greater organizational efforts and bear higher expenses since specific data is needed for blockchain traceability. Government incentives and knowledgeable customers who ask for its features might both have an impact on the environment and the adoption of BT [205]. The role that governments can play is also highlighted in other studies [203,212]. If the value propositions are emphasized for various stakeholders in the supply chain as an incentivization mechanism, the obstacles to the adoption and deployment of BT can be removed [203].

Manufacturing Industry

Traditional supply chains are being upended by the pandemic [213] and technological spillovers, which is resulting in a sustainable digital economy powered by modern manufacturing breakthroughs and business models [214]. Manufacturing industries are increasingly conscious that chasing only financial gains would not enable them to compete successfully [215]. Sustainable supply chains, which are created by utilizing technologies such as blockchain, attract more and more attention every day and are considered necessary to maintain competitive advantage and long-term existence [216–219], and increase manufacturing firms' profits [216]. The positive impact of blockchain on green supply chain practices including green manufacturing, green design, green distribution, and green procurement has been confirmed by Mubarik et al. [217].

The supply chain integration can be exceptional in the manufacturing industry if the transactions are sufficiently transparent and can be traced [220]. Due to its real-time transparency, eliminating the need for intermediaries, and cost-saving advantages, BT has been suggested for sustainable supply chain management in the manufacturing industry [216,218]. By reducing redundant paperwork, enabling businesses to estimate demand and supply in real-time, and, as a result, preventing unnecessary extra production, blockchain strengthens the supply chain's resilience and integration [217].

BT is also recommended in different applications to support sustainability, such as plastic recycling, steel manufacturing, additive manufacturing, and cloud manufacturing. The usage of blockchain as smart contracts is advised to separate plastics and increase the accuracy of data on recycled plastics [221]. These technologies are useful for effectively sorting plastics and can be relied upon in the plastic circular economy. With the use of these technologies, data can be safely shared between parties including segregators, recyclers, and manufacturers. Similarly, for steel manufacturing supply chains, BT has been suggested to make a resilient supply chain possible [213]. Concerning additive manufacturing, as there is less energy wasted during additive manufacturing, it is a more environmentally friendly method of production. If blockchain and additive manufacturing technologies are combined, the manufacturing industry can gain a great deal [222]. In addition, a blockchain-based cloud manufacturing system can conduct real-time analytics and traceability for better quality control, inventory management, and audit reliability [214]. Moreover, real-time analytics can reduce carbon footprint as audit reliability is carried out in real time and in-person travel to verify papers and inventory stock are avoided [214]. It is also stated that when the government offers incentives, businesses will embrace BT to track their carbon emission activity [219].

Han and Rani [223] have recently investigated the barriers to BT adoption in sustainable supply chain management in the manufacturing industry and identified 25 barriers including "fear of change", "the infancy of the technology", "organizational culture", "cyber security concerns", "lack of awareness", "possible fear of data misuse", "regulations for blockchain development", "massive financial investment", etc. Lack of awareness was determined to be the main obstacle to the BT adoption. Another study looked at common barriers to the use of BT in remanufacturing. It showed that "scaling of technology," "operational challenges," and "lack of awareness on blockchain risk" were the three main obstacles [215]. In addition, elimination of these barriers can also have impacts on Sustainable Development Goals. For example, by eliminating the "lack of awareness of blockchain risk", the industry can train its employees with BT and promote learning opportunities (its associated goal is SDG 4-quality education) [215].

Maritime and Shipping Industries

The shipping industry, which has been impacted by the long-term instability of global trade, has recently gone from having excess transportation capacity to lacking it, and both situations seriously impair the shipping industry's ability to grow sustainably [224]. Blockchain supports sustainable business models and promotes sustainable practices in these industries by enabling greater knowledge cycling and relational actions among supply chain operators [225]. For example, Korean shipping firms integrate BT into their operations to generate sustainable profit [226]. In addition, machine learning on the cloud inside BT was recommended by Wong et al. [227] to achieve technological sustainability, as it can fulfill the increasing blockchain needs and learn from the blockchain's big data.

Moreover, maritime and shipping supply chains can be made traceable using the blockchain platform for distributed data and information storage and sharing, smart contracts to perform transactions automatically, and many supporting technologies (such as IoT devices, GPS, and sensors) [228]. The two crucial stages in the lifespan of a transaction within the blockchain network are transparency and security [229]. To provide more security and transparency, smart contracts can be put up at key locations along the shipping route [229] and it might help many parties by cutting back on workloads, the amount of inspection, and time-wasting [230].

Increased visibility, transparency, and real-time information across routes, decreased paperwork, data and information authenticity, enhanced collaboration and cooperation, decreased rework and recall, decreased risk of document loss, improved job performance [231], increased competitiveness and efficiency [228], and decreased need for manpower which can cause a lot of mishaps aboard ships [230] are some of the positive effects of BT in the maritime industry. In addition, a blockchain-based approach and identification mechanism may raise people's awareness of the need to control marine plastic debris, which is a problem that affects both the environment and human life [232]. On the contrary, some of the risks that come with using BT can be summed up as follows [233]:

- It is possible for smart contracts to be misunderstood, and smart contracts frequently need to be updated to account for shifting circumstances in the real world. As a result, there may be discrepancies between what is expected of them and what really happens.
- There can be cyberattacks against elements of the blockchain, such as ledger and blockchain maintenance nodes.
- Failures of the hardware or infrastructure upon which the blockchain system is based can happen.
- There may be unintentional exposure or leakage of private company information.
- This technology may result in infrastructure failures, smart contract hazards, delays in payment processing, and bottlenecks throughout the supply chain.

Automotive Industry

The automotive industry is the most affected and challenging sector, especially after COVID-19 pandemic [234]. BT provides great advantages in automobile industry [235], particularly for internet-connected or autonomous automobiles [236]. In many global supply chains, there is a lack of information transparency, which may lead to product quality uncertainties. For this reason, information flows should be developed for automotive products from supply chain raw material to sales distribution [235]. BT can be utilized to build a trustworthy peer-to-peer network [236] and is also guaranteed to make solving environmental problems and challenges with the global supply chain easier [237].

The problem of sustainability is more significant nowadays due to growing environmental concerns, pressure on businesses from customers, communities, as well as national and international government representatives [237], and the circular economy's integration with Industry 4.0 components like BT [238]. Supply chains can be more sustainable and flexible by using the latest technologies [234,239]. For example, through the influence on the adoption of green supply chain practices in the automotive industry, Industry 4.0 technologies have an influence on the performance of the supply chain [240].

Integrating blockchain increases item traceability and decreases waiting times, increasing supply chain operating efficiency [241]. For example, Daimler created a blockchain-based platform to record all financial and transaction information about the lifecycle of a vehicle. This will be the basis for all subsequent information, including vehicle delivery, registration, maintenance, and last kilometer. Since each vehicle will have a separate digital identity, users can monitor and examine the whole traffic history [235].

In terms of raw material traceability, information monitoring, immutability, and cost savings, BT has paved the way for the sustainable growth of the automotive supply chain [235]. For these reasons, it is now important to research how BT promotes supply chain sustainability [237]. Xu et al. [235] conducted a case study examining the supply chains of some automotive companies such as Daimler, Wolkswagen. Research results show that recycling and remanufacturing procedures significantly increase the efficiency of car components. For instance, the system should incorporate procedures like the usage of batteries with sustainable qualities in the electric vehicle industry [237]. About a century later, due to existing technological developments, electrical automobiles seem to have a multi-faceted development compared to traditional cars. To reduce global CO_2 emissions, the automobile industry is switched to electric motors from internal combustion engines. The need for more flexible, cost-effective, and high-quality mobility solutions directs the industry to increase expenditures on smart and sustainable technologies [242]. To obtain long-term cost savings without decreasing the quality of their goods, it is advised that automakers invest more in recycling technologies [237].

In addition, there are also some obstacles that have been emphasized, such as lack of internal and external cooperation, lack of technical infrastructure, uncertainty of high return on investment, lack of digitization in the supply chain, security issues, difficulty in combining existing software, and procedures with the blockchain structure [235].

Healthcare and Pharmaceutical Industries

BT has generated interest from all over the world because it has the potential to revolutionize sustainable supply chain management in the healthcare industry [243]. In particular, the COVID-19 pandemic has had a huge impact on the healthcare industry on a global scale, resulting in serious difficulties for multi-layered supply chain management [244] and raised questions about the long-term viability of the healthcare system [245,246]. These concerns have accelerated the adoption of digital technology, and one of these emerging digital technologies is blockchain, which stands out for a variety of reasons [243]. The benefits of using blockchain in the healthcare industry include increased performance efficiency, higher patient satisfaction, openness, and traceability [243,247].

The existing pharmaceutical supply chains have issues as well; for instance, it restricts manufacturers and regulatory bodies insight into and control over the distribution of pharmaceuticals; cannot resolve the issue with cyber security [248]. To avoid medicine shortages or waste in any healthcare facility, an effective system of supply management should be put in place. The efficacy of pharmaceutical supply chains can be affected by the adoption of blockchain, which will also have an impact on the organization's supply chain sustainability [248]. In addition, by tracking and monitoring in near-real time just the medical deliveries that need refrigeration for temperature changes along their supply chain path, blockchain with RFID tags and other intelligent IoT technologies might help lower transportation-related costs [249].

Drug counterfeiting is a global problem with significant risks to consumers and the public in general, as well as threatening the reputation of the pharmaceutical industry [249,250]. The implementation of BT in pharmaceutical supply chains to support traceability is recommended in reviewed studies [248–250]. Controlling illegal actions, promoting sustainability performance, boosting operational efficiency, improving supply-chain coordination, and detecting market trends are identified to be the business requirements for traceability systems [249]. Companies' expertise, teamwork, technical maturity, supply chain practices, leadership, and governance of the traceability activities are crucial success elements for implementation [249].

The reviewed publications in the healthcare industry focused on medical and personal protective equipment (PPE) and the use of blockchain in the blood bank supply chain [244,245,247]. It is suggested that BT can be integrated into the system by utilizing IoT and other technologies [244,247]. In most studies, model proposals have been developed in which the blockchain is integrated into the health system. By exchanging real-time supply-demand data between each blood bank and hospital using BT, for instance, there will not be any issues such as maintaining more blood inventory than necessary, according to a research model for a blood bank proposed in [247]. Patient satisfaction can also be increased as the required blood will be swiftly called through the system and delivered to the patient.

Mining and Mineral Industries

There are various abuses or damages caused by many mining and mineral applications. Cobalt, for example, is used for many different purposes including the production of lithium-ion batteries for electronic devices but mining practices associated with cobalt are notorious for violations of human rights, such as child and slave labor [249,251].

To maintain sustainability, ethical practices in the mining and mineral industries have been recommended emphasizing the role of blockchain [251–253]. Industry initiatives are being made to increase the sustainability of mineral supply chains by using digital certification and traceability [254]. Blockchain-based systems are currently placing a lot of attention on the chain of custody governance and traceability in the cobalt supply chain, such as providing secure information about the circumstances of raw material extraction and processing and transmitting this information to businesses along the supply chain and all the way down to the brand user [249,251,253]. Blockchain technologies make guarantees that information is communicated in a way that cannot be altered and is available to the relevant actors, making it easy to track items between several supply chain levels [252].

For example, the Congolese cobalt industry uses BT to store and transport data using distributed ledger technology. The information traces the evolution of the minerals from their original state to that of hydroxide, sulfate, cathode, and ultimately batteries. Even though there are hundreds of suppliers in this intricate supply chain, data on child labor, poor working conditions, and other dangers is kept up to date and available to the user [253]. Significant technologies other than blockchain are a crucial component; for example, IBM conducts chemical analysis research using AI technology to determine the origin of cobalt [252].

The minerals in which BT is used vary in terms of the processes involved. Compared to minerals like cobalt, diamond-tracking blockchain technologies are easier to use. For instance, while one company preserves the distinct identities of diamonds generated from more than 40 attributes, minerals like cobalt tracked by other companies go through challenging steps like smelting and refining, making it challenging to adopt a perfect approach [252].

BT can effectively build the chain of trust between enterprises in the coal industry (e.g., realizing data encryption, information sharing and credit transmission of enterprises, reducing human intervention and operational risks with the help of smart contracts) and greatly enhance the growth of supply chain finance in the coal industry [255].

The interaction between the blockchain and trust is investigated in the metal industry, focusing on steel and copper supply chains [256], and BT is viewed as a very promising technology regarding trust in the supply chain partner, particularly in the context of sustainability. When technology trust is investigated, there is a lot of dependence on records that have previously undergone authentication testing (such as "eco-labels" that track the sustainability qualities of items). However, there is still a lot of reliance on third-party certificates in the metal industry, since there is less confidence in the data's reliability or accuracy [256]. In addition, blockchain-enabled traceability solutions can fall short of challenging the access and resource usage disparities that already exist [254].

Energy Industry

Decarbonization, digitization, and decentralization are the three "Ds" of the energy transition [257]. According to the International Energy Agency's key benchmarks for monitoring development in the energy sector, transport emissions must be decreased by 43% by 2030 [258]. Incorporating BT is crucial for enhancing the trust, accountability, transparency, cooperation, and information sharing in supply chains for sustainable energy [259]. Blockchain can uncover the enormous potential of linking decentralized grid-end nodes and offer a common network for peer-to-peer energy transactions between parties by eliminating the restrictions imposed by a centralized supply chain [257].

BT has mostly focused on sustainable energy. Consumers increasingly desire a smarter, cleaner, and more sustainable energy source than in the past due to technological advancements and the declining cost of renewable energy [260]. In addition, energy-efficient smart homes are getting more and more attention. Every prosumer aspires to create a more cost- and energy-efficient, sustainable house [261]. BT encourages the adoption of renewable energy sources. The global energy industry is becoming smarter as a result of the advent of smart devices and supporting software, as well as the declining cost of renewable energy [260].

Applications for blockchain have the power to significantly improve and change current energy networks. Schletz et al. [262] created a pilot model to investigate blockchain application in energy supply systems. This architecture uses IoT devices to gather and assess real-time energy production and demand data. When a generator produces more energy than it needs, the extra is delivered to the local grid and sold to a different nearby generator in the blockchain-based marketplace. When a manufacturer requires energy, IoT devices automatically purchase it from the blockchain market, or they turn the devices off to reduce energy use. When energy prices are low, IoT devices use more energy, and when energy prices are high, they use less. This process makes flexible pricing possible and eliminates a monopolistic market structure.

BT benefits the energy industry in several ways, enabling both small and large businesses to operate in an energy efficient manner, and thus offering an advantage for the emergence of new business models that can increase energy efficiency in developing countries [262]. Ensuring the entry of small renewable energy producers into the energy market, the elimination of uncertainties in product supply and price through smart contracts, and helping regulators to document energy transactions (transparency in carbon emissions, etc.) can also be counted among these benefits [260]. Moreover, decentralized and distributed trading systems are made possible by BT, which also creates a more reliable, secure, and transparent trading environment [261]. Adoption of BT is, however, hampered by the main obstacle, which is regulatory uncertainties as current regulatory frameworks do not support blockchain as a possible technology or allow energy trade from prosumers to consumers [262]. In addition, the other significant obstacle to the use of blockchain in sustainable energy supply chains is determined to be "high investment cost" [259].

4.2.2. The Methodology-Based Evaluations

The methods and theories included in the studies examined are given in Table 5.

Table 5. Methods and Theories Used in the Publications.

Industry	Categories	F	Publications
Food and Agriculture	**Methods**		
	Quantitative	31	[31,43,79,97,109,114,118,123,125,129,136,142,151,160,161,165,167,175,176,179–181,183,188,191,194,263–266]
	Qualitative	8	[109,121,129,148,182,195,267,268]
	Proposal (model, architecture, etc.)	24	[79,100,102,103,112,125,128,130,135,146,147,158,159,162,166,172–174,187,189–191,193,269]
	Case Study	28	[42,77,101,110,111,115,126,131–133,137–139,141,144,146,149,152–154,156,177,181,184,185,187,192,267]
	Literature Review	47	[42,43,79,95,96,98,99,104–108,110,113,115–117,119,120,122,127,129,132–134,137,138,140,143,145,146,150,155,157,163,164,168–171,177,178,186,190,196,267,270]
	Theories		
	Critical Success Factors Theory	1	[263]
	Cumulative Prospect Theory	1	[31]
	Game Theory	2	[161,175]
	Technology, Organization, Environment Theory	2	[176,180]
	Unified Theory of Acceptance and Use of Technology	1	[176]
	E-CAOS Model	1	[141]
	System Theory and System Dynamics Modelling	1	[184]
	Innovation Resistance Theory	1	[148]
	Information Processing Theory	1	[194]
	Dynamic Capability Theory	1	[194]
Fashion, Textile, and Apparel	**Methods**		
	Quantitative	4	[202,208,211,212]
	Qualitative	1	[209]
	Proposal (model, architecture, etc.)	3	[197,206,271]
	Case Study	8	[198,200,203,205–207,210,272]
	Literature Review	4	[198,201,204,271]
	Theories		
	Social Capital and Resource Based Theory	1	[210]
	Diffusion of Innovation Theory	1	[211]
Manufacturing	**Methods**		
	Quantitative	9	[215–221,223,273]
	Qualitative	1	[273]
	Proposal (model, architecture, etc.)	1	[223]
	Case Study	4	[213–215,223]
	Literature Review	2	[213,222]
	Theories		
	Resource Based Theory and Network Theory	1	[218]
	Technology, Organization, Environment Theory	1	[219]
	Unified Theory of Acceptance and Use of Technology	1	[220]
Maritime and Shipping	**Methods**		
	Quantitative	1	[226,233]
	Qualitative	1	[228,233]
	Proposal (model, architecture, etc.)	3	[224,225,227]
	Case Study	5	[225,227–229,232]
	Literature Review	3	[227,230,231]
	Theories		
	Technology Acceptance Model Theory	1	[229]

Table 5. *Cont.*

Industry	Categories	F	Publications
Automotive	**Methods**		
	Quantitative	5	[234,236–238,240]
	Proposal (model, architecture, etc.)	3	[239,241,242]
	Case Study	2	[234,235]
	Theories		
	Dynamic Capabilities Theory	1	[236]
	Technology, Organization, Environment Theory	1	[235]
Healthcare and Pharmaceutical	**Methods**		
	Quantitative	2	[243,247]
	Qualitative	1	[249]
	Proposal (model, architecture, etc.)	3	[245,248,250]
	Case Study	1	[246]
	Literature Review	1	[244]
	Theories		
	Technology Adoption Models Theory and Task-Technology Fit	1	[247]
	Graph Theory and Matrix Approach Theory	1	[246]
	Unified Theory of Acceptance and Use of Technology	1	[250]
Mining and Mineral	**Methods**		
	Qualitative	3	[249,254,256]
	Proposal (model, architecture, etc.)	2	[251,255]
	Case Study	2	[252,256]
	Literature Review	2	[251,253]
Energy	**Methods**		
	Qualitative	2	[258,259]
	Proposal (model, architecture, etc.)	1	[261]
	Case Study	3	[259,260,262]
	Literature Review	1	[257]

4.2.3. Future Directions

There are general directions that are independent of the industry and industry-based suggestions when the future directions of the studies are considered. After the general directions are given below, the industry-specific directions are given next to the industry name.

The application of BT in different industries is recommend in studies [197,205,209]. Many companies offer BT solutions with a limited scope (only with the pilot projects) but on the other hand, they need a ready-made solution. To take full benefits of BT, suitable systems should be developed in the future that includes required infrastructure, standard operating procedures, strict quality norms and skilled human resources [135]. It will be beneficial to create complex socio-technical systems that call for multidisciplinary skills from a variety of fields, including computer science, the social sciences, and business [157]. Future studies can also investigate how engineers, operational professionals, and the academic community can work together to improve the reliability of the blockchain system [229], to create standards and offer useful performance metrics for the use of BT [223].

In addition, as certification firms are crucial to the supply chain participants' compliance, certification organizations' roles in supply chains may be further investigated and operationalized [206]. Future research might also focus on the elements influencing the success or failure of blockchain after adoption [223]. The employees must also receive the necessary training in order to handle and utilize this cutting-edge technology [273]. Analyzing the return on investment or performing the cost-benefit analysis of the proposed architecture for adoption and scaling up can also be an important area of future work [191].

New ideas have emerged that connect BT with various Industry 5.0 technologies such as big data, the IoT, radio frequency identification (RFID), near-field communication (NFC) [96], artificial intelligence, augmented reality, autonomous robot, digital twin, virtual reality and, 3D printing that can be taken into account in future studies [270].

Research on implementing BT in sustainable supply chain management is still in its early stages. More study is required to fully explore the potential of BT in various industries considering various nations [232]. Future work intends to use parameters like finance, policy, pollution, and energy to evaluate sustainable/smart BT [263]. Furthermore, other highlighted challenges, such as regulatory, technical, and interoperability issues, should be addressed in more detail [116]. As studies have concentrated more on the economic aspect of sustainability, it is necessary to look into the social sustainability of access rights and privacy concerns of the BT integration [227] and environmental aspects [236].

- *Food and Agriculture Industries:* Despite its many benefits, the real implementation of blockchain in the agricultural food supply chain is still in its infancy [79,153,180,264]. Much research should be done to use it to create reliable and secure decentralized apps [172]. Unvalidated sustainable e-agriculture implementation and non-informalized sustainable analysis are still understudied as developing themes [106]. The biggest issue with this is that there are not many incidents of it happening, and the direct and indirect social and environmental benefits of the technologies have not been properly tracked down or measured yet. Longitudinal studies could be very helpful to detect the direct and indirect social and environmental benefits of the technologies in the long run [153,268]. It would also be helpful to compare the effects on different supply chains, including long and short FSCs [153].
- *Fashion, Textile and Apparel Industries:* Since the implementation of BT is complicated, future research can focus more on to examine the challenges related to implementation in these industries [197], and the interaction and integration of diverse blockchain systems [206]. Considering the methodological point of view, case studies are based on a small sample in the reviewed studies, as very few brands and suppliers in the fashion, textile, and apparel industries are starting to adopt the use of blockchain. Therefore, future studies may include more brands and suppliers [203]. Additionally, other than qualitative case studies, it is advised to use quantitative techniques to create robust inferences in cases [205,210].
- *Manufacturing Industry:* Future research is suggested to focus on the creation of an integrated technological application framework to combine blockchain and artificial intelligence in the manufacturing sector [213]. In addition, the multi-cloud seamless method for collaborative enterprise management, wherein corporate information systems based on various clouds are capable of handling synchronous workloads, can be the focus of future research [214]. Future research should involve more companies and larger sample of areas or countries [218]. For instance, the reviewed studies focused on Malaysian [218], Danish [215], and Chinese [220] manufacturing companies. More research is also needed to compare BT uses in both traditional manufacturing and remanufacturing [215]. It is advised that the government enact necessary regulations to encourage the use of BT throughout the nation or industry (manufacturing) [273]. Although the concept of combining BT with additive manufacturing is recommended, in practice it is considerably more complicated, and more research should be conducted [222]. A blockchain-based additive manufacturing system will need to work in harmony with a variety of stakeholders [222].
- *Maritime and Shipping Industries:* On various maritime information infrastructures, cross-sectional and longitudinal case studies can be carried out [225] as more case studies needed to generalize the findings [227]. Regarding the many aspects, including environmental, business internal, and technological, a study on the collaboration between shipping companies and shippers is suggested [226]. By creating an end-to-end blockchain network combining smart contracts with machine learning features for the global process of exporting and importing, future research can further utilize the

shipping sector [229]. In addition to a risk-focused strategy, examining the difficulties and suggested adaptive techniques in implementing a blockchain integrated system may provide a more thorough understanding of blockchain's potential in the maritime shipping industry [233]. Moreover, future studies can concentrate on examining the unique characteristics of maritime industry in comparison to other industries in terms of blockchain acceptability, as well as the role of government authorities in terms of the adoption and usage of the technology [231].

- *Automotive Industry:* Since research generally is based on the data taken from the automobile industry of a particular country (for example, India), it would not be correct to generalize the results of the studies in this sector to the whole world. The results will likely be different for less developed countries with limited organizational skills and access to information resources [236]. Future researchers can extend the models used by using complex mathematical modeling and simulations to reveal the underlying phenomena between variables [237].
- *Healthcare and Pharmaceutical Industries:* The examined publications' recommendations for future research emphasized the need for governments to assist the use of BT by enterprises for innovative solutions [247]. It is also crucial to consider other aspects of the healthcare industry and the various types of equipment that are used [244]. In addition, many methods can be used, including real case studies and additional mathematical and empirical modeling tools for these industries BT applications [245].
- *Mining and Mineral Industries:* Like other industries, more case studies and quantitative analysis are required for mining and mineral industries in future studies [256]. Future studies might compare blockchain versus non-blockchain solutions more thoroughly in terms of costs and other factors, and look at the relationship between consumers' traits and how they respond to BT-based items [252]. It is also important to carefully consider how mandatory and optional frameworks of blockchain implementations differ from one another [253].
- *Energy Industry:* Blockchain adoption in energy research is still in its early stages [257,260,262]. Future research needs to obtain empirical data from pilot studies [262]. The findings in [260] stressed the significance of incentives for the energy industry. The establishment of research platforms and the study of BT should be supported by several institutions, such as companies, institutions, and universities. In addition, governments should streamline management processes and increase management levels and efficiency to safeguard energy blockchain innovation. In future studies, a blockchain-based energy transaction platform can be implemented in a smart home environment. In addition, long-term comparisons can be made by calculating the energy costs between a normal home and a smart home using the recommended platform [261].

5. Discussion and Conclusions

The use of BT in increasingly digitalized and globalized supply chains and logistics has been explored in the context of sustainability using a mixed-method approach. This study includes 552 studies published between 2017 and September 2022 in the Scopus and WoS databases on blockchain and sustainability in supply chains and logistics for bibliometric analysis. Studies focusing on certain industries were assessed among the publications collected in the bibliometric study, and a total of 185 articles were reached for content analysis. The study provides the current state of the research components with bibliometric indicators as well as appreciates the industry-based view of the field using content analysis.

To address the first research question (RQ1), the status of the research on blockchain and sustainability, various bibliometric analyses and rules have been applied. The results of the distribution of publications over the years (RQ1.1) show that this field is on the rise as stated in [3,26], and the field has attracted more attention since 2019, showing an annual growth rate of 152.19%. To identify top research components (sources, authors, affiliations, countries, keywords) and how they relate (RQ1.2), three-field analysis is used. Joseph Sarkis [1,2,40,76,180] is the most productive author with more relationships with the main research field and many of the listed core journals. Many top-productive authors have published their studies in *Sustainability*, *Annals of Operations Research and Business Strategy*, and *The Environment* journals. For the top keywords, other than search strings, IoT, circular economy, Industry 4.0, COVID-19, and agri-food keywords indicate relationships with top authors. For the top countries, China and India have more relationships with top affiliations. Many collaborations between countries, affiliations, and authors are also detected, such as, The Hanken School of Economics (Finland) has relationships with Finland, the USA, Denmark, China, and France and many top authors.

It is also investigated whether the research collection complies with Bradford's Law and Lotka's Law (RQ1.3), and it was found to confirm. Source clustering and author productivity calculations with bibliometric laws highlight that there are a few journals (e.g., *Sustainability*, *Journal of Cleaner Production*, and *International Journal of Production Research*) that publish many articles and many journals that publish few articles. Similarly, 84.5% of authors publish only one article in the research field. The top cited publications are investigated (RQ1.4), and it is found that Saberi et al. [76], providing an overview of BT, its use in supply chains, and the challenges it faces, have the most citations in the field.

When the discovered themes are examined (RQ1.5), in accordance with the statements about the themes' persistency in [81], it can be concluded that since IoT, traceability, and Industry 4.0 have been studied for all time periods, these themes have a greater likelihood of remaining in the next periods. In addition, COVID-19 with food industry themes can also be prevalent and popular in later periods because they appear as motor themes in this year's map, and the effects of COVID-19 have been studied by researchers in recent years (e.g., Galanakis et al. [164] discuss potential innovations (internet and communication technologies, blockchain, etc.) for the food industry affected by the pandemic). Since carbon emission, supply chain finance, and renewable energy themes are located in emerging themes, the development of these themes can gain popularity if they receive interest from researchers.

The themes highlighted by the bibliometric study, such as COVID-19 and traceability, were expanded upon by industry-specific content analysis. Food and agriculture are the most popular industry in this discipline, followed by fashion, textile, and apparel, while energy is the least popular industry. To appreciate the industry-based insights of the research on blockchain and sustainability in supply chains (RQ2), the benefits, challenges, and uses of BT (RQ2.1), the methods and theories (RQ2.2), and future directions (RQ2.3) in the research collection are investigated.

One of the most significant benefits of using blockchain in supply chains, according to findings, is its potential strength in enabling the development of a more sustainable system for all industries. The other benefits are as follows: transparency, traceability [128,129,134,201,202,231,243,247–250,259], fewer negative environmental effects [143], quality assurance, resilient and more efficient supply chain systems, [97,125,129,216], real-time management, utilization of resources [98], cost efficiency [126,139,216,218], increased synergy between supply chain actors [156], improved visibility and the immutability of records [98,126,129,153–156], and reduced fraud and counterfeiting attempts [102,110,123,135,149,157–159]. On the other hand, there are challenges, such as the lack of resources for technical expertise, education, and training [99,167,235], lack of awareness and knowledge [118,203,204,215,223], high investment costs [175,176,259], regulatory, governmental [168,237,262], operational [215], scalability [98,170–172,203,204,215], and security and privacy [79,178,179,203,204,235] issues.

Usage areas of blockchain-based sustainable supply chains include e-farming applications [31,106,113,114], open to trace food tracking systems from farm to fork [80,105,109,146,163–166], detection of counterfeiting in fashion products (e.g., luxury bags, dresses) [201,209], plastic recycling, steel manufacturing, additive manufacturing, and cloud manufacturing [213,221], determining routes and destinations in shipping [226,229], customs procedures [229], processes between blood banks and hospitals [244,245,247], renewable energy systems [260], and the journey of precious minerals and metals [252,253,256]. It has been suggested that expanding the use of BT across all industries can provide more fruitful outcomes such as the development of global, data-driven, intelligent, agile, and autonomous systems in supply chains [98,101,104,105,111,112], and advance the realization of sustainability in all its forms: economic, social, and environmental. IoT, digital twins, AI, machine learning, cloud computing, and RFID are some of these technologies [99,109,110].

When the methods used are examined, it is seen that quantitative, qualitative, proposal (model, architecture, etc.), case study and literature review studies are carried out. Considering industries, literature reviews for food and agriculture, case studies for fashion, textile, and apparel, maritime and shipping, and energy, quantitative studies for manufacturing and automotive, proposal studies for healthcare and pharmaceuticals, qualitative studies for mining and minerals are the most used. When theory usage is evaluated, it has been observed that theories are employed very rarely in studies overall and not at all in studies of the mining, mineral, and energy industries. The Technology, Organization, Environment Theory is used in the food and agriculture [176,180], manufacturing [219], and automotive [235] industries. The Unified Theory of Acceptance and Use of Technology is also utilized in different industries: food and agriculture [176], manufacturing [220], and healthcare and pharmaceutical [250].

When the directions for future research are considered, it is highlighted that more research should be done and that various institutions should collaborate to work in this area, increase incentives (for instance, by governments), and diversify the use of BT with innovations like IoT, RFID, digital twins, big data, and artificial intelligence.

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