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Blockchain Technology in Operations & Supply Chain Management: A Content Analysis

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Abstract: Scholars are increasingly examining how the distributed blockchain technology can counter specific supply chain and operations management challenges. Various research approaches emerge from different scholarly backgrounds, but the interrelation of research areas and current trends has not been adequately considered in a systematic review. We employ a data-driven content analysis approach to examine previous research on blockchain technology in operations management and supply chain management. We investigate the extent to which blockchain technology was considered in scholarly works, structure the research efforts, and identify trends, interrelated themes, and promising research opportunities. Quantitative and qualitative content analysis is conducted on an extensive literature sample of 410 articles. Results indicate an optimistic attitude due to potentials such as tracking and tracing abilities, efficiency increases, and trust-building. Conceptual studies dominate the literature set, with increasing qualitative research efforts. Grand theories are seldomly addressed in the studies. Blockchain technology is outlined as particularly useful when combined with other technologies like IoT. We also identified sustainability implications of the technology, such as enabling transparency for SC stakeholders. Cryptocurrencies can facilitate further efficiency gains if legal uncertainties are reduced. The study is concluded with managerial and theoretical implications and future research opportunities.

Keywords: blockchain technology; operations management; supply chain management; content analysis; systematic literature review

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1. Introduction

Modern supply chains are complex, intertwined systems that have attracted the attention of many firms and the general public through the recent COVID-19 pandemic [1–3]. The integration and streamlining of activities along the supply chain (SC) include the flow of goods, information, and value. These approaches are consolidated in management activities addressed by the supply chain management (SCM) theory [4]. SCM is closely related to operations management (OM), as a terminology for managing assets dedicated to manufacturing and supplying products and services [5]. Efficient SCM and OM activities enhance visibility, reduce costs and supply chain vulnerability, optimize revenues, and enable to meet increasingly complex customer requirements [4]. Digital transformation offers an opportunity for these management activities to shape change and respond appropriately to the complexities of modern SCs. Firms can engage in and enhance inter-organizational collaboration with their partners such as suppliers and customers through information technologies. Such collaboration includes sharing information, synchronizing decisions, and aligning goals with the respective stakeholders [6], and information technologies have been recognized as key elements in facilitating swift and secure collaboration [7,8]. Several modern information technologies have affected the SCM and OM community and led to maximized transaction speed and enhanced visibility [9].

As one of these emerging technologies, blockchain technology (BCT) has experienced considerable attention and hype in recent years, both in industry and research [10,11]. The distributed ledger of transaction records enables to conduct business in a "trustless environment [...] protected by the science of cryptography" (Pournader et al. 2020, p. 2064) [12]. Initially, research on BCT focused on explaining the technology and its potential implications for different business areas [13–16]. Potentials such as facilitated transparency, secure communication, and unalterable transactions in the B2B environment have been identified and implemented in various applications and proof of concepts [10,17]. Barriers were identified as lacking awareness, missing management support and standards, unclear governance implications, and more [12,17–20]. In parallel, different industries started experiencing with BCT and developed proofs-of-concepts. Practical applications for OM and SCM, e.g., include efforts to digitalize global sea freight [21], facilitate additive manufacturing [22], or IoT-related concepts [23]. The eagerness to adopt BCT is also confirmed in industry surveys: In a KPMG survey in 2019, 48 percent of 740 technology leaders stated that they think that BCT is likely or very likely to change their business in the three years to come [24], while in a Deloitte survey 53 percent of the respondents see BCT adoption as one of the priorities of their firms [25].

BCT is located at the intersection of information technology (technology aspect), cryptography (security aspect), and economics (application aspect). Although this interdisciplinarity exists, research is mainly conducted in traditional scientific silos, detached from each other [26,27]. Networking between these subject areas and collaborative research efforts still fail to meet expectations [26].

Previous literature reviews (see Section 2.2) reported on identifying drivers of BCT deployment in SCM [10,12,18], potentials of BCT application [28,29], or challenges to BCT diffusion [18,30,31]. Some also refer to rather specific application areas of the technology [32,33], while existing bibliometric reviews did not focus on OM and SCM and only marginally tapped into these research areas [34,35]. Moreover, these bibliometric reviews mainly focused on keyword co-occurrence, network analyses, or the geographic distribution of articles. A comprehensive and systematic review of the literature on BCT in OM and SCM using content analysis that provides insights on research trends and key topics in scholarly exploration is missing. While scholarly literature on BCT is growing fast, the promising prospects for rapid and widespread industry adoption of the technology have not yet materialized to the same extent [36]. Therefore, it is valuable to analyze the interrelationships between the research areas (e.g., connecting the technology with the application aspect) and reveal the underlying research designs. These interrelationships and a concise overview of current research trends can enable a more realistic view of the phenomenon. Therefore, this study aims to complement valuable prior BCT literature reviews by utilizing a comprehensive literature sample in a category-guided and software-aided analysis. Thus, the study attempts to contribute to a better understanding of existing research focal points while highlighting areas where future research is worthwhile.

This study analyzes the available scientific literature on BCT with a specific focus on OM and SCM and a comprehensive and interdisciplinary perspective. We aim to investigate the extent to which BCT has been considered in the literature on OM and SCM and identify trends and promising research opportunities. Therefore, we conduct a quantitative and qualitative content analysis of an extensive literature sample of 410 publications. Content analysis (CA) is a valuable method to identify patterns and trends in publications and is suited for large literature sets [37,38]. CA is data-driven and can be based on predefined, unbiased recording units [39]. It is a useful research method in social sciences, OM, and SCM [37,38,40,41].

We aim to contribute to the state-of-the-art of research on BCT in OM and SCM by answering the following research questions (RQs) through the application of CA:

RQ1: How can research on blockchain technology in OM and SCM be classified and structured within a theory-based framework?

RQ2: Which blockchain concepts and topics related to its application have been identified as promising in OM and SCM research? Which were explored primarily?

RQ3: Which research opportunities for BCT in OM and SCM remain to be addressed?

The remainder of our article is structured as follows: Blockchain technology is introduced concisely in the next section, followed by an overview of recent literature reviews on its application, potential, and research trends in OM and SCM. Section 3 details the methodology of the applied CA, the approach of generating the literature set comprehensively, and elaborates on the conceptual framework for the CA and the specific analysis procedure we applied during the CA. Section 4 is devoted to this study's findings, including a descriptive analysis of the literature set, followed by the quantitative results and interpretation in subsections according to the conceptual framework. Section 5 provides the main managerial and theoretical contributions by answering the research questions while setting future directions. Then, Section 6 outlines our concluding remarks for the article. Additional insights and results are provided in the Appendix.

2. Blockchain Technology in Operations and Supply Chain Management

2.1. Blockchain Technology—A Concise Introduction

Blockchain technology (BCT) essentially represents a distributed ledger of transaction records stored in a distributed way among network nodes. BCT was first mentioned by Nakamoto (2008) as the underlying technology for the Bitcoin cryptocurrency and has since evolved through several stages [42]. Many different platforms and protocols are now available that differ from the original Bitcoin blockchain in technical terms. The rise of Ethereum led to a Blockchain 2.0 stage, while the third stage is now focused on the interoperability of blockchains. All blockchain variants pursue the following design principles: The immutable transaction records are validated and redundantly stored on the nodes in the peer-to-peer network. The transactions consist of information, value, or other data types. Several transactions are aggregated in blocks, and the employed consensus mechanism then enables the network to agree on the block that should be next added to the chain of blocks—forming the blockchain [14,43]. The ledger and the transactions carried out are protected by cryptographic measures, including private keys to sign off transactions and hash functions to link the subsequent blocks [14]. Network configuration may vary and can be public or private and permissionless or permissioned blockchains, depending on the needs of the actors involved. The following features of blockchain have led to its reputation for potential disruption in the business environment: Transparency for all partners involved, built trust through eased information sharing, immutability and irreversibility of transactions, disintermediation, and smart contract automation potential [12,17,19,44,45]. Smart contracts are computerized transaction protocols that automatically execute pre-specified contracts if the contract criteria are met [14,46]. Thus, business logic may be implemented in these network entities, and external data can be connected through oracles [16].

As the peer-to-peer network conceptually does not rely on a trusted third-party intermediary, many new business applications emerge from blockchain features. Bischoff and Seuring (2021) indicated disintermediation, transparency, decentralization, and immutability as the dominating constructs of BCT [47], while Lim et al. (2021) highlighted shareability, security, and blockchains smart capabilities [26]. Furthermore, the employed consensus mechanisms and cryptographic measures can reduce opportunism [48] and ensure legal verifiability [17]. Therefore, collaboration among partners can be enhanced through trust in data and other network participants. Blockchain can also ease communication between different IoT protocols, leading to tokenization of assets or shared production and transportation capacities in the network [17]. While the initial cost of setting up a blockchain solution in a network is not negligible, the returns may only materialize in the longer term. The still-prevailing uncertainty about the return on investment impedes certain projects. However, several industry initiatives utilize BCT for use cases and proofs-of-concept in OM and SCM. For example, Maersk and IBM collaborated to transform global trade activities to a digital format and enable paperless trade in a project called TradeLens [21,49].

Projects in OM, e.g., focus on additive manufacturing [22,50,51] or IoT connection with blockchain tokens [23,52]. The reader is referred to the literature for comprehensive reviews on blockchain projects [18,44,53].

2.2. Blockchain Technology in OM and SCM—Implications and Existing Reviews

The two interconnected areas of OM and SCM today face several issues due to their complexity, uncertain market conditions, and customer expectations for fast product delivery—also referred to as "VUCA" for vulnerability, uncertainty, complexity, and ambiguity [54]. BCT can be useful in countering these threats and challenges as it potentially facilitates collaboration in the SC through the ease of information sharing, transparency of transactions, and security [55,56]. These features affect not only SC operations but also their design and organization [57,58]. Therefore, scholars are increasingly examining BCT applications and their implications for OM and SCM [30]. Academic literature has also recently called for an assessment of BCT within organizational strategies and principles to establish solid theoretical foundations for BCT literature [19].

BCT has several implications for well-known theories in OM and SCM. This includes principal-agent theory, where BCT changes trust and information asymmetry relations of the principal and the agent [44], or transaction cost theory, where BCT can reduce transaction costs, limit opportunistic behavior, and uncertainties of the environment [48]. Investigating these theories in detail and taking on novel lenses by grounding in established theoretical foundations is vital to investigating novel technologies such as BCT and its application potentials and implications.

With the increase in publications in the last five years, several literature reviews have been published on BCT in OM and SCM, each focusing on specific aspects. With a slight modification of our search string later used for the content analysis (see Section 3.2), we gathered all relevant reviews on the topic of BCT in the specific domain of OM and SCM (("blockchain*") AND ("review" OR "survey") AND ("supply chain*" OR "logistic*" OR "operation*" OR "produc*") in the title of documents in Scopus on 18 April 2022). Out of 74 results, 28 articles were included after assessing the full text. These review articles were subsequently analyzed in detail [10,12,18,26–35,59–73]. The studies are deemed relevant as the authors provide the used search strings and databases in the articles and therefore follow a systematic approach in the sense of Tranfield (2003) [74]. Table A1 in Appendix A summarizes the relevant information, including author names, publication year and journal, focus and findings, search strings, restrictions, databases used, date of publication, search dates, and the number of articles. Other more narrative reviews include [19,20,61,75–87]. The reader is also referred to the summary of existing reviews by Lim et al. (2021), which provides additional information on potentially interesting aspects [26].

The overview of existing reviews reveals that many reviews either refer to specific application areas of the technology (e.g., food supply chains [32,33,69,76] or automotive supply chains [31,68]) or focus on the potentials or risks of applying the technology [18,28–30]. Other bibliometric reviews on BCT had a broader focus, without a specific view on OM and SCM and only marginally tapped into these research areas [34,35]. Moreover, they mostly focused on keyword co-occurrence, network analyses of the literature, and geographic distribution of articles. A comprehensive, systematic review and content analysis of the literature on BCT in OM and SCM that provides insights on research trends and key topics in scholarly exploration is missing.

We address this research gap through our comprehensive literature sample of 410 analyzed articles as well as the category-guided and statistical analysis, as explained below. Thus, our study differs from the existing reviews by scope and methodology as we investigate both SCM and OM with a thorough approach aiming at the content of the articles rather than solely bibliometric factors such as authorship or keyword co-occurrence. In this way, we pursue capturing the entire domain of BCT in these research areas. In the context of emerging technologies that are constantly changing and being studied from different perspectives, a regular review of the literature is necessary to reflect and, if necessary, refocus research efforts [88]. By employing content analysis with the help of software-guided auto-analysis steps, we are able to investigate a comprehensive sample of research articles to highlight research trends, used methodologies, and remaining areas to address in future studies. We also analyze co-occurrences of recording units in the literature to identify patterns of association and connections between category pairs. The methodology is described in detail to allow reproducibility and ensure the reliability of the findings. In this way, we enable scholars to target their future efforts while uncovering research gaps that go beyond those included in existing classification schemes in other reviews.

3. Research Design

This section is devoted to the methodology applied in this study. First, the CA methodology is elaborated. Second, the generation of the literature sample for the CA is explained in detail. Third, the conceptual framework for the CA is presented, which enables us to answer RQ1. Fourth, we present the content analysis procedure.

3.1. Content Analysis Methodology

CA has been defined in various ways in the literature [38,89], with a well-known definition by Krippendorff (2004) classifying CA as "a research technique for making replicable and valid interferences from texts (or other meaningful matter) to the contexts of their use" [90]. The term "content analysis" is also commonly used in social science to analyze expert interviews, e.g., [91,92]. This CA variant also relies on textual data (e.g., transcripts of interviews) and can therefore be set in a similar context. CA enables a systematic, objective, quantitative, and qualitative analysis of published information of any kind [90]. It can be used as an instrument to determine the key ideas and themes in publications on a topic [39]. Prior studies in OM and SCM have shown the applicability and usefulness of the method [37,40,93–95]. The CA in this paper can be classified as descriptive in the framework of Neuendorf (2002), as we aim to uncover key research themes in this research field and structure the research on blockchain technology in OM and SCM [89].

This study's specific methodology is based on [38] and is shown in Figure 1. First, the research questions were formulated, followed by a systematic generation of the literature sample (Section 3.2). Then, we created the CA's conceptual framework (Section 3.3) to address RQ1 and evaluated the literature sample using coding and auto-analyses features (Sections 3.4 and 4). The formulated research questions RQ2 and RQ3 are then answered in Sections 4 and 5.

This section is devoted to the methodology applied in this study. First, the CA methodology is elaborated. Second, the generation of the literature sample for the CA is explained in detail. Third, the conceptual framework for the CA is presented, which enables us to answer RQ1. Fourth, we present the content analysis procedure.

3.2. Generation of the Literature Sample

We applied a systematic literature search and sampling methodology to generate the CA's literature set to make the process transparent and reproducible for other scholars [74]. The research team consisted of multiple researchers (two senior and one junior researcher) to reduce research bias. The systematic procedure also promotes the rigor of the CA application [38].

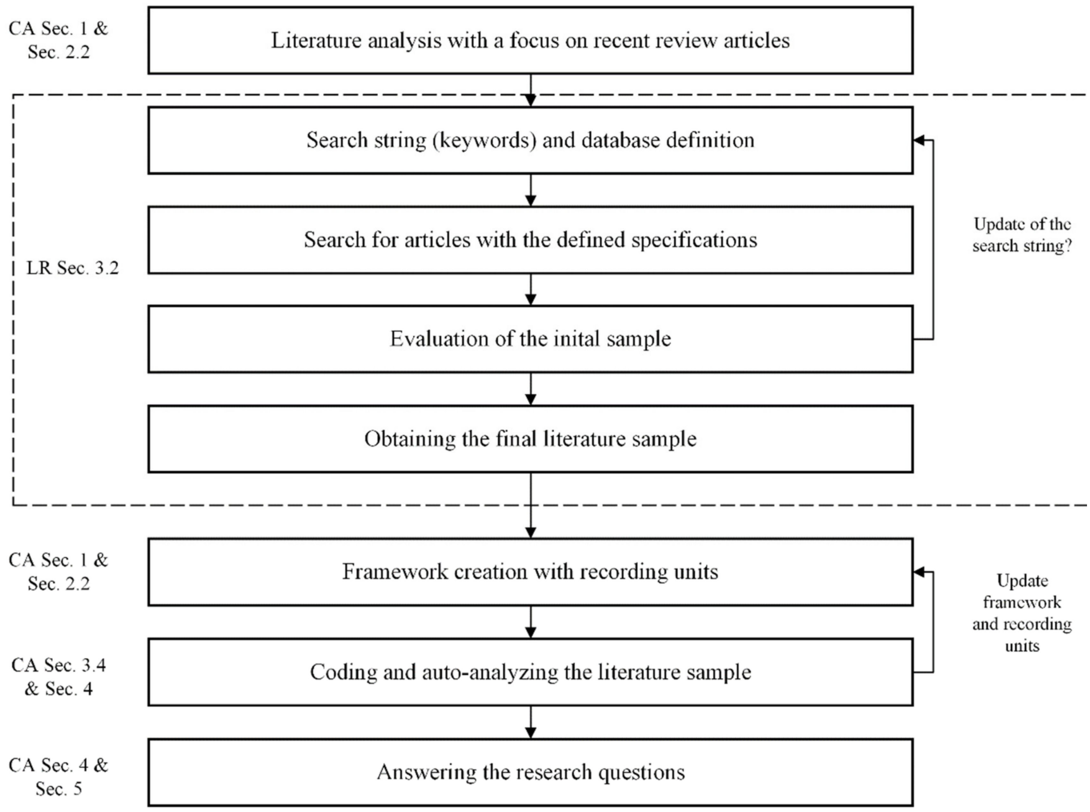


Figure 1. Research methodology of this study.

First, we chose *Scopus* as the primary database for our search due to its comprehensive coverage of academic journals in OM and SCM, information research, and related disciplines [96]. All 67 journals rated A+ to C in the renowned *VHB Jourqual 3* ranking [97] of logistics, operations research, and operations management are included in Scopus. Additionally, renowned conferences from computer sciences (e.g., Lecture Notes in Computer Sciences) and various IEEE conference proceedings are indexed in the Scopus database. We double-checked the search results with the *Web of Science* database to avoid any bias stemming from a search in just one database and found no additional articles. To ensure comprehensive coverage of the literature, we opted for the search string ("blockchain*") AND ("supply chain*" OR "logistic*" OR "operation*" OR "produc*"). After validating the search string in the author team following Denyer and Tranfield (2009) [98], using it in the title, abstracts, and keywords of entries in the Scopus database returned 6126 hits on 20 September 2021. This initial literature sample was checked for relevance by the author team. We noticed that the search in the abstracts and keywords produced many results that did not correspond to the study's subject. For example, BCT has been examined as one of several digital technologies in the context of Industry 4.0 for a specific research topic. However, we are interested in more specific contributions focusing on BCT. Therefore, the following selection criteria were developed and applied: (1) the articles had to contain the keywords in the article's title; (2) only academic journal and conference articles in English were included.

With this approach, we again searched the Scopus database, which led to 905 hits. Two of the authors then applied the inclusion and exclusion criteria to the articles, which contained that only peer-reviewed articles that address BCT in relation to OM or SCM were included in the sample [98]. A total of 53 articles were excluded that were incorrectly displayed in the database and not retrievable, and another 43 articles as they had not undergone an adequate peer-review process. For applying the exclusion and inclusion criteria for the remaining articles, we calculated the intercoder reliability for the first

50 assessed articles to ensure the reliability and reproducibility of the literature sampling. The full text of the articles was read by two researchers in a blind review process to enhance validity. Each researcher marked the articles for inclusion or exclusion, after which the list of articles was shared among the author team. In case of a disagreement on including an article, the third researcher decided on the matter. For the subsample of 50 articles, this was necessary in two cases resulting in a Cohen's κ of 0.917, Krippendorff's α of 0.918, and a percent agreement of 96 percent. These rates indicate the high reliability of the sampling process [90,99].

In the following selection process, 52 literature reviews were excluded from the list to prevent any double coding of recording units (refer to Section 2.2 for all systematic reviews found and analyzed). In addition, we excluded another 347 articles that investigated topics not relevant to this study (e.g., focusing on digitalization technologies per se, with BCT being just a subset of technologies investigated or articles without a specific focus on OM or SCM). This approach led to a final sample of 410 articles, of which a comprehensive reference list is provided in Appendix B. Figure 2 indicates the literature selection process in a PRISMA flow chart. In the following subsection, we present the conceptual framework developed to analyze the content of the literature sample.

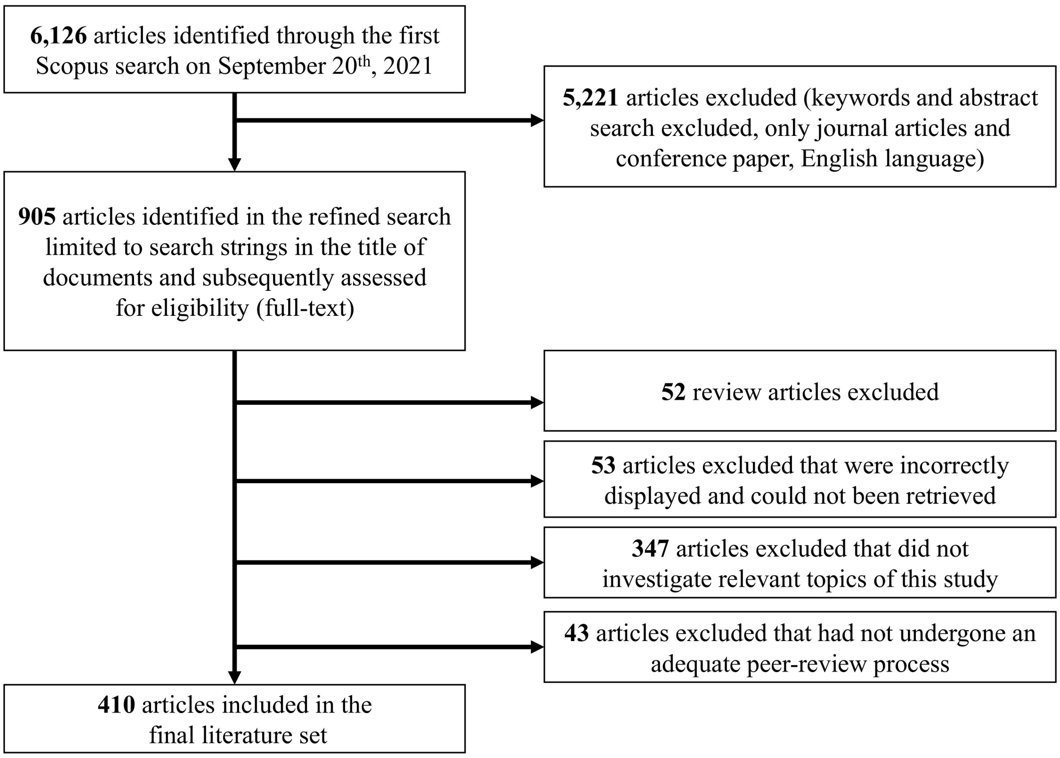


Figure 2. PRISMA flow chart of the literature selection process.

3.3. Conceptual Framework

The final literature sample was analyzed to answer the research questions. An abductive approach is followed in this study, which can be referred to as theory modification [100] or contextualized explanation [101]. We argue that "intermediate theory" is available on the use and prospects of BCT in OM and SCM, which can be enhanced (Durach et al. 2021, p. 9) [101]. We thus combine a bottom-up and top-down approach and develop a conceptual framework to address RQ1, consisting of existing categories and constructs deducted from the literature, as well as elements that we inductively added from the examined material. The framework for our content analysis includes main categories and subcategories that are combined with matching terms and abbreviations (referred to as "recording units" in the following). The recording units of such a conceptual framework can then be used to code the material in the content analysis process [90,100] (see Section 3.4).

All authors participated in creating the conceptual framework to ensure reliability and validity [38]. A first draft of the framework was created separately by each of the authors based on the literature reviews in Table A1 and the prominent articles in the literature sample with the highest citation counts as counted and displayed in the *Scopus* database (including [18,20,102–106]). The framework categories and subcategories were created iteratively, with discussions and amendments after each iteration. The framework was later updated inductively using the first analysis runs with the MAXQDA Plus 2020 software. Specifically, we examined all single words with frequent hits in the word count of our sample (>500 hits) to identify any missing but critical recording units to be added to the initial conceptual framework. Several subcategories were added after discussion with the author team, and some initial subcategories were amended, leading to the final framework with thirteen categories (see Table 1). The conceptual framework and its components are explained below.

Table 1. Conceptual framework for the CA with main categories and subcategories.

Category	Subcategories
Research focus	Operations management, supply chain management, information systems
Industry focus	Agriculture, forestry, fishing, mining, food, beverage, tobacco, textiles, wood, chemicals, pharmaceutical, metal, electronics, electricity, water supply, construction, wholesale, transportation, financial, real estate, legal, humanitarian, public administration, education, human health services, arts, automotive, aeronautics, defense, engineering, maritime, petroleum, postal, tourism
Methods	Conceptual research, survey research, qualitative research, case study and action research, archival research, simulation, optimization
Theories used in the articles	Transaction cost theory, resource-based view, market-based view, principal-agent theory, institutional theory, network theory, information theory, innovation diffusion theory, dynamic capability theory, technology adoption model (TAM), technology-organization-environment (TOE) framework
Business areas addressed	Strategic management; procurement, logistics, and distribution; SC risk management, finance, and accounting; marketing and sales
Technology interfaces	Internet of things, artificial intelligence, big data analytics, cloud computing/manufacturing, additive manufacturing, cyber-physical systems, robotic process automation, Industry 4.0, radio frequency identification (RFID), robots, cybersecurity
Potentials of the technology	Trust, security, transparency, traceability, disintermediation, cost savings, collaboration, information sharing, decentralization, tokenization, autonomy, smart contracts
Barriers of the technology	Awareness, network setup, know-how, data disclosure, missing management support, lack of trust, unclear governance, missing standards, legal uncertainties, regulatory uncertainties
Adoption status	Proof of concept, use case, productive application
Consensus mechanisms used	Proof-of-Work, Proof-of-Stake, Proof-of-Authority, Byzantine Fault Tolerance, Proof-of-Elapsed-Time
Platforms used	Ethereum, Bitcoin, Hyperledger, Multichain, R3 Corda, Cardano, EOS, Iota, OpenChain, Tron, Tezos, Stellar, BigChainDB, Lisk, Quorum
Network configuration	Public blockchain, private blockchain, permissioned, permissionless, consortium
Other	Green, sustainability, environment, cryptocurrencies

The first category contains a classification of the *research focus*. In the framework, we focus on the subcategories of OM, SCM, and information systems. The articles are classified based on the research area they address. This serves to analyze in which areas the technology has been addressed so far and to what extent. Next, *Industry focus* refers to the industry that the use case or conceptual focus in the articles stems from. Existing reviews have indicated that blockchain solutions are being developed across various industries [10,30]. Here, we will analyze which industries are mainly in the focus of research and for what reasons. Various industries were included here, following the NACE classification of the European Commission [107]. *Methods* relates to the research methodology applied in the literature [26,27]. Both qualitative and quantitative methods are considered here, and the distribution is analyzed to obtain insight into the research efforts to date. Next, the category *Theories used in the articles* relates to the different theoretic lenses applied to study BCT. Articles are classified according to their theories, including grand theories of SCM and OM such as principal-agent theory or transaction cost theory [62,108,109]. Then, the different *Business areas addressed* for which the blockchain application was designed for are examined. For example, articles focusing on a specific SC risk management application using BCT can be classified through the "SC risk management" subcategory and so on. *Technology interfaces* relates to other information and communication technologies that BCT was studied in combination with in the articles. The categories were created based on the literature conception of Industry 4.0 technologies [110,111]. The interaction with other technologies can either facilitate or hinder BCT application and should therefore be analyzed. The following categories include *Potentials of the technology* and *Barriers of the technology* that have been identified concerning BCT [17,18,29,30]. We apply these observations to a broader set of data and examine the relative importance of the subcategories in detail. The category *Adoption status* aims at the maturity level of the applications, i.e., whether they represent a proof of concept or are already being used productively [53,112]. This enables a statement about the current development state of BCT, e.g., from joint research projects with industry or case studies. The various *Consensus mechanisms* form the next category [16], to capture the state-of-the-art consensus mechanisms used in technical applications of BCT. Next, *Platforms used* refers to the platforms such as Ethereum or Hyperledger that can be used to develop or deploy BCT in use cases [113]. The intention here is to analyze whether a trend in favor of one or more platforms is foreseeable, which may develop into industry standards. A strict interpretation of the term blockchain would lead to the exclusion of some of the platforms in our list that rather belong to the general distributed ledger family (such as IOTA). We have nevertheless added them to the category for comparison purposes. *Network configurations* addresses the access and writing permissions used in the configurations of the developed blockchain solutions [114,115]. Here, we differentiate the accessibility of the network into permissioned and permissionless (writing rights) and public and private systems (reading rights) [17]. Consortia are a particular form and have therefore been listed separately. Then, *Other* summarizes additional topics of interest that could not be explicitly assigned to any of the other categories but are increasingly examined in the literature on BCT, e.g., sustainability-related aspects [11,20] or the use of cryptocurrencies [116,117].

We argue that the framework is "mutually exclusive and collectively exhaustive" [118] as it is comprehensive but without overlaps in the subsets. Our framework includes categories on how and why research for the articles in our literature sample was conducted (i.e., the research focus, the scientific methods and theories, the addressed business area) and technological categories that address the adoption of the technology, as well as prerequisites and implications of its use that were investigated by recent studies (i.e., the interfaces to other technologies, the potentials and barriers of the technology, and the state of implementation). Lastly, technical categories (i.e., consensus mechanisms, platforms, or network configurations) provide information about the scholarly approach used in existing projects with best practices from applied research that could be valuable for future research endeavors.

3.4. Content Analysis Procedure

Based on the conceptual framework provided in Table 1 and the subcategories, different terms can be assigned to the subcategories to reflect the dimensions and are referred to as “recording units”. All the recording units assigned to the subcategories can be accessed in Appendix C. The analysis procedure of searching through the sample to identify textual elements to code in the framework categories can be supported by computer-aided qualitative data analysis software that facilitates the handling of large data amounts [119]. We chose *MAXQDA Analytics Pro 2020* for this study. The PDF files for all 410 articles were first added to a *MAXQDA* project before manually converting them into text documents to conduct the analysis. In the conversion process, we checked for conformity and deleted/added any text not recognized by the system (mainly from images or tables). The reference sections were removed to avoid discrepancies and focus on the content of the individual articles [40]. The software module *MAXDictio* was then used for auto-analysis of the literature sample. We constructed a dictionary of the recording units identified and used this dictionary to count the number of hits of all recording units in the sample, the number of articles a recording unit was found in, and the hits per article ratio. Thus, our data-driven approach assumes that the frequency of recording units is a valid indicator of its importance in the literature sample [39,40]. Based on the results and after several correctness check iterations, the articles were then auto-coded with the hits identified. This means that if, e.g., “transaction cost theory” was found in an article, the reference was then assigned to the “transaction cost theory” code. The software-based automated coding process helps reduce investigator bias [90]. Recently, this approach was applied successfully in OM, e.g., by [37,40].

As the recording units for the categories *potentials of the technology* and *barriers of the technology* are context-sensitive, i.e., a hit for a recording unit such as ‘trust’ does not automatically mean that the recording unit is also mentioned regarding BCT potential, we performed an additional check of the context of the keyword to ensure that the unit was indeed counted in the specific context. Then, a sample check of the correct counting was carried out for all main categories and subcategories, leading to satisfactory accurate results.

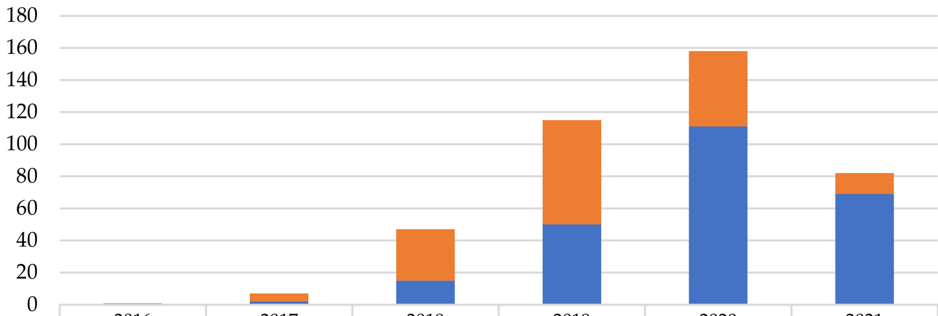
We also performed statistical analysis using the *MAXQDA Stats* module, which has similar features as other software tools such as *IBM SPSS*. The codes were transformed into document variables for further analysis. Analyzing co-occurrences of recording units enables identifying patterns of association and connections between category pairs [90]. Contingency analyses can be performed, for example, and have been applied successfully in research on SCM [120]. However, this type of analysis cannot be performed in a statistically sound way in our case due to a large number of categories and different sizes of recording units (one word to three words) [90]. Instead, we examine the correlation of recording units within the articles. The *MAXQDA Stats* module allows the calculation of bivariate correlations among codes and variables, including Pearson’s r and Spearman’s ρ. As a test for normal distribution showed that the data is not normally distributed, we calculated the rank correlation according to Spearman [121]. All variables were selected and the correlation coefficient ρ_{sp}, the *p*-value, and the number of valid cases were obtained for all combinations. We refer to the significantly correlated items in the following sections and point the reader to the detailed results file in the supplementary material. All 68,906 values of the matrix of 263 code variables can be accessed there, with significant correlations with a *p*-value below 5 percent marked in green.

The statistical analysis enabled us to obtain statistically sound statements about the interrelationships of categories and recording units. The analysis and interpretation of the recording units’ distribution facilitate the identification of thematic trends and research areas that are overrepresented or underrepresented. Additionally, it allows answering the research questions RQ2 and RQ3 in the next sections on the findings.

4. Findings of the Content Analysis

4.1. Descriptive Analysis of the Sample

Starting with descriptive statistics and analysis of the literature sample, Figure 3 indicates the number of sampled articles by publication year and type. Without restricting the search period, the first article was published in 2016.



	2016	2017	2018	2019	2020	2021
Conference Paper	1	5	32	65	47	13
Journal article	0	2	15	50	111	69

Figure 3. Number of articles in the literature set by publication year and type.

Interestingly, the publication type shows a pattern of moving from conference proceedings to journal publications (from 71 percent of all articles in 2017 to 29 percent in 2020), indicating the research topic's manifestation and highlighting its significance and incipient maturity. As sometimes scholars send papers to conferences and later to journals, we checked the literature set for such occurrences of articles with largely similar content but found none.

Figure 4 shows the journals with the highest number of published articles (only presenting the journals with at least four articles). Sixteen other outlets cover three articles each, while 153 articles are the only related articles in other publications. Interestingly, two rather complimentary research areas are already evident by analyzing Figure 3. There is a large group rather focused on business and engineering streams (e.g., *International Journal of Production Research*, *International Journal of Production Economics*, and *Supply Chain Management*), whereas a second group with almost the same number of publications in total is more focused on information systems research (e.g., *IEEE Access*, *Lecture Notes in Computer Science*, and *International Journal of Information Management*). Our analysis also shows that over 1000 different authors contributed to BCT research in OM and SCM. The authors with the most publications are Choi, T.-M. (13 articles), Li, Z. and Huang, G.Q. (both 7 articles), Fosso Wamba, S. (6 articles), and Queiroz, M.M. (5 articles). The most-contributing universities are Hong Kong Polytechnic University, The University of Hong Kong, Chinese Academy of Sciences, Worcester Polytechnic Institute and TBS Business School. Table 2 indicates the top ten most cited articles in the literature set.

Several special issues on BCT have been published in different journals, whose articles are included in the literature set of this article, including *International Journal of Production Research* (58:7), *Robotics and Computer Integrated Manufacturing* ("Blockchain technology in industry"), *International Journal of Production Economics* ("Exploring supply chain structural dynamics: new disruptive technologies and disruption risks") and *Computers and Industrial Engineering* ("Blockchain and Tokenization for Industry and Services").

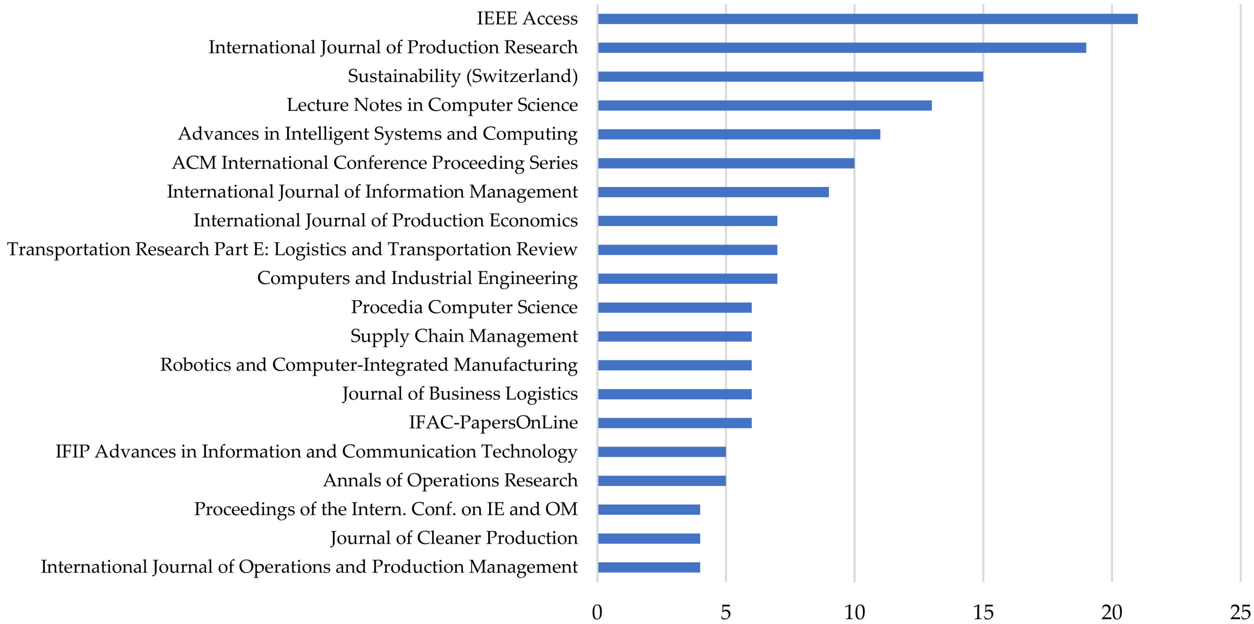


Figure 4. Number of articles per journal/conference.

Table 2. Top cited articles in the literature set (according to Scopus).

Article/Citation	Citation Count
Saberi et al. (2019) [20]: Blockchain technology and its relationships to sustainable supply chain management	781
Tian (2016) [102]: An agri-food supply chain traceability system for China based on RFID &blockchain technology	658
Kshetri (2018) [103]: Blockchain's roles in meeting key supply chain management objectives	625
Tian (2017) [104]: A supply chain traceability system for food safety based on HACCP, blockchain & Internet of things	371
Korpela et al. (2017) [122]: Digital supply chain transformation toward blockchain integration	344
Queiroz & Fosso Wamba (2019) [106]: Blockchain adoption challenges in supply chain: An empirical investigation of the main drivers in India and the USA	318
Kim & Laskowski (2018) [105]: Toward an ontology-driven blockchain design for supply-chain provenance	291
Caro et al. (2018) [123]: Blockchain-based traceability in Agri-Food supply chain management: A practical implementation	281
Toyoda et al. (2017) [124]: A Novel Blockchain-Based Product Ownership Management System (POMS) for Anti-Counterfeits in the Post Supply Chain	265
Kamble et al. (2019) [58]: Understanding the Blockchain technology adoption in supply chains-Indian context	241

4.2. Results of the Content Analysis

We now present the detailed results of the CA, starting with an overall results overview, followed by the results of the categories of the conceptual framework to answer RQ2 and RQ3. We identify and postulate several research propositions to facilitate elevating future research efforts to a more focused level.

Figure 5 indicates the percentage distribution of the recording unit hits for the thirteen categories, which can be interpreted as an indicator of the prevalence of the different categories. The percentages illustrate the frequency of the recording units' hits, e.g., 31.4 percent for *potentials of the technology* means that of the 107,375 total hits of the dictionary-based analysis of the documents, 33,693 (and thus 31.4 percent) are in the *potentials of the technology* category.

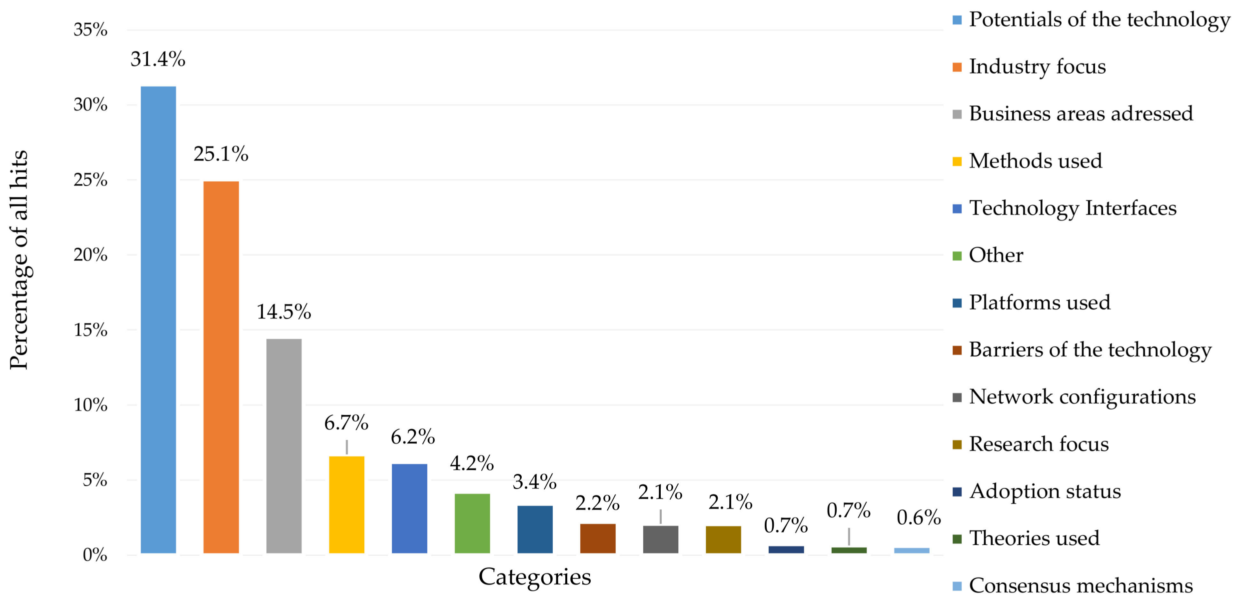


Figure 5. Percentage distribution of the recording unit hits for the thirteen categories.

Hits related to *Potentials of the technology* were identified in 2.65 times more articles than the *barriers of the technology* category. This result indicates a trend that scholars continue to be particularly concerned with the potentials of the technology. The value proposition of BCT within OM and SCM is still being framed and application opportunities are being explored. Research on specific barriers and possible solutions to improve the adoption of the technology is yet scarce. This finding is also reflected in the *adoption status* category receiving few hits (0.7 percent). Another finding is that few articles are theory-driven (0.7 percent). There is certainly research potential here.

Next, we analyze the top 10 recording unit hits overall and the top 10 recording unit hits by the number of articles to assess the relative importance of recording units in the literature set. Table 3 indicates the recording units with the highest number of hits, where the category *potentials of the technology* dominates, similar to the overall percentage distribution in Figure 5. The high number of hits for the 'food' sector highlights the value of BCT for this fragmented retail sector, which benefits from both traceability and provenance features of the technology. 'Traceability' use cases enabled by BCT are the main potential perceived by research across the board, followed by 'smart contracts' and their abilities to automate and transparently execute business processes. Other potentials frequently mentioned include 'trust', 'transparency', 'security', and 'cost saving, increased efficiency'. The high number of hits for the 'logistics' sector illustrates the importance that researchers and practitioners allocate to this business area, which is succeeded by 'production'. The most significant potential in the interaction of technologies is seen with the 'Internet of Things'.

Table 3. Top 10 recording unit by hits.

#	Recording Unit(s)	Hits	No. of Articles	Hits per Article	Category
1	trace*	5935	364	16.30	Potentials/Traceability
2	food*	5338	265	20.14	Industry focus/Food
3	smart contract*	4998	340	14.70	Potentials/Smart contracts
4	trust*	4945	375	13.19	Potentials/Trust
5	logistics	4558	287	15.88	Business areas addressed/Procurement, logistics and distribution
6	transparen*	3800	370	10.27	Potentials/Transparency
7	security	3118	356	8.76	Potentials/Security
8	production*	2856	311	9.18	Business areas addressed/Operations
9	efficien*	2523	361	6.99	Potentials/Cost savings, increased efficiency
10	IoT	2383	248	9.61	Technology interfaces/Internet of Things

For some units of analysis, every word ending leads to the expected result. Therefore, we have included all of these word endings by using the word stem combined with an asterisk.

Turning to the top 10 recording units by the number of articles (see Table 4), conclusions can be drawn on the relative importance of recording units. Interestingly, 'trust', 'transparency', 'traceability', 'efficiency', 'security', 'smart contracts', and 'production' were mentioned in many articles and also frequently overall, emphasizing the devotion of scholars to these topics. These recording units and the related topics have thus been significant for research. In addition, 'framework' indicates the current state of research methods, which so far are mainly conceptual. With 'decentralized' and 'tracking', two further potentials are part of Table 4, demonstrating the main research focuses on exploring the potential benefits of the technology.

Table 4. Top 10 recording units by no. of articles.

#	Recording Unit(s)	Hits	No. of Articles	Hits per Article	Category
1	trust*	4945	375	13.19	Potentials/Trust
2	transparen*	3800	370	10.27	Potentials/Transparency
3	trace*	5935	364	16.30	Potentials/Traceability
4	efficien*	2523	361	6.99	Potentials/Cost savings, increased efficiency
5	security	3118	356	8.76	Potentials/Security
6	smart contract*	4998	340	14.7	Potentials/Smart contracts
7	production*	2856	311	9.18	Business areas addressed/Operations
8	framework	2215	308	7.19	Methods/Conceptual research
9	decentralized	1572	304	5.17	Potentials/Decentralization
10	tracking	1436	290	4.95	Potentials/Traceability

For some units of analysis, every word ending leads to the expected result. Therefore, we have included all of these word endings by using the word stem combined with an asterisk.

The detailed results for all recording units, as well as the significant correlations, can be accessed in Appendix C and the supplementary material (see the correlation matrix). We now move to the detailed findings for the categories of our conceptual framework.

4.2.1. Research Focus

The first category consists of three subcategories, of which 'supply chain management' received the highest hit count (1500 hits in 283 articles), followed by 'information systems' (449 hits in 146 articles) and 'operations management' (278 hits in 54 articles). Figure 6 indicates the different hits for these subcategories. The result highlights the current research focus on SCM, which is a prime candidate for BCT use due to its overall complexity, media disruptions, and lack of visibility across different stakeholders [125–127]. SCM shows significant correlations (ρ_{sp} between 0.209 and 0.333) with the subcategories 'sustainability' and 'environment', 'procurement', 'inventory management', 'efficiency', 'transparency', and 'collaboration'. BCT can pose as a key technology to ease sustainability movements in SCs and value networks [11,20,128] and lead to enhanced efficiency in transactions [129,130] as well as network effects that facilitate collaboration [17,131,132]. SCM is also mentioned at least once in more than 69 percent of the articles compared to the other two subcategories.

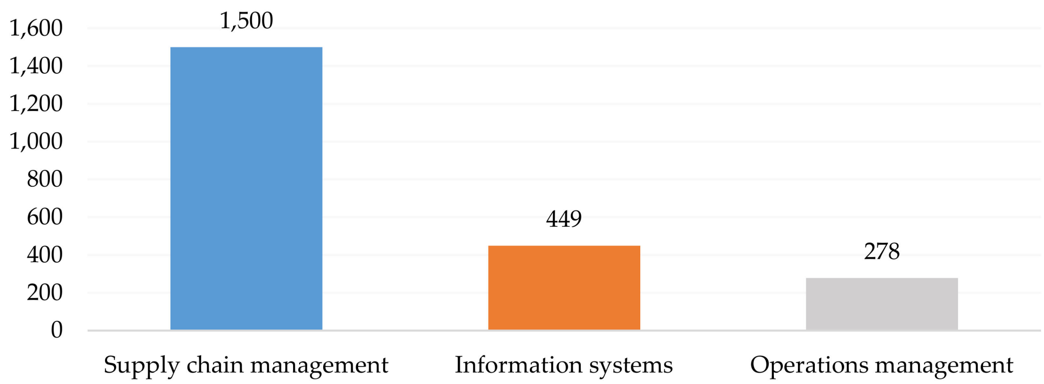


Figure 6. Subcategories of 'research focus' and their hit frequency.

'Information systems' was mentioned individually and in conjunction with SC as 'supply chain information systems' (18 hits). Connecting BCT to other enterprise information systems is a key focus here, with BCT perceived to replace traditional, inefficient information systems [126,133–135]. Significantly correlated hits (ρ_{sp} between 0.184 and 0.226) occur with the recording units 'conceptual' and 'empirical' [136,137], the 'technology adoption model' [58,138], as well as 'collaboration' and 'information sharing' [133,139,140].

The production function of OM has been least researched so far, as indicated by a few hits for 'manufacturing system' and 'operations strategy'. However, scholars perceive the potential of BCT for OM in real-time sharing of information, increasing the efficiency of transactions, interacting with IoT, and optimizing the capacity utilization of equipment [141,142]. Barriers still exist due to the necessary assurance of the reliability of input data, the potentially complex connection with IoT devices and the scalability for a data-intensive production environment in the course of Industry 4.0 [17,143]. Significant correlations of the recording unit (ρ_{sp} between 0.226 and 02.48) were identified with the recording units 'empirical' [17,144,145], 'optimization' [146,147], and 'information sharing' [148,149].

Thus, we postulate the first proposition:

Proposition 1. *In SCM, BCT can especially lead to increases in efficiency, transparency, and intensified collaboration, whereas for information systems and operations management, the simplified sharing of information can be particularly beneficial.*

4.2.2. Industry Focus

Turning to the industries in the research focus, Figure 7 shows the fifteen industries most studied in relation to BCT.

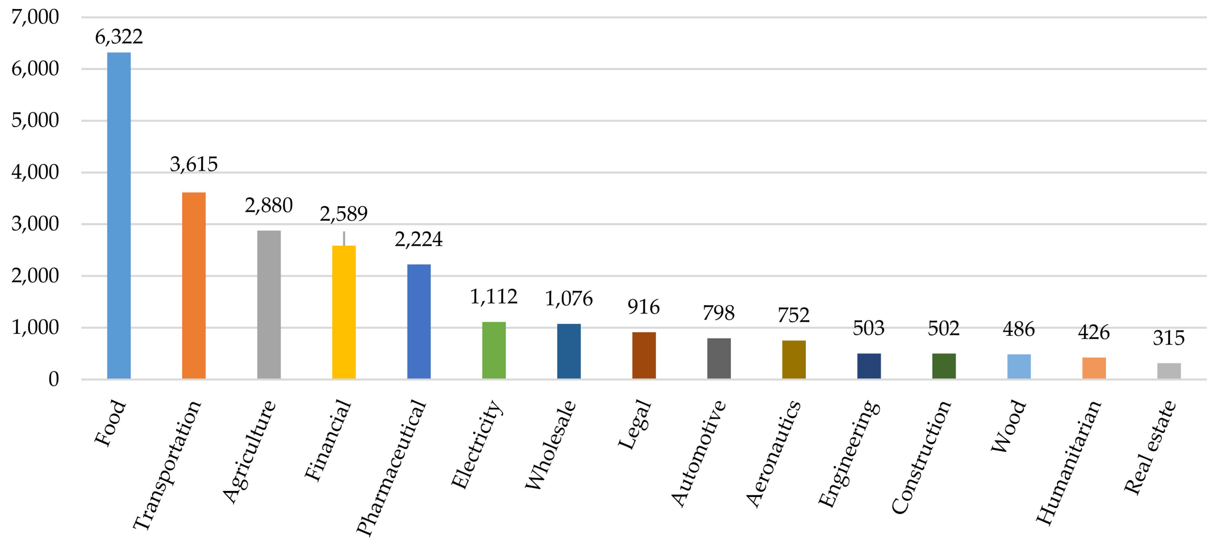


Figure 7. Top fifteen industries studied in relation to BCT in our sample.

The 'food' sector dominates this category with 6322 hits in 265 articles. Consumers are becoming more sensitive and demanding about food provenance, and at the same time, the perishable nature of the goods makes efficient cold chain traceability essential [150,151]. Blockchain can leverage its potential here and in related industries such as 'agriculture' [152,153] or the 'pharmaceutical' sector, where counterfeit products are a real concern for the global supply of pharmaceutics [154,155]. 'Traceability' is significantly correlated with all recording units of this category (ρ_{sp} between 0.224 and 0.563), underlining this substantial potential of BCT for perishable goods supply chains. A connection with IoT devices makes tracking and tracing applications an important use case for blockchain to track and immutably store transportation temperature, surroundings, and humidity of medicines [156–158]. The recent SARS-CoV-2 (COVID-19) pandemic has also highlighted this potential, where BCT is utilized for secure and trustworthy vaccine supply chains [159]. 'Regulatory uncertainty' is also significantly correlated with 'food' and 'pharmaceutical' (ρ_{sp} between 0.202 and 0.218) and is considered from two angles. Increasing regulation drives firms to use the technology [160]. However, in areas where comprehensive regulation is not yet in place, technology-savvy firms are moving forward and employing BCT to push regulatory authorities towards stricter regulations and facilitate increased BCT adoption [161,162]. Other significantly correlated recording units include 'Ethereum' and 'Hyperledger' (ρ_{sp} between 0.08 and 0.216), the two most used platforms for BCT use cases in these industries [103,163,164]. Additionally, 'permissioned' and 'Proof-of-Authority' are significantly correlated with 'pharma' (ρ_{sp} between 0.205 and 0.23), which indicates that BCT is rather employed on a permissioned level there, with selected participants and authorities to secure trustworthy information on the chain [154,165,166]. Unlike in the food or agricultural sector, visibility and traceability within the pharmaceutical supply chain appear to be more critical than provenance for (and involving) the end customer.

'Transportation' is the second most frequently mentioned industry, again related to visibility and tracking and tracing solutions [130,167,168]. Significantly correlated items (ρ_{sp} between 0.173 and 0.226) include 'information sharing', 'IoT', 'traceability' and 'cost' as well as 'efficiency' [109,169,170]. For the still rather paper-based industry, handling cargo on a digital level with blockchain-assisted tracking of distribution steps facilitates information sharing along the SC and can enhance efficiency by lowering handling and administrative costs.

'Financial applications' are also emphasized (255 articles). Significantly correlated items (ρ_{sp} between 0.153 and 0.27) are 'intermediaries', 'trust', 'cost', and 'regulatory uncertainties', highlighting the potential of BCT to disintermediate financial transactions in SCs, increasing trust among (unknown) actors [135,171,172]. Costs can be reduced, especially in globally interconnected supply chains, but the widespread adoption of cryptocurrencies is hindered by regulatory uncertainties that need to be addressed in the future [44,148,173].

'Humanitarian logistics' is an interesting sector for BCT with a high hit count per article (19.36). Blockchain is being tested in various use cases as it can efficiently and comprehensively map current data for the multitude of actors involved that do not need to share any other proprietary information system [140,174,175]. 'Trust' is again one of the significantly correlated recording units (ρ_{sp} = 0.178), as trust is low among unknown partners that often have to facilitate partnerships swiftly, which can be eased with BCT [176,177].

Other industries have been studied to a limited extent yet and leave room for further research efforts as BCT has special characteristics that need to be considered in detail for each particular industry. This leads to our second proposition:

Proposition 2. *Different characteristics of BCT are potentially valuable for different industries. A detailed investigation of potentials, risks, and suitable use cases is necessary for an individual assessment*.

4.2.3. Research Methods

The next category is related to the research methods applied in the literature set, with Figure 8 showing the percentage distribution of the recording unit hits. Conceptual and qualitative methods are applied most, with 38 percent and 31 percent of the hits in this category, respectively.

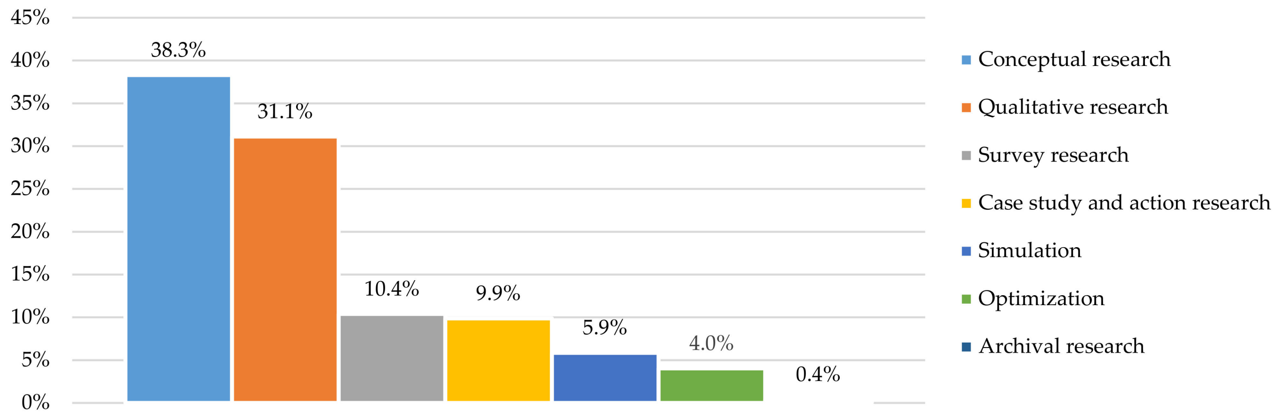


Figure 8. Subcategories of 'methods' and their shares in the hit count of the category.

The high number of hits for 'framework' as part of conceptual research (2215 of 2765 hits; 308 articles) illustrates the early stage of research on BCT. In many articles, frameworks are developed and called for to guide decision-makers and scholars to further develop and innovate blockchain-based systems [174]. 'Sustainability', 'unclear governance', 'trust', 'collaboration', and 'transparency' are significantly correlated with the conceptual research recording units (ρ_{sp} between 0.298 and 0.352). Several scholars applied conceptual research methods for sustainability use cases in OM and SCM [178,179]. Unclear governance is highlighted as one of the main barriers to widespread adoption of BCT and used as motivation for creating conceptual frameworks for different industries [180–182].

In the qualitative methods category, mainly 'interviews' (989 hits in 78 articles) are conducted to explore the fit of the technology or, e.g., to assess barriers and adoption requirements [17,150]. Significant correlations (ρ_{sp} between 0.29 and 0.381) of the qualitative methods with other categories include potentials of the technology ('transparency', 'cost', 'trust', 'information sharing') [51,183,184], theories ('network theory', 'technology adoption model', and the 'resource-based view of the firm') [150,185,186] as well as barriers of the technology ('unclear governance', 'skill', 'awareness', 'missing standards') [17,187]. 'Case studies' (688 hits in 150 articles) are further applied to generate insights into successful blockchain projects or use cases (e.g., [103]), with a focus on sustainability applications [188] and the food industry [162,189] as significantly correlated items (ρ_{sp} between 0.211 and 0.242). Here again, 'transparency' and 'traceability' are important (ρ_{sp} between 0.211 and 0.214).

More quantitative approaches are yet scarce. Some 'surveys' (558 hits in 135 articles) emerged recently that focus on exploring blockchain implementation [58,190] or the impact on SC performance [191] on a larger scale. The technology adoption model is a significantly correlated recording unit for the survey category (ρ_{sp} = 0.295). So far, few studies have used 'simulation' (423 hits in 102 articles) or 'optimization' (272 hits in 104 articles). Archival research is still limited due to the novelty of the technology.

Thus, the third proposition is introduced:

Proposition 3. *Currently, literature on BCT is strongly based on conceptual and qualitative research so that more quantitative approaches can add value to exploring the benefits and risks of adopting BCT and shed light on the key performance indicators addressed.*

4.2.4. Theories Used in the Articles

BCT can be analyzed using different theoretical lenses, which we evaluate in this category. The popular theories used in SCM and OM are all part of the conceptual framework (including transaction cost theory, the resource-based view of the firm, market-based view, principal-agent theory, institutional theory, network theory, information theory, innovation diffusion theory, and dynamic capability theory) as well as the technology adoption model (TAM) and the technology-organization-environment (TOE) framework, which are often used for technology adoption analysis. Figure 9 indicates the number of articles referring to the different theories in the literature set.

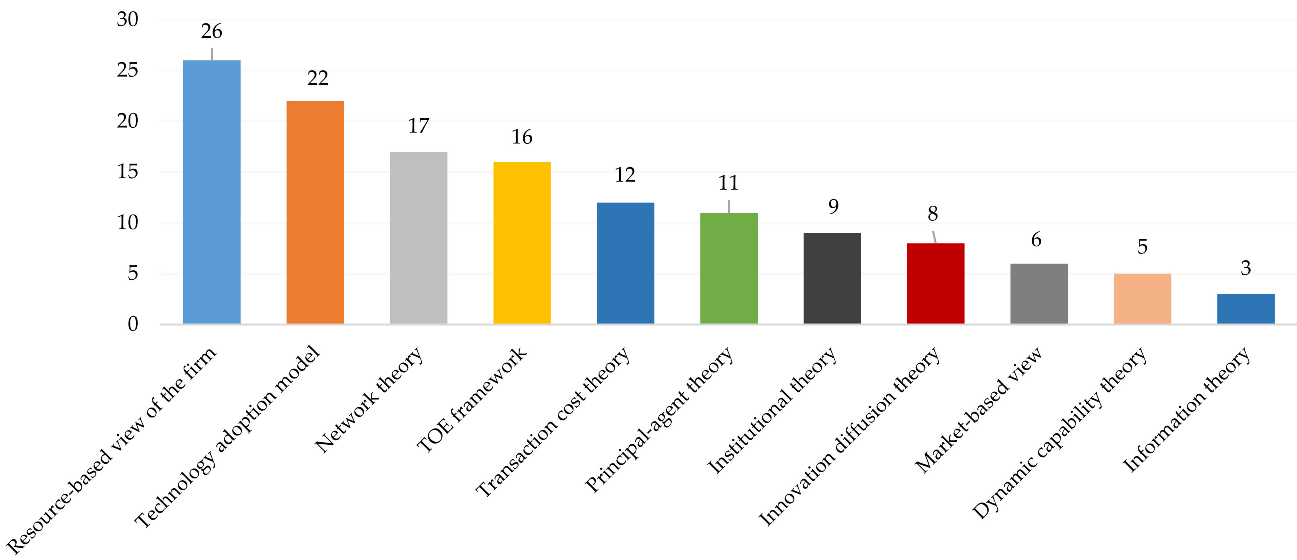


Figure 9. Number of articles referring to different theories in the literature set.

The 'resource-based view of the firm' (RBV) is the most used theory (26 articles) of the grand theories, followed by 'transaction cost theory' (TCT) in 12 articles. A key question in the RBV context is the nature of blockchain-related resources that generate competitive advantages [109]. RBV is significantly correlated with several recording units (ρ_{sp} between 0.196 and 0.288), including 'efficiency', 'collaboration', 'information sharing', and 'expertise' [192–195]. BCT is expected to lead to a shift in competitive advantages, rendering some such as asymmetric information obsolete. On the other hand, BCT can become a competitive advantage itself if companies use the technology to tap into new networks and derive benefits from transparency and traceability, for example [109].

The articles on TCT focus on the potential optimization of transaction costs and accompanying changes in the relationships and governance structures of networks [48,109]. TCT is significantly correlated with 'disintermediation', 'transparency', and 'cost' [44,48,196,197].

These significant correlations (ρ_{sp} between 0.127 and 0.188) relate to the ability of BCT to establish peer-to-peer connections and a shared ledger while altering "the forces involved in market transactions" and "dramatically lowering transaction costs by extensively reducing the need for intermediaries" (Cole et al. 2019, p. 479) [44].

Consistent with the technology's novelty, the 'technology adoption model' (TAM) has been used and addressed in many articles (168 hits in 22 articles). It addresses the adoption factors from the perspective of an organization or a network and mainly uses three antecedents for adoption: perceived benefits, organizational readiness, and external pressure [198,199]. In our sample, significantly correlated benefits (ρ_{sp} between 0.146 and 0.230) are the recording units 'disintermediation', 'efficiency', 'collaboration', and 'transparency' [48,129,200]. Organizational readiness is hindered by 'missing management support', 'know-how'/'expertise' in the organization, and limited 'awareness' [20,138]. The TOE framework is related to the TAM and examines technical, organizational, and environmental factors driving or hindering BCT adoption and application. TOE is referred to in 16 articles of our literature sample, including [128,177,180,201].

Overall, it is evident that less than one-fifth of the articles are based on theory and fewer are truly theory-driven, i.e., examining BCT adoption and application in light of grand theories of SCM and OM. Increased efforts could be made to investigate the grand theories' applicability to BCT to understand the technology in its essentials and contribute to facilitated technology adoption. There is certainly research potential here.

Thus, we develop our fourth proposition:

Proposition 4. *Resource-based view of the firm and transaction cost theory can be extended to further BCT study, while other grand theories are still largely unexplored and could provide important insights into the use and adoption of the technology.*

4.2.5. Business Areas Addressed

Moving to the next category, we assess the business areas for which BCT was considered and examined (see Figure 10). Consistent with this article's focus and potentially driven by the search terms, most articles focus on the areas of 'procurement, logistics, and distribution' (8758 hits in 287 articles), followed by 'operations' (2910 hits in 311 articles).

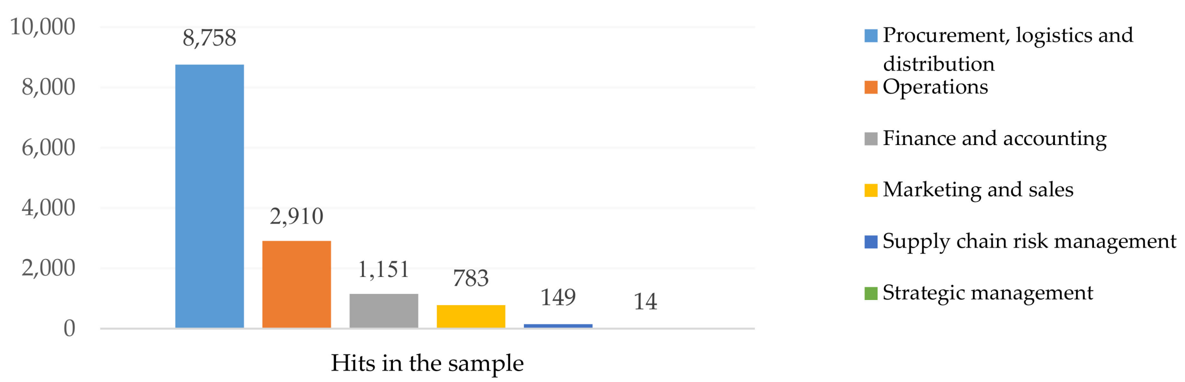


Figure 10. Hits per subcategory for the business areas addressed.

For procurement, logistics, and distribution, improved tracking and tracing of materials and products along the SC and in the distribution phase to the customer is recognized as a main benefit of BCT compared to traditional solutions, where asymmetric information and data corruption are common issues [184,202–204]. Here again, the integration with sensors is meaningful [205,206]. Demand forecasts and inventory management can be improved through transparency and symmetric (near) real-time information sharing in the network. This mainly resides in the immutability of the shared ledger and the trust-free ecosystem that the technology creates [207,208]. BCT facilitates collaboration with previously unknown and potentially untrusted business partners that can, e.g., provide trusted ledger data to prove their reliability [103]. In procurement, smart contracts are highlighted as they create certain contract flexibility and mitigate the bullwhip effect as the transparency is increased across multiple tiers [19]. Significantly correlated recording units for this subcategory include 'empirical', 'framework', 'conceptual', 'efficiency'/'cost', 'transparency', and 'traceability' (ρ_{sp} between 0.146 and 0.230). While the first three significantly correlated units indicate the research methods most applied in this area (including [48,209,210]), the latter three reveal the most recognized potentials for this business area [173,211].

'Financial' applications continue to play a central role (909 hits in 167 articles for 'finance' and 'supply chain finance'), with further hits on 'accounting' (242 hits in 90 articles). Following the basic idea of blockchain as the foundation of cryptocurrencies and secure financial flows, the technology can also contribute to secure and convenient financial systems in SCM and OM [212]. For SC finance, the valuable contribution of BCT is again its transparency that enables a distributed system to overcome asymmetric information and potentially eliminates intermediaries needed in centralized, traditional SC finance solutions [213]. Fittingly, 'bank' is one of the significantly correlated recording units (ρ_{sp} = 0.398). Another significant correlation includes SC risk management (ρ_{sp} = 0.162), where BCT for financial transactions can reduce risks in the network as it ensures immediate and transparent payment solutions that improve collaboration and trust in the network [214].

Next up is 'marketing & sales' (783 hits in 178 articles). The potential of BCT in this area is to provide secure and reliable provenance information to the customer and ensure that sustainability measures are undertaken in the correct way, which are major marketing moves for firms producing goods currently [157,161,215]. Additionally, the logging and sharing of sales data enables the focal firms to develop and adjust marketing principles and approaches swiftly [216,217]. Accordingly, significantly correlated recording units for this subcategory include 'awareness', 'sustainability', 'transparency', and 'green' [215,218,219], with ρ_{sp} between 0.206 and 0.233.

The area of SC risk management can be argued to be underrepresented (149 hits in 36 articles), although BCT potentially facilitates improvements in SC risk management, as proactive measures can be taken in SC networks through increased transparency while identifying disruptions at an early stage [214,220]. Significantly correlated recording units (ρ_{sp} between 0.163 and 0.264) include 'SC finance' (as mentioned above), 'cybersecurity' [220,221] and 'sustainability' [20,195]. Furthermore, combining technological research on the use of blockchain in manufacturing with the use cases at the SC level should be addressed [51,177]. The few hits on 'strategic management' focus on BCT's role in improving certain dynamics in volatile and fast-developing SCs such as offshore wind energy [222,223].

Accordingly, we develop our fifth proposition:

Proposition 5. *Research on BCT in other business areas than procurement, logistics, and distribution is worthwhile, as these areas have not been adequately addressed yet and offer improvement potential. Additionally, bridges built across business areas can provide valuable insights into the benefits of BCT and should be pursued.*

4.2.6. Technology Interfaces

Blockchain is often referred to and analyzed in relation to other technologies in the literature. Figure 11 shows the overall hits per subcategory for the technology interfaces category. The greatest synergy effects and mutual enablers for BCT are expected with the Internet of Things (3006 hits in 248 articles), followed by RFID (1490 hits in 206 articles).

Big data analytics (689 hits in 128 articles) and artificial intelligence (514 hits in 81 articles) trail further in the rankings.

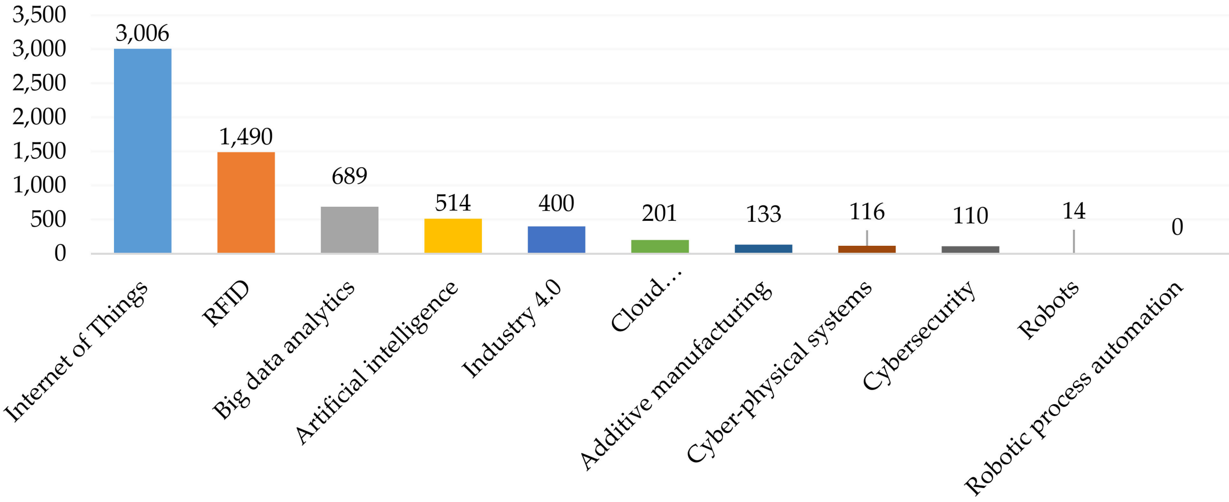


Figure 11. Hits per subcategory in the technology interfaces category.

IoT devices can lead to autonomous and secure business transactions—the combination with blockchain enables a decentralized and near real-time logging and sharing of data among business partners, which could have a lasting and significant impact on SCM and OM [104,192,224]. This is relevant as traditional, standalone IoT solutions face security and privacy issues [133]. The combination of IoT and BCT is expected to become more vital with the widespread introduction of low-latency and high-speed 5G coverage [225]. Significantly correlated recording units (ρsp between 0.209 and 0.401) include 'RFID', 'cybersecurity', 'environment', and 'Ethereum'. BCT is expected to increase the security of IoT systems through consensus mechanisms and distributed storage compared to a centralized, traditional IT system [103,157,220]. Environmental data, e.g., temperature of goods in a container, can be tracked in real-time and any deviations made available transparently on the ledger [132,226]. Ethereum is the platform most utilized for IoT and sensor connections to blockchain ledgers [163,225].

The contribution of RFID mainly resides around tracking and tracing solutions, where products are tagged and captured securely along the production lifecycle [151]. This is also indicated by the significantly correlated recording units, which include 'security', 'foods', 'IoT', and 'traceability' (ρ_{sp} between 0.167 and 0.420). As there are overlaps in content, RFID is often discussed along with IoT [227–230]. Together, these technologies provide the needed data to increase the automation of SC processes and facilitate exploiting the benefits of BCT [102].

Big data analytics can expand the contribution of BCT as the related technologies help analyze and interpret the large data amounts stored on the distributed ledgers, derive insights, and facilitate targeted decision-making for the management [17,58,231]. Significantly correlated recording units (ρ_{sp} between 0.189 and 0.33) such as 'inventory management', 'efficiency'/'cost', 'Industry 4.0' 'AI', and 'logistics' point towards the opportunities arising with the enhanced visibility and information sharing along the SCs. These insights enable firms to increase efficiency and reduce safety stocks as demand forecasting can be based on reliable, immutable, and (near) real-time data [129,232]. Complimentary Industry 4.0 technologies and artificial intelligence allow to collect and interpret data automatically and develop sophisticated strategies to align the SC and respond to disruptions or short-term customer demands [197,233]. Logistics as a subarea of SCM appears to be the core addressee of big data analytics for BCT [234,235].

Further on Industry 4.0 and artificial intelligence, both technologies are significantly correlated with additive manufacturing (ρ_{sp} between 0.225 and 0.263), where the connection with BCT is helpful to select the top-priority products to be locally produced by additive manufacturing methods such as 3D printing [51,174]. BCT also enables to address issues with additive manufacturing related to authorizing access to data, intellectual property protection and anti-theft measures [236].

There is not yet a strong tie of BCT to traditionally centralized 'cloud systems', 'robots', or 'robotic process automation'. We postulate our sixth proposition accordingly:

Proposition 6. *BCT can be a mutual enabler for and with other digital technologies. BCT can be strategically used to enhance security and transparency in sharing information along the SC with different stakeholders.*

4.2.7. Potentials of the Technology

In the next category, the potentials of BCT are assessed. Figure 12 indicates the number of hits for the subcategories.

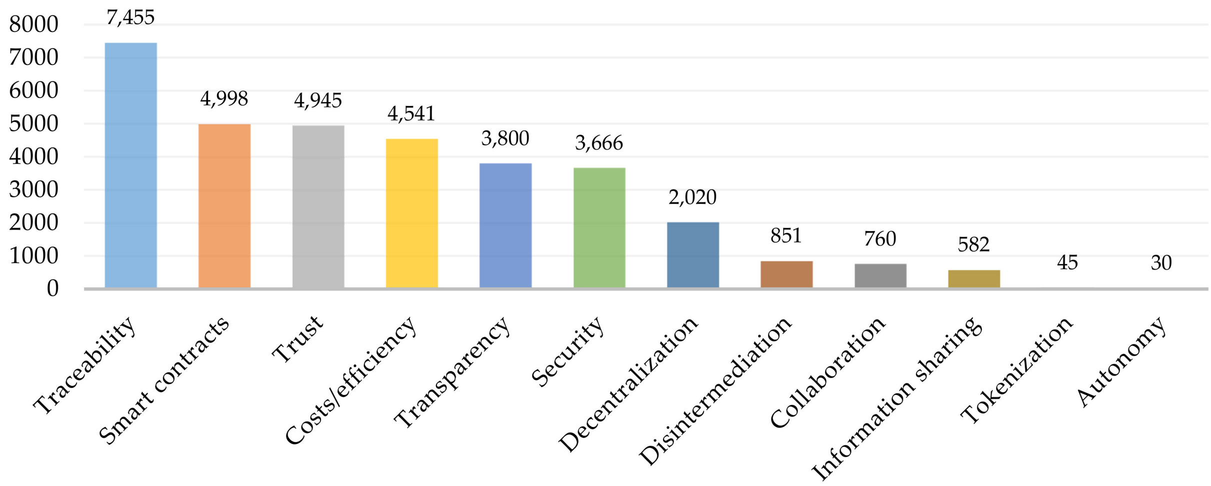


Figure 12. Hits for the category related to the potentials of the technology.

Traceability dominates the category with 7455 hits in 364 articles and a hit rate of 20.48 per article. Through BCT, goods and information can be traced in a trusted manner along the SC. Each transaction is securely stored and time-stamped in the blockchain as symmetric information visible to all participants [102,237]. Several studies identify traceability as the most crucial feature for technology adoption and use [104,237–239]. Significantly correlated recording units (ρ_{sp} between 0.38 and 0.563) include 'foods', 'pharma', 'agriculture', where traceability is essential for providing proof of origin to SC stakeholders and/or the customers [154,240,241]. The main technologies used for ensuring secure and timely transactions in the ledger coupled with real-world movements and status changes are 'IoT' [231,242] and 'RFID' [243,244], with ρ_{sp} between 0.305 and 0.42. Other significantly correlated potentials are 'transparency', 'immutability', 'security', and 'trust' [154,169,194,245], while 'case study' research was mainly conducted [162], as discussed in Section 4.2.3 (ρ_{sp} between 0.214 and 0.311).

Smart contracts are the next feature of BCT recognized with high potential in existing studies on SCM and OM. Securely implementing business terms and conditions in automatically executing contracts can potentially lead to cost savings and increased efficiency [57], increase trust among SC stakeholders [151], and allow for incorporating cryptocurrencies in financial compensation [143]. Significantly correlated recording units (ρ_{sp} between 0.219 and 0.457) include 'trust', 'immutability', and 'efficiency' for other potentials of BCT [151,246], 'Ethereum' and 'Hyperledger' for tools to employ and code smart contracts [159,247,248] and 'use case for the adoption status category [148,249]. Other significant correlations (ρ_{sp} between 0.193 and 0.236) exist with 'permissioned', 'permissionless', 'consortium' [166,250,251] and the different consensus mechanisms that can be used, such as 'Byzantine Fault Tolerance' or 'Proof-of-Authority' [252,253].

Next, trust is often addressed (4945 hits in 375 articles), which some authors believe is either *built* by BCT [44,139,254] and others argue is *replaced* by BCT [51,255,256]. In the end, it comes down to a similar argument: stakeholders can build corporate relationships through the use of BCT without having to know and trust each other beforehand or involve an intermediary because the technology stores the history of the companies securely and immutably and makes it transparently available to all connected nodes in the network. Significantly correlated recording units (ρ_{sp} between 0.293 and 0.407) with trust include 'immutability', 'transparency', 'collaboration', and 'intermediaries' as related potentials as well as 'conceptual' and 'empirical' as research methods that were utilized to examine the changes in relationships among BCT adoption [220,257–259].

Cost savings and increased efficiency of business transactions are recognized in 361 articles. The potential is mainly seen in enhancing information sharing among stakeholders as a common solution exists that, if configured correctly, automatically keeps data consistent and up-to-date [194,260]. Sharing information in real-time and transparently in the network can also enhance collaboration while reducing networking costs and other components such as verification costs for the quality of goods in manufacturing firms [44,261]. Significantly correlated items include 'transparency' [106,262], 'collaboration' [194,197], 'disintermediation' [20,57,263], 'information sharing' [194,260] and 'trust' [176,249], as well as 'logistics' [264], but also 'regulatory uncertainties' [142,265] and 'unclear governance' [48,266], with ρ_{sp} between 0.287 and 0.379.

Transparency is a potential mentioned and examined regularly in the articles (3800 hits in 370 articles). As the ledger is replicated among all participating nodes (disregarding technical deep-dives into light node concepts here), the transactions and the movement of goods and information are transparent for all stakeholders. In addition, e.g., transparent ownership can impact different industries and alter traditional governance structures [266,267]. Significantly correlated recording units include 'empirical', 'efficiency', 'awareness', 'disintermediation', 'traceability', and 'sustainability', which have mostly been discussed above (ρ_{sp} between 0.364 and 0.381). Awareness of transparency as a potential is limited in some industries, even where transparency is sensible for the SC partners and the customers [160,229].

Then, security is the next recording unit in the potentials category. One aspect is information security, which is related to preventing unauthorized access or misuse of information. Xu et al. (2021) highlight the decentralized consensus, the distributed ledger, and the cryptography system as critical features of BCT for information security [268]. Another aspect is the reliability of data accessibility, which is argued to be improved by BCT through its distributed nature [269]. Ensuring trustable data can add another security layer to business transactions [270]. Security is significantly correlated with 'decentralization' [152,271], 'IoT' [243,272], 'trust' [146,256], 'efficiency' [254,273], and 'cybersecurity' [103,157,274], with ρ_{sp} between 0.269 and 0.319.

Topics such as the influence of 'decentralization' (2020 hits in 304 articles), 'disintermediation' (851 hits in 192 articles), and 'collaboration' (760 hits in 169 articles) have been less in focus so far. The 'tokenization' of assets (45 hits in 16 articles), a topic that blockchain experts consider significant [17], has so far been rather neglected by research.

This leads to the seventh proposition:

Proposition 7. *While traceability, trust creation, smart contracts, and efficiency gains through BCT have been particularly explored and highlighted as potentials of the technology, further potential can be found in the disintermediation of business domains, ease of collaboration, simple and secure sharing of information or tokenization of assets that should be investigated.*

4.2.8. Barriers of the Technology

Overall, the barriers category received considerably fewer hits than the potentials category. This finding may indicate that researchers are pretty optimistic about the technology and/or that the benefits of BCT outweigh its risks. However, many blockchain projects that were started with big promises failed before making it to productive use [36]. Additionally, the difference may stem from the fact that suggesting specific potentials based on conceptual research is easier done than the empirical research needed to identify barriers for technology adoption or application, especially as the technology is so relatively novel. Figure 13 indicates the results for the category.

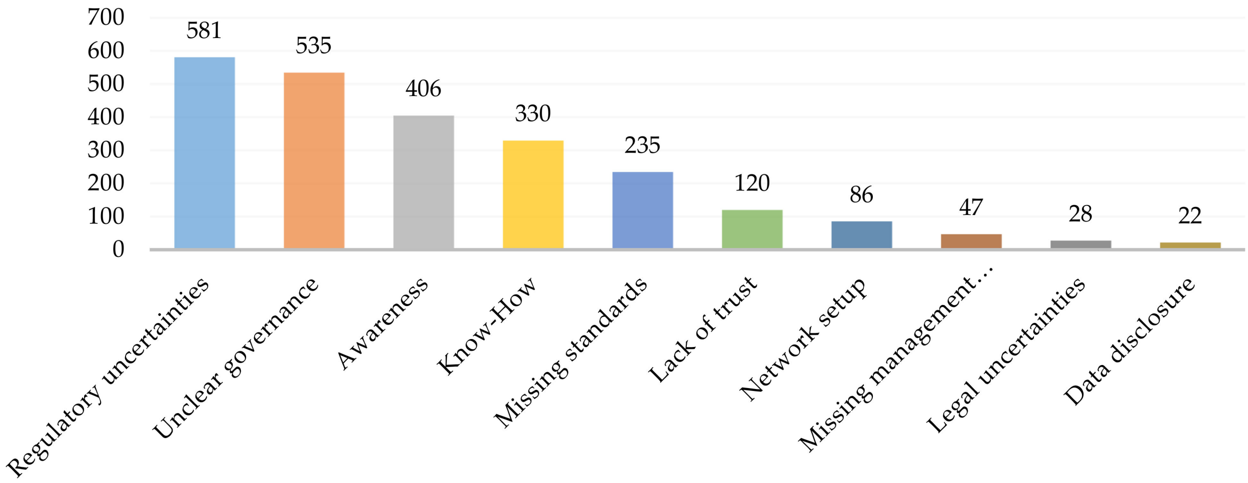


Figure 13. Hits for the barriers of the technology.

In the literature sample, 'regulatory uncertainties' received the most hits (581 in 143 articles). Regulatory uncertainties hinder firms from investing substantially in blockchain projects or joining blockchain consortia [51,275,276]. While Kurpjuweit et al. (2019) stress that there are uncertainties regarding digital signatures and blockchain records as well as smart contracts that delay blockchain adoption [51], Wang et al. (2020) and Wong et al. (2020) indicate issues mainly residing in permissionless blockchain configurations where access restrictions cannot be applied [275,276]. Significantly correlated recording units include 'permissioned' [277,278], 'trust' [152,279], 'cost' [161,265], 'empirical' [17,276], 'expertise' [51,275], and with 'unclear governance' [17,48] also to a related barrier (ρ_{sp} between 0.266 and 0.334).

In addition, 'unclear governance' implications of adopting and applying BCT persist. SCM and OM need to adapt to new governance forms and methods to cope with the disruptive influences of new digital technologies and especially the prospects of fair distributed decision-making authority of BCT [48,225]. Here, significant correlations (ρ_{sp} between 0.298 and 0.371) exist with the recording units 'transparency' [194,255], 'empirical' [48,175], 'conceptual' [135,280], 'trust' [44,185], 'collaboration' [11,126], and 'regulatory uncertainties' [17,48].

Other barriers are related to the missing 'awareness' towards the use and merits of BCT, missing 'know-how' on how to employ the technology and engage in projects, and the 'lack of standards' still existing in the industry today. Interestingly, problems with 'network setup' and implementation or the need to 'disclose data' were rarely mentioned in the articles, although practitioners frequently cited them as barriers [281].

Thus, we develop our eighth proposition:

Proposition 8. *Barriers such as regulatory uncertainties, unclear governance in blockchain-based networks, and missing standards need to be addressed on a social-political level globally, while other* *barriers such as lack of awareness, know-how, and trust need to be tackled by the blockchain industry and interested firms simultaneously.*

4.2.9. Adoption Status

The adoption status category assesses the maturity level of BCT applications, i.e., whether they represent a proof of concept or are already being used productively [53,112]. 'Use cases' continue to be explored (660 hits in 145 articles), while 'proof of concepts' (120 hits in 42 articles) and a few 'productive applications' (11 hits in 4 articles) are mentioned (see Figure 14).

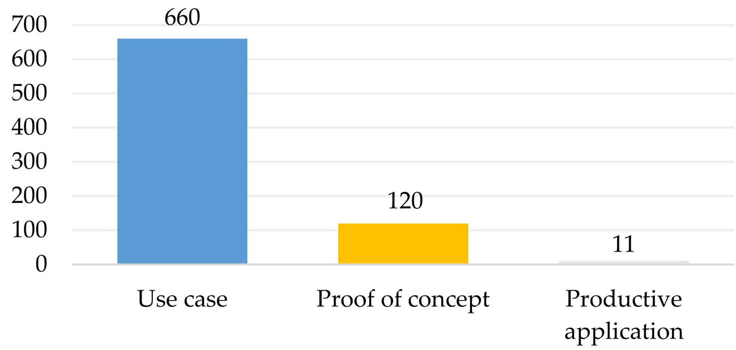


Figure 14. Hits for the adoption status category.

Use cases as a recording unit is significantly correlated with the potentials 'immutability' [148,282] and 'smart contracts', as well as 'permissionless' and 'permissioned' configurations [215,283,284]. Furthermore, significantly correlated barriers include 'regulatory uncertainties' [279,285], 'unclear governance' [17,51] and 'missing standards' [17,162] (ρ_{sp} between 0.227 and 0.319).

Proof of concepts are conducted once a concept has been developed for a use case and technically implemented in a first usable form. The recording unit is significantly correlated (ρ_{sp} between 0.179 and 0.261) with 'permissioned' [286,287], 'pharma' [165,288], 'regulatory uncertainties' [186,289], and 'case study' [135,190], indicating that most proofs of concepts are conducted in secure and somewhat isolated test environments due to existing regulatory uncertainties. The pharmaceutical industry has seen several proofs of concepts being developed (refer to Section 4.2.2).

Productive applications were investigated mainly by Tönnissen and Teuteberg [135], who mentioned, e.g., *OceanFreight*, *Origin Tracking*, *Everledger*, and *CargoChain* as productive applications of BCT. Important decisions to be made at this stage are reflected in the significant correlations with the recording units 'network setup' and 'legal uncertainties' [17] (ρ_{sp} between 0.241 and 0.352).

We develop our ninth proposition accordingly:

Proposition 9. *BCT projects rarely moved from use case to proof of concept and productive applications. Regulatory and legal uncertainties and the complex network setup still impede the transformation of many projects into productive use.*

4.2.10. Consensus Mechanisms Used

Consensus mechanisms are needed in every blockchain system to facilitate an agreement ("consensus") among nodes on the transactions and the order of transactions in a newly mined block. Ideally, all nodes in the network would take part in the consensus, and majority votes would be feasible [16]. However, especially in permissionless networks, this would lead to insecurity, as malicious actors could take over the majority through a Sybil attack, i.e., creating and using multiple accounts [290].

Therefore, Bitcoins' consensus mechanism Proof-of-Work (PoW) makes mining complicated and lets participating miners solve a cryptographic puzzle based on the SHA256 hashing algorithm that is hard to solve but easy to verify [291]. PoW is energy-intensive by design, ensuring a secure network but at high computational costs that are mostly superfluous, as only one miner per block can be successful and thus determines the next block to be added. The energy consumption of PoW blockchains such as Bitcoin is rather large, while blockchains that employ other non-PoW consensus have considerably lower energy consumption [292]. In line with this analysis, the significantly correlated recording units for PoW include 'Bitcoin' [250,293], 'energy' [293,294], 'security' [295,296], and 'cryptocurrencies' [127,297] (ρ_{sp} between 0.199 and 0.534). PoW dominates the consensus category with 257 hits in 69 articles (see Figure 15). The large number of articles containing the PoW recording unit at least once is related to the novelty of BCT and the perceived necessity by authors to explain the technicalities to the readers of their articles.

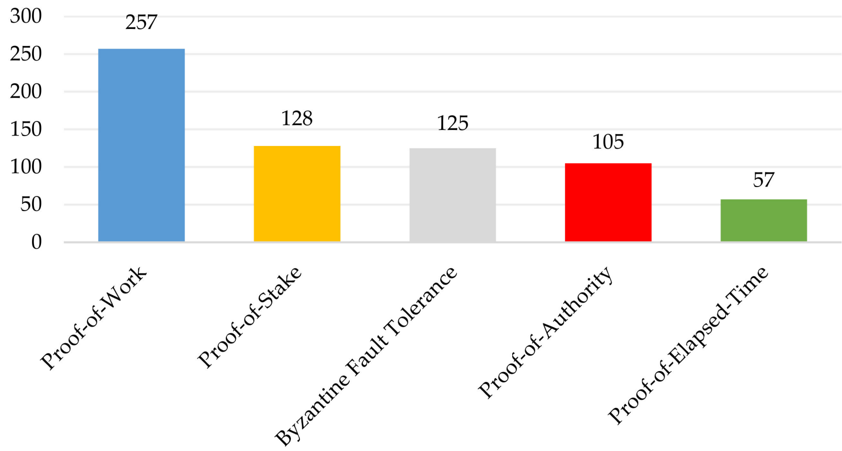


Figure 15. Hits for the consensus mechanism category.

Proof-of-Stake (PoS) is the next sub-category with 128 hits in 51 articles. PoS moves from staking computational resources as the scarce commodity to staking capital. Nodes to verify the next block are chosen randomly, but the probability of being selected is tied to the capital that each node has deposited and locked ("stacked") accordingly [292]. Significantly correlated recording units include 'Ethereum' [258,298], 'security' [102,299], and 'decentralization' [164,300] (ρ_{sp} between 0.164 and 0.203). Ethereum is transitioning from PoW to PoS and thus is often highlighted as a major cryptocurrency that aims to boost transaction throughput while reducing its network's energy consumption [258]. The network's security remains high, although the degree of decentralization is lower for PoS networks than PoW.

Other consensus mechanisms are 'Byzantine Fault Tolerance' (125 hits in 56 articles), 'Proof-of-Authority' (105 hits in 17 articles), and 'Proof-of-Elapsed Time' (57 hits in 14 articles). The latter two are solely found in permissioned blockchain networks, which is also significantly correlated with both mechanisms [301,302] (ρ_{sp} between 0.133 and 0.162).

Overall, it is noticeable that the consensus mechanisms are all significantly correlated with at least two other consensus mechanisms (ρ_{sp} between 0.28 and 0.534), indicating frequent joint consideration in paragraphs. Furthermore, the recording units of network configuration such as 'permissioned', 'permissionless', or 'public blockchain' are frequently significantly correlated with the consensus mechanisms. This indicates a strong relationship between both categories, and we thus postulate our tenth proposition:

Proposition 10. *Consensus mechanisms and network configurations are often discussed jointly in current BCT research and should therefore be considered together when building BCT networks.*

4.2.11. Platforms Used

Different platforms have emerged that can be used to develop or deploy BCT in SCM and OM. Our framework includes several well-known and upcoming platforms in this category (see Figure 16). Applications can either be using the native blockchain, e.g., the public and permissionless Bitcoin blockchain or build decentralized applications (DApps), using, e.g., the Ethereum network or a standalone platform.

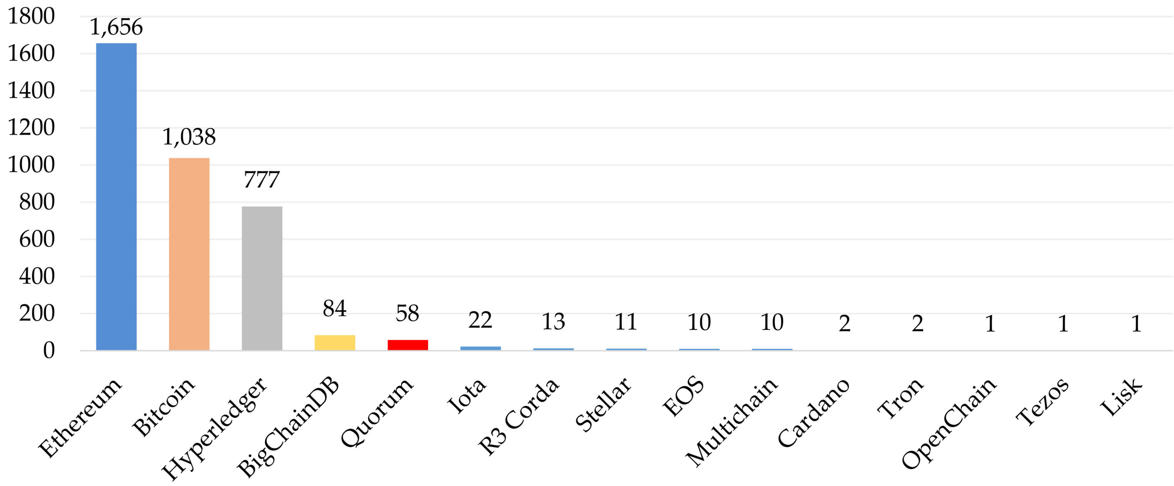


Figure 16. Hits for the platforms category.

Considering our literature sample, although 'Bitcoin' is found in most articles (1038 hits in 282 articles), this is primarily due to the fact that authors describe blockchain as a technology and refer to the whitepaper of Nakamoto (2008). Bitcoin is significantly correlated (ρ_{sp} between 0.198 and 0.358) with the recording units 'cryptocurrencies' [197,258], 'Proof-of-Work' [250,293], 'bank' [166,303], and 'trust' [304,305], highlighting its original purpose of serving as a digital transfer of value among the peers in the network running on PoW consensus ("cryptographic proof" (Nakamoto, 2008, p. 1) [42]) without a trusted intermediary or third party. Other significantly correlated recording units include 'security' [58,306] and 'immutability' [307,308] (ρ_{sp} between 0.182 and 0.231)

While Bitcoin is mentioned in most articles in our literature sample, Ethereum is the platform with the most hits overall (1656 hits in 208 articles). This result indicates that Ethereum lives up to its nickname "Blockchain 2.0", offering great potential via its Turing-complete programming language and smart contract automation capabilities that go beyond the capabilities of Bitcoin. Ethereum as a recording unit is significantly correlated with 'smart contracts' [126,309], 'decentralization' [285,310], 'cryptocurrencies' [116,298], 'IoT' [163,225], and 'traceability' [311,312] accordingly (ρ_{sp} between 0.207 and 0.457).

Next, Hyperledger follows with 777 hits in 141 articles. The umbrella project provides several open-source tools and frameworks that can be customized and used for cross-industry collaboration [313]. The high rate of hits per article indicates the significance of Hyperledger for developing and deploying BCT solutions. Hyperledger Fabric is a permissioned blockchain platform with a configurable consensus mechanism and smart contract capabilities often used for consortium blockchain solutions [213,314]. Significantly correlated recording units are 'Byzantine Fault Tolerance' [153,315], 'permissioned' [207,316], 'smart contracts' (which is referred to as "chaincode" in Hyperledger Fabric) [307,317], and 'consortium' [214,318] (ρ_{sp} between 0.224 and 0.338).

Thus, we postulate our eleventh proposition:

Proposition 11. *Platforms such as Ethereum and Hyperledger are considerably well-suited for proofs-of-concept and new consortia based on BCT due to their openness and adaptability, combined with smart contract capabilities.*

4.2.12. Network Configurations

The next category refers to the network configurations used in BCT application and adoption (see Figure 17). Depending on the use case, the stakeholders involved, and needed accessibility of the network, reading and writing rights differ [114,115]. As mentioned in Section 3.3, accessibility can be differentiated into permissioned or permissionless and public or private systems, with consortia as mixed forms of both configuration types [17].

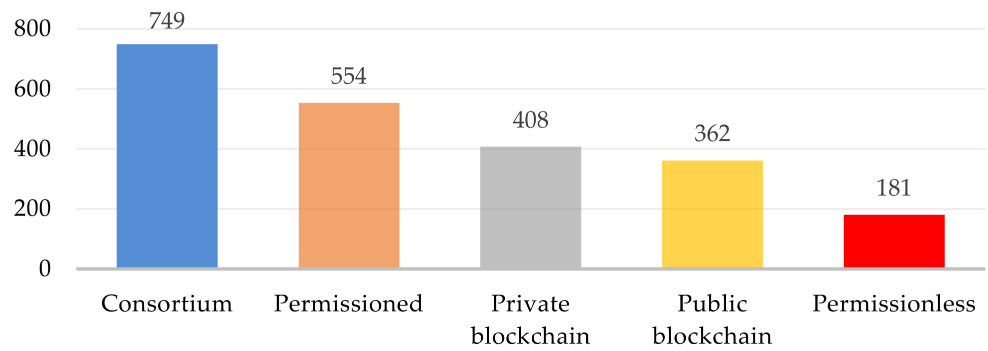


Figure 17. Hits for the network configurations category.

Analyzing the literature sample, consortia were built and mentioned the most in the articles (749 hits in 124 articles). They enable specific stakeholders to explore BCT applications jointly and with a clear set of governance rules that can be defined in advance [186,266]. Hyperledger is the main platform used to build and develop networks and is significantly correlated with the 'consortium' recording unit [142,246]. Other significant correlations include 'smart contracts' [172,278] and 'use case' [319,320], as many consortia explore use cases with smart contracts in a proof-of-concept or use case exploration phase. Additionally, 'unclear governance' [206,275] and 'regulatory uncertainties' [278,321] are barriers to further consortium development perceived in the studies (all ρ_{sp} between 0.202 and 0.229).

Regarding the writing rights of the ledger, 'permissioned' received more hits (554 hits in 140 articles) and are rather the go-to choice for blockchain networks for business transactions, at least for 'use cases' [127,287] or 'proof-of-concepts' [284,322] that are significantly correlated (all ρ_{sp} between 0.3 and 0.344). Even if the network access is restricted and the solution more centralized than a permissionless network, 'immutability' plays a critical role in permissioned networks [225,301]. 'Unclear governance' and 'Hyperledger' are significantly correlated recording units for both permissioned [20,166] and permissionless networks [184,307].

On the other hand, permissionless networks are helpful if decentralization is a key argument of choosing a blockchain solution and, e.g., audits of third parties need to be conducted transparently (181 hits in 65 articles). Significantly correlated recording units include 'disintermediation' [294,323], with the consensus mechanisms enabling coordination among nodes without a central party [47]. 'Productive applications' in SCM and OM are yet scarce but could leverage the potential of cryptocurrencies for fast settlement [17], while 'regulatory uncertainties' pose risks for stakeholders in SCs and networks as both the transparency of information as well as the pseudonymity of actors in the permissionless networks need to be considered [275] (all ρ_{sp} between 0.243 and 0.252).

Looking at reading rights, private blockchains received slightly more attention than public blockchains (408 hits in 106 articles vs. 362 hits in 130 articles). 'Private' is significantly correlated with 'Proof-of-Work' [258,324] and 'Proof-of-Stake' [283,302] as solutions can move from PoW to PoS or other consensus mechanisms in private blockchain solutions, which would facilitate scalability (ρ_{sp} between 0.213 and 0.234). 'Consortium' is also significantly correlated (ρ_{sp} = 0.298) with private blockchains as they are often used in these networks [173,278]. On the other hand, 'public' is significantly correlated with

'Ethereum' [280,323] as the go-to choice for BCT applications in public blockchains, 'immutability' as the key feature of the ledger [44,215], and 'use case' indicating the past use of public chains as a test environment for specific use cases rather than for productive use [240,294] (ρ_{sp} between 0.204 and 0.25). We developed a twelfth proposition:

Proposition 12. *In terms of accessibility, BCT solutions for SCM and OM remain focused on consortia as well as private and permissioned blockchains due to regulatory uncertainties in public and permissionless systems. The immutability of transactions is a key feature of BCT, even in private and permissioned systems that are more centralized than public and permissionless systems.*

4.2.13. Other

The last category includes subcategories that cannot be assigned to the other categories. Sustainability is addressed as well as 'environment' and 'green', while the remaining item is related to cryptocurrencies (see Figure 18).

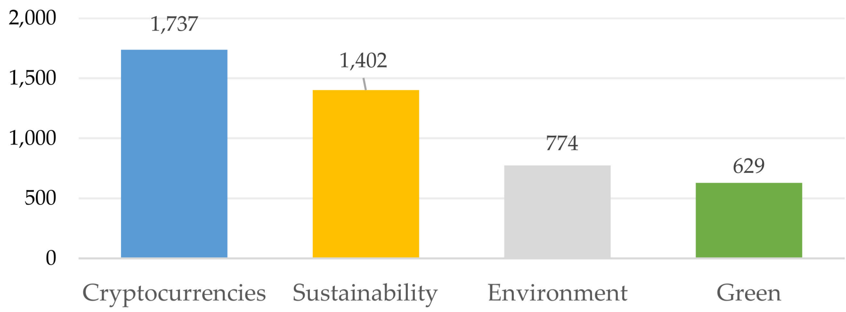


Figure 18. Hits for the category 'other'.

'Green' (629 hits in 98 articles), 'environment' (774 hits in 157 articles), and 'sustainability' (1402 hits in 152 articles) as terms related to sustainability are significantly correlated and often occur together in the articles (ρ_{sp} between 0.366 and 0.421). Blockchain could facilitate a move towards more sustainable and greener SCs through enhanced visibility and provenance capabilities. Purportedly green products can be verified to be environmentally friendly by all stakeholders, including the end customer [11]. Significantly correlated recording units (ρ_{sp} between 0.184 and 0.387) from other categories include 'transparency' [250,325], which is related to the visibility in the SC, 'awareness' [125,219] for BCT sustainability solutions, 'energy' focusing on the potentially large energy consumption of blockchain solutions due to PoW [20,215], 'empirical' as the primary research method employed [180,326] and the 'technology-organization-environment framework' as one framework than can be used to assess the implications of BCT on sustainability dimensions [11,201].

Regarding cryptocurrencies (1737 hits in 188 articles), it is evident that research perceives and investigates the potential added value, but the use in projects has been limited so far. The use of public cryptocurrencies is unlikely at present due to regulatory uncertainties and volatility. In addition, private, dedicated cryptocurrencies have not been a requirement in consortia to date [17,220]. Significantly correlated recording units include 'tokenization' [19,171], 'trust' [327,328], 'trade' [305,329], 'smart contracts' [179,330], and 'immutability' [325,331] (ρ_{sp} between 0.215 and 0.279).

We postulate our thirteenth proposition accordingly:

Proposition 13. *BCT can ease sustainability initiatives for SCs and enable transparency for all SC stakeholders and the customer. Additionally, cryptocurrencies are valuable to truly leverage smart contracts as intended and drive efficiencies, including the financial settlement of business transactions.*

5. Discussion

5.1. Managerial Implications

Managers keen to facilitate the digital transformation of their SCs and networks can derive several insights and implications from this study. Inter-organizational collaboration with stakeholders, increased visibility and transparency, and trust are some of the prospects of adopting and applying BCT in OM and SCM [17]. This study provides an up-to-date overview of trends and the focus of research activities based on a comprehensive literature set, which managers can use for an initial assessment of the implications of the technology. The various interfaces to other technologies enable new BCT adoption and further development approaches. The study also highlights specific business areas that have been explored so far. Potentials and barriers have been analyzed and interpreted and can thus be evaluated for the respective use case in a targeted manner.

Thus, managers can focus on the weak spots in their own or their SC partners' organizations to develop the right capabilities to utilize BCT to increase efficiency and conduct secure business transactions securely, immutable, and transparently. Additionally, it provides insights on aspects that are more mature, which might mitigate adoption risks. The correlation analysis conducted in this study reveals relationships between categories, highlighting connections that practitioners should also be aware of when considering BCT adoption and configuration. Furthermore, the propositions established serve as a brief overview of identified relations and conclusions in the studies examined. For example, Proposition 1 and Proposition 2 reveal that the implications of BCT differ among the operational purposes and that a specific investigation of potentials and risks is deemed necessary for individual use cases. Based on these propositions, targeted analysis and subsequent technology adoption is facilitated.

5.2. Theoretical Implications and Future Research Opportunities

Our study also contributes to theory in several ways that we indicate in this section. The conducted screening of existing reviews of BCT in OM and SCM revealed that existing reviews focused on various specific application areas. Additionally, potential risks of applying BCT were strongly discussed for specific literature subsets. Therefore, the systematic review of a more comprehensive literature set conducted in this study provides insights on research trends and key topics in scholarly exploration. We employed content analysis in a rather novel way with software support in a mixed-methods approach, combining qualitative and quantitative proportions. The detailed methodology ensures reproducibility and reliability of the results. With the developed theory-based conceptual framework, scholars can target their future research efforts and advance the field. In addition, the developed propositions provide assistance in analyzing the relationships and conclusions in the studies examined and in testing them in further studies.

Our findings indicate that the potentials of the technology take a greater share than the barriers, with tracking and tracing abilities, transparency increases, trust, cost savings, immutability and security, and smart contract automation potential as the most significant. Barriers prevail in governance issues, regulatory uncertainties and awareness of the technology, missing know-how, and standards. In the literature set, few articles are theory-driven, and OM is less researched than SCM. The industry focus has so far been on food, agriculture, and pharmaceutics. Methodological approaches are still mainly conceptual and qualitative. Interfaces to other technologies are perceived as promising related to IoT and RFID technologies. Sustainability applications are also an emerging topic. This helps to answer the second research question (RQ2).

Recommendations for further research are included in the following to answer the third research question (RQ3). The analysis indicated a lack of specific empirical research on BCT adoption and existing barriers to adoption. Examining these measures grounded in theory is meaningful to guide managers in adopting BCT and evaluating its impact. There is research potential in specific theory-based views on BCT and how the technology influences existing theories in OM and SCM or even leads to new theories. Few scholars have yet studied BCT with quantitative research methods, such as simulation or optimization. Valuable opportunities emerge in this context, as a targeted adoption of BCT needs to be supported by economic investigations and positive prospects. Smart contract functionalities and sophisticated data analytics techniques might enable a more efficient SC collaboration and facilitate increasing resource sharing among SC entities that need to be supported by rigorous operations research. Additionally, scholars could focus on SC risk management use cases and applications. Combining technological research on BCT in OM and SCM with value-adding use case assessment would further increase the technology's adoption potential. Tokenization of assets, blockchain's impact on the degree and the type of network collaboration, and disintermediation are further promising research avenues for the potential of BCT. Sustainability initiatives for SCs and value chains can also profit from BCT adoption and application and should be addressed.

A related research agenda with specific research questions might include the following aspects and research avenues:

(i) How can the developed BCT solutions be used in a targeted manner to provide the industry with a monetary incentive to be early adopters that use the technology in real-world, operational processes?
(ii) Which new business models are emerging in the area of platforms for SC networks?
(iii) How will these business models and new network forms influence the governance and performance of collaborations?

Furthermore, research in specific business areas and use cases should include the following assessments:

(iv) How can blockchain's transparency enable an increase in network resilience and allow disruptions to be identified more swiftly?
(v) How can SC finance pursue an efficient settlement via BCT without any intermediary and which implications arise from a blockchain approach?
(vi) How can BCT be used purposefully to bring added value to both manufacturing companies and their customers?
(vii) Which characteristics of the technology influence its adoption and use in sustainability applications?

There are numerous further promising starting points for research, including the interaction with other Industry 4.0 technologies, which can rarely operate independently and should be investigated. Interested readers are encouraged to explore the correlations between the terms indicated above to uncover other exciting topics. We also encourage scholars from other disciplines to conduct CA studies on the impact of BCT on their research areas, like human/social sciences or the management of organizations.

5.3. Limitations

The methodology of this article has certain limitations. The sample was generated using two scholarly databases with a limited set of keywords, and only peer-reviewed articles in English were considered relevant. Using other databases and search strings might have led to a different sample and thus different findings. Due to the applied CA methodology relying partly on an auto-analysis of specific recording units, potentially relevant and interesting themes or recording units may have been missed. This is true despite our combined deductive and inductive approach to developing the conceptual framework. Furthermore, due to the rather simple counting of hits in the articles for the categories and as the literature set is quite large, it is not necessarily feasible to draw a reliable connection between the relevance of the category and the individual hits in all cases. The results were not causally validated across all categories and hits. This may have led to misconceptions about the relevance of the categories and, in particular, the perceptions and actions of practitioners may differ from scholars in this area. Therefore, we encourage other scholars to replicate the study with different recording units and literature sets. In addition, as the research field is dynamic and evolving rapidly, we recommend repeating the study in the near future to provide new insights or test the findings of this study. The focus on rather technical properties of BCT may have neglected relations on human/social aspects of technology adoption and integration, which should be examined in further studies as well.

6. Conclusions

This study investigated a systematically generated literature sample of 410 articles on BCT in OM and SCM through content analysis (CA). We developed a theory-based conceptual framework consisting of thirteen categories and numerous subcategories in a mixed knowledge creation approach to identify trends and key research topics on the technology. The categories include research and industry focus, research methods and theories used in the articles, technology interfaces, business areas addressed, potentials and barriers of the technology, adoption status, platforms used, network configurations, and a category focusing on related aspects such as sustainability and cryptocurrencies.

We identified the different perceptions of technology in the research areas studied and the differences between industries that necessitate individual analysis. While conceptual approaches are extensive and qualitative research efforts are increasing, quantitative approaches could add further value to the impact of BCT on performance levels in OM and SCM. Grand theories such as principal-agent theory, innovation diffusion theory, or dynamic capability theory have not been adequately addressed in relation to BCT yet. BCT integrates different technology elements and is particularly useful when combined with other technologies like IoT. Then, BCT shows its real potential to improve security and transparency in sharing information along the SC. Bridging gaps across different business areas can provide interesting insights into the benefits of BCT and should be pursued. Recognized and well-addressed potentials in the literature include traceability of transactions, trust creation in the network, smart contract capabilities, and efficiency gains. Other potentials like disintermediation, secure information sharing, and tokenization of assets should be investigated in further SCM and OM research. On the other side, barriers that prevail were identified with regulatory uncertainties, unclear governance in networks, and missing standards that both research and industry can address. Only a few projects have made it from the use case level to a productive application, which is also due to the legal difficulties and complex network structures. On a more technical level, we identified that consensus mechanisms and network configurations (private/public and permissioned/permissionless) are interrelated and should be considered in an integrated approach. Platforms such as Hyperledger and Ethereum pose opportunities for proofs-of-concept of BCT applications in various configurations and align with the identified industry tendency to rely on consortia or private and permissioned networks to test and exploit BCT. Other interesting aspects include the technology's sustainability implications, such as enabling transparency for SC stakeholders and beyond. Cryptocurrencies can facilitate smart contract application and further efficiency gains if legal uncertainties are reduced. Managerial and theoretical implications, as well as limitations of the study, are provided in Section 5. Arising research opportunities include examining the tokenization of assets, the impact of BCT on the degree and the type of network collaboration, and disintermediation that could lead to new business models in OM and SCM.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14106192/s1, Correlation analysis as.xlsx.

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Appendix A. Table on Existing Literature Reviews

Table A1. Summary of existing literature reviews on blockchain technology in SCM and OM (sorted by publication date).

Author(s)	Journal and Publication Year	Focus	Results/Conclusions	Search Strings	Search Limitations	Databases	Published Online	Search Until	Quantity of Relevant Articles
Wang et al. [18]	Supply Chain Management, 2019	Identifying drivers of BCT deployment in SCs, areas where BCT provides value for SCM, challenges/barriers to BCT diffusion	- Drivers for deployment are trust, SC complexity, product authenticity, and public safety - Areas include extended visibility and product traceability, SC digitalization and disintermediation, improved data security for information sharing, smart contracts - Challenges: Organizational, technological, operational	blockchain or "digital ledger" or "distributed ledger" or "shared ledger" consists of "logistics", "supply chain", "demand chain" and "value chain"	All Content	ABI Inform Global, Emerald, IEEE Explore, Jstor, Science Direct, Scopus, Springer, Taylor and Francis, and Web of Science	14 January 2019	Jan 18	29 of 227
Pournader et al. [12]	International Journal of Production Research, 2020	Assessing the literature in SCs, transport, and logistics and their key knowledge areas through bibliometric and co-citation analysis	- Four main clusters were identified: trade, trust, traceability/transparency, and technology - Main findings related to SCM: technology connection with IoT systems, trust-related to information sharing and collaboration, trade associated with energy trading, traceability to ensure social and environmental sustainability	blockchain OR distributed ledger OR smart contract AND supply chain OR logistics OR transport	Title, abstract, and keywords	Scopus	11 August 2019	Oct 18	48 of 132
Queiroz et al. [10]	Supply Chain Management, 2019	Assessing the main current BCT applications in SCM, main disruptions and challenges in SCM due to BCT adoption, future of BCT in SCM	- Studies classified by application area, context, technologies used, and theoretical approach - Applications mainly in the electric power industry and pharmaceutical SCs - Disruptions due to smart contracts, traceability, and transparency, new business models	blockchain AND (supply AND chain) OR logistics OR manufacturing OR transportation OR purchasing OR (smart AND contracts) OR (suppliers) OR (green AND supply AND chain) OR (sustainability) OR (environment) OR (production AND systems) OR (industry 4.0) OR (iot OR internet AND of AND things) OR (cps OR cyber AND physical-systems) OR (bda OR big AND data)	Title, abstract, and keywords	Scopus, ScienceDirect (Elsevier); Emeraldinsight (Emerald); Wiley Online Library (Wiley); Taylor & Francis Online (Taylor and Francis); Sagepub (Sage Journals); IEEE Xplore Digital Library (IEEE); and Springer Link (Springer)	22 August 2019	Feb 18	27 of 92

Table A1. *Cont.*

Author(s)	Journal and Publication Year	Focus	Results/Conclusions	Search Strings	Search Limitations	Databases	Published Online	Search Until	Quantity of Relevant Articles
Frizzo-Bakeret al. [29]	International Journal of Information Management, 2020	Definition of BCT, research topics in focus, benefits, and risks	- Findings indicate more conceptual than empirical papers - Focus on financial applications, followed by law and governance and accounting - Benefits: trust-free nature, disintermediation, cost reduction - BCT with disruptive effects on SC, financial services, and media	"blockchain"	Title, abstract, and keywords	Business Source Complete, SpringerLink, and Web of Science	11 November 2019	Dec 18	155 of 529
Gurtu & Johny [28]	International Journal of Physical Distribution and Logistics Management, 2019	Assessing the potential of BCT in SCM, without investigating specific themes or articles	Advantages of BCT are summarized as data security, risk reduction, fraud detection	"blockchain"	Title, abstract, and keywords	EBSCO Premium	29 November 2019	Dec 18	30 of 299
Wamba et al. [59]	Production Planning and Control, 2020	Defining the concepts of BCT, Bitcoin, and Fintech in the SC domain	- Application domain: digital payment, legal regulation, accounting - Benefits: security, immutability, disintermediation, transparency, trust	Blockchain OR Bitcoin OR Fintech	All Content	ABI/INFORM Complete, Academic Search Complete, Emerald Journals, JSTOR, and ScienceDirect	4 December 2019	Dec 17	141 of 314
Juma et al. [60]	IEEE Access, 2019	BCT in trade supply chain solutions	- Electronic trading solutions, validation solutions, supply chain optimization as three main categories. - Promising features are traceability and data integrity. Adoption is influenced by scalability, willingness, and costs	blockchain AND (trade supply chain OR customs OR trade monitoring OR counterfeit trade OR trade facilitation)	Title, abstract and keywords	IEEE, ACM, scientist direct, Scopus, Springer, Taylor and Francis	18 December 2019	~Nov 19	34 of 105
Gonczol et al. [30]	IEEE Access, 2020	BCT implementations and use cases in SCs	- Three clusters were identified: theoretical analyses addressing BCT benefits and challenges, conceptual systems to showcase the suitability of BCT, implemented systems for case studies - Industries in focus for use cases: food, pharmaceutical, and shipment - Most implementations on Ethereum or Hyperledger Fabric - Adoption challenges: technical vs. policy making	blockchain, distributed ledger, supply chain, implementation	not provided	Google Scholar, IEEE, ACM, DTU Find-it	8 January 2020	~Oct 19	29 (?)

Table A1. *Cont.*

Author(s)	Journal and Publication Year	Focus	Results/Conclusions	Search Strings	Search Limitations	Databases	Published Online	Search Until	Quantity of Relevant Articles
Duan et al. [33]	Int. Journal of Environmental Research and Public Health, 2020	BCT in food supply chains	- Benefits: food traceability, SC transparency, combination with IoT devices - Challenges of adoption: know-how, scalability issues, stakeholder alignment, regulations	"blockchain" AND "food supply chain"	not provided	Web of Science, Scopus, and EBSCO	9 March 2020	~Nov 19	26 of 57
Wan et al. [61]	IEEE Access, 2020	Blockchain-enabled information sharing in SCs	Industries in focus: medical and health industry, smart construction and smart cities, banks, textile SC	• blockchain technology AND information flow AND supply chain • blockchain technology AND information sharing AND supply chain • blockchain technology AND information asymmetry AND supply chain • blockchain technology AND supply chain • information sharing AND supply chain • information symmetry AND supply chain • information flow AND supply chain	not provided	Scopus, Web of Science, Emerald Insight, IEEE Xplorer digital library, and Business Complete	20 March 2020	~Dec 19	31 of 447
Kummer et al. [62]	Future Internet, 2020	Organizational theories used in BCT literature in logistics and SCM	Main theories used are: agency theory, information theory, institutional theory, network theory, RBV, and TCT	"blockchain" AND "logistics" OR "SCM" OR ("supply chain") OR "transport"	Abstract	EBSCO Business Source Complete, (ISI) Web of Knowledge (Social Sciences Citation Index (SSCI)-Database)	23 March 2020	Jan 20	22 of 228

Table A1. *Cont.*

Author(s)	Journal and Publication Year	Focus	Results/Conclusions	Search Strings	Search Limitations	Databases	Published Online	Search Until	Quantity of Relevant Articles
Chang and Chen [27]	IEEE Access, 2020	Current status, applications, and future directions of BCT in SCM	- Dominating topics identified are physical distribution and logistics as well as agricultural and food applications - Topics dominate as traceability and transparency, physical distribution, combinations with other technologies - Research methods: Many descriptive papers, conceptual frameworks, case studies rather than quantitative methodologies	Blockchain OR Distributed Ledger OR Shared Ledger OR Decentralized ledger System OR Smart Contract AND Supply Chain Management OR Supply Chain Integration OR Logistics OR Business Operation OR Value Chain OR Business Process Reengineering	not provided	ABI Inform Global, ACM, Emerald, IEEE Explore, Google Scholar, Science Direct, Springer, Taylor and Francis, Web of Science, Wiley	14 April 2020	~"Early 2020"	106 of 433
Leng et al. [63]	Renewable and Sustainable Energy Reviews, 2020	Blockchain-empowered sustainable manufacturing models and methods	- Framework to analyze articles along with sustainable manufacturing and product lifecycle management - BCT as an enabler drive existing manufacturing information systems (e.g., ERP or MES) and from the product management perspective, BCT could provide a tool to share product information, enable untrusted manufacturers to exchange capabilities and requirements	combination of "blockchain", "sustainable manufacturing", "sustainable product lifecycle", and "Industry 4.0"	not provided	Science Direct, IEEE Xplore, Taylor & Francis Online, Springer, Wiley InterScience, Emerald Insight, AIS Electronic Library, Georgia Tech Library, and MDPI	16 July 2020	~Nov 19	183
Upadhyay et al. [31]	Journal of Global Operations and Strategic Sourcing, 2020	Challenges and opportunities of BCT adoption in the automotive industry	- Challenges are network design, security, energy consumption, interoperability, scalability, technical expertise, regulatory uncertainties - Opportunities are disintermediation, cost reduction, security opportunities, new business models	'Blockchain', 'Blockchain Technological Challenge', 'Blockchain Management Challenges', 'Blockchain Technological Opportunities' and 'Blockchain Management Opportunities'	(1) Title or keywords(2) Abstract and main text	Journals from the Association of Business School (ABS) Journal Quality Guide, found in the databases Emerald Insight, Taylor and Francis, Wiley Online Library, Elsevier and IEEEXplore	12 September 2020	March 20	69
Paliwal et al. [64]	Sustainability, 2020	BCT for sustainable SCM	Developed a classification framework based on TRL and Grounded Theory with several subcategories to categorize the literature according to the technology readiness maturity level with most papers in the first three of nine levels	"blockchain" AND "sustainable supply chain management"	not provided	EBSCO Host, ProQuest, Directory of Open Access Journals, Springer Link, Emerald Open Access, Harvard Business Review, MDPI, and Science Direct	16 September 2020	~"Early" 20	187 of 448

Table A1. *Cont.*

Author(s)	Journal and Publication Year	Focus	Results/Conclusions	Search Strings	Search Limitations	Databases	Published Online	Search Until	Quantity of Relevant Articles
Müßigmann et al. [65]	IEEE Transactions on Engineering Management, 2020	Bibliometric analysis of BCT in logistics and SCM to identify the influential articles and research clusters	Identification of five clusters: theory development, the conceptualization of BCT applications, digital SCM, the technical design of SCM applications, framing BCT in SCs	(1) supply chain OR logistics OR transport AND blockchain; (2) supply chain OR logistics OR transport AND block chain; (3) supply chain OR logistics OR transport AND distributed ledger technology	Title, abstract, and keywords	IEEE Xplore, Springer, Google Scholar, Ebsco, Taylor and Francis, Emerald Insight, Science Direct, SSRN, Scopus, and Web of Science	9 October 2020	Dec 19	613 of 991
Centobelli et al. [34]	Technological Forecasting & Social Change, 2021	Bibliometric analysis of BCT	- Classification of the literature in six clusters: basic applications, Industry 4.0 applications, security and privacy applications, supply chain applications, financial applications, and energy applications - Four main themes for the clusters were identified: motor themes, basic themes, emerging/disappearing themes, specialized themes	"blockchain*" AND "block chain*"	Not provided	Web of Science	22 December 2020	October 19	2233
Lim et al. [26]	Computers and Industrial Engineering, 2021	Addressing the value of BCT for SC, the themes with the most attention, which methodologies were used and which industries were focused	- Themes: Impact, Function, Configuration - Methods: Conceptual (31 articles), empirical (28), modeling (24), and system implementation (23) - Industries: Agriculture, manufacturing, light industry, construction	"blockchain" AND ("supply chain" OR "transport" OR "logistics" OR "cross-border trade" OR "manufacturing")	Theme	Web of Science core collection	20 January 2021	March 20	106 of 421

Table A1. *Cont.*

Author(s)	Journal and Publication Year	Focus	Results/Conclusions	Search Strings	Search Limitations	Databases	Published Online	Search Until	Quantity of Relevant Articles
Etemadi et al. [66]	Information, 2021	BCT for SC risk management	Eight clusters were identified: disruption risk management, shared and trusted information, digital transaction records, integration of BCT with IoT, transparency and traceability, anti-counterfeiting, information privacy, safety, and security	TITLE-ABS-KEY (“block-chain” OR “blockchain” OR “block chain” OR “distributed ledger”) AND TITLE (“cyber risk” OR “security” OR “risk” OR “protection” OR “threat” OR “disruption” OR “resilience” OR “crime” OR “attack” OR “breach” OR “failure”) OR KEY (“cyber risk” OR “security” OR “risk” OR “protection” OR “threat” OR “disruption” OR “resilience” OR “crime” OR “attack” OR “breach” OR “failure”) AND TITLE-ABS-KEY (“supply chain” OR “supply network”)	See column to the left (Scopus Advanced Search)	Scopus	7 February 2021	July 20	192
Moosavi et al. [67]	Environmental Science and Pollution Research, 2021	Bibliometric and network analysis on BCT in SCM	- Main keywords are blockchain, supply chain management, IoT, smart contract, transparency, traceability, information management, and sustainability - Key related technologies identified as IoT and smart contracts - BCT contribution in SCs mainly traceability and transparency	“blockchain” OR “block chain” AND “supply chain” OR “supplychain”	Title, abstract, and keywords	Scopus	27 February 2021	~Oct 20	300 of 685
Reddy et al. [68]	Computers and Industrial Engineering, 2021	Blockchain applications in automotive supply chains	- Four clusters were identified: pre-production, transportation, production, and distribution - Benefits of BCT for automotive SCs identified as improvement of visibility, transparency, traceability, SC efficiency through disintermediation, real-time data sharing, and data access	Automotive AND supply chain AND sustainable AND business AND practices AND block AND chain OR digital AND ledger OR shared AND ledger OR ALL decentralized AND ledger OR Smart AND contracts	Not provided	Scopus	16 April 2021	~May 20	70 of 389

Table A1. *Cont.*

Author(s)	Journal and Publication Year	Focus	Results/Conclusions	Search Strings	Search Limitations	Databases	Published Online	Search Until	Quantity of Relevant Articles
Vu et al. [69]	Production Planning & Control, 2021	Blockchain adoption in food supply chains	- Research approaches are mostly conceptual or proof-of-concepts - Drivers were internal (enhanced traceability, SC transparency, efficiency increases, food fraud combat, cost reduction) and external (customer pressure, SC partner pressure, regulation) - Barriers: intra-organizational (implementation cost, lack of expertise, privacy req., suitability), inter-organizational (SC readiness, input inaccuracy, missing standards), technological (scalability, smart contract design), external (regulatory uncertainty) - Applications mainly for traceability, food safety, process optimization, sustainability improvement, information security)	(Blockchain OR smart contract OR distributed ledger) AND (food OR agriculture OR perishable OR fresh) AND (supply chain OR value chain OR demand chain OR logistics OR cold chain) AND (implementation OR traceability OR transparency OR visibility OR tamper* OR security OR safety OR integrity)	Full text	Scopus, EBSCO, Web of Science	3 June 2021	June 20	69 of 568
Khanfar et al. [70]	Sustainability, 2021	Applications of BCT to sustainable manufacturing	- Three pillars identified along the triple bottom line: economic, environmental, and social - Economic: reliability, responsiveness, flexibility, financial performance, quality - Environmental: use of resources, pollution, dangerousness, natural environment - Social: work conditions, human rights, societal commitment, customer issues, business practices,	("Sustainab*" OR "environ*" OR Green OR "eco*" OR "Social" OR "Societal" OR "CSR") AND ("Blockchain" OR "Smart Contract" OR "distributed ledger")	Title, abstract, and keywords	Scopus	14 July 2021	March 21	21 of 295
Li et al. [32]	International Journal of Production Research, 2021	BCT in food supply chains—platforms, benefits, and challenges	- Classification along three dimensions: enablers (transparency, traceability, authenticity, data security, automated transactions), benefits (food safety, reduction of time and costs, increased revenue, improved SC performance, sustainability promotion), and challenges (technology, governance, regulations, cost, awareness, and education) - KPIs of BCT platforms in food SCs: Data accessibility, knowledge requirement, software integration	(food OR agri) AND (blockchain OR block-chain OR distributed ledger)	Title	Web of Science, Business Source Premier, ScienceDirect, Academic Search Premier, and ProQuest	13 September 2021	May 21	74

Table A1. *Cont.*

Author(s)	Journal and Publication Year	Focus	Results/Conclusions	Search Strings	Search Limitations	Databases	Published Online	Search Until	Quantity of Relevant Articles
Tandon et al. [35]	Technolog-ical Fore-casting & Social Change, 2021	Bibliometric review of BCT applications in management	- Four clusters of BCT research in management were identified: strategy and regulation, enablement and implication, multi-domain deployment, inefficiencies of bitcoin	Blockchain or ethereum or distributed ledger technology or smart contract	Not provided	Scopus	16 February 2021	August 2019	586 of 1658
Nabipour et al. [71]	Sustainability, 2021	Review on deploying BCT in supply chain strategies and the COVID-19 pandemic	- Categorized BCT into four groups: visibility, digitalization, transparency, and smart contracts - Large proportion of the reviewed articles have focused on digitalization and visibility - research emphasized the overall role of BCT in SC and its - applications in the control of the COVID-19 pandemic rather than a specific industry sector - predominant methodologies of reviewed studies have been qualitative	Blockchain AND supply chain AND COVID-19 or SARS-CoV-2 or coronavirus	Keywords	Scopus, Google Scholar, Web of Science, Proquest	23 September 2021	June 2021	72 of 446
Hussain et al. [73]	Sustainability, 2021	Review of blockchain-based IoT devices in supply chain management	- Mostly RFID devices are used for blockchain-based IoT communication - Future research is needed to lower CPU requirements to operate blockchain code on moderate IoT smart objects - and building fault tolerance in the interchange between devices and networks	Blockchain AND IoT AND ("Supply Chain")	Not provided	IEEE Xplore, ACM Digital Library, ScienceDirect, Springer Link, Wiley Online Library, Sage Journals, Taylor and Francis Online	10 December 2021	November 2021	44 of 1480
Dasaklis et al. [72]	Sustainability, 2022	Review of blockchain-enabled supply chain traceability implementations	- Available blockchain-enabled SC traceability implementations encompass SC domains such as generic, food, agriculture/agri-food, pharmaceuticals, manufacturing, electronics, apparel, aviation, automobile, industry, and construction - most implementations do not include advanced and functional interfaces - Lack of regulations, standards, and inherent technological issues were identified	(blockchain OR "distributed ledger" AND "supply chain" AND traceability)	TITLE-ABS-KEY	Scopus	20 February 2022	November 21	72 of 668

Table A1. *Cont.*

Author(s)	Journal and Publication Year	Focus	Results/Conclusions	Search Strings	Search Limitations	Databases	Published Online	Search Until	Quantity of Relevant Articles
This article	-	Content analysis of BCT in OM & SCM	- Theory guided development of a conceptual framework on BCT in OM and SCM - Content and statistical analysis on 410 articles in the categories of research and industry focus, research methods and theories used in the articles, technology interfaces, business areas addressed, potentials and barriers of the technology, adoption status, platforms used, network configurations, and a category focusing on related aspects such as sustainability and cryptocurrencies	("blockchain*") AND ("supply chain*" OR "logistic*" OR "operation*" OR "produc*").	TITLE	Scopus, Web of Science	-	September 2021	410 of 6126

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Appendix C. Results of the CA for the Categories, Subcategories and Recording Units

Preliminary remarks on the CA methodology:

- In the course of the auto-analysis, different spellings of recording units were considered and are indicated in the following comprehensive Table A2.
- For some units of analysis, every word ending leads to the expected result. Therefore, we have included all of these word endings by using the word stem combined with an asterisk.
- We ensured that the words are only counted in the relevant context through MAXQDA functionalities that allow counting words exclusively once they appear as whole words separately in the text.

- The categories of the developed framework are indicated in the first column with their subcategories in the second column. To explicitly include all industries at hand for the category 'industry focus', we used the NACE classification of the European Commission called 'EU Code A*38" (Eurostat 2008).
- The column "hits in the sample" indicates all hits for the specific recording unit in the literature set, where several hits per document are also counted several times. The column "no. of articles" indicates the number of individual documents that contain the recording unit(s). The next column, "% articles", shows what percentage of the total literature sample the "no. of articles" represents. The last column, "hits per article", then provides information about the number of hits per article by dividing the total number of hits in the sample by the number of articles. To give the reader an impression, the recording unit 'operations management' was found 223 times in the literature sample and in 54 individual articles. These 54 articles represent 13.2% of the whole sample. Overall, the recording unit had 4.13 hits per article (223 hits divided by 54 articles).

Table A2. Results of the CA for the categories, subcategories, and recording units.

Category	Subcategory	EU Code A*38	Terms	Recording Units	Hits in the Sample	No. of Articles	% of Articles	Hits per Article
Research focus	Operations management			operations management	223	54	13.2%	4.13
				manufacturing system*	54	31	7.6%	1.74
				operations strateg*	1	1	0.2%	1.00
	Supply chain management			supply chain management	1500	283	69.0%	5.30
	Information systems			information system*	449	146	35.6%	3.08
Industry focus	Agriculture	A	Agriculture	agricult*	1196	144	35.1%	8.31
				agri-cult*	0	0	0.0%	0.00
				crop	291	57	13.9%	5.11
				seed*	200	33	8.0%	6.06
				animal*	173	43	10.5%	4.02
				agrifood*	13	8	2.0%	1.63
				agri-food*	534	79	19.3%	6.76
			Forestry	forest*	87	22	5.4%	3.95
				tree*	307	71	17.3%	4.32
			Fishing	fishing	61	19	4.6%	3.21
				aquacultur*	18	6	1.5%	3.00
	Mining	B	Mining	mining industr*	2	1	0.2%	2.00
				quarrying	2	2	0.5%	1.00
	Food	CA	Food	food*	5338	265	64.6%	20.14
				meat	131	60	14.6%	2.18
				fruit*	136	53	12.9%	2.57
			Beverage	beverage*	51	23	5.6%	2.22
				wine	637	46	11.2%	13.85
				beer	9	6	1.5%	1.50
				drink*	20	13	3.2%	1.54
			Tobacco	tobacco	51	5	1.2%	10.20
	Textiles	CB	Textiles	textile*	119	27	6.6%	4.41
				apparel	102	26	6.3%	3.92
				leather	7	6	1.5%	1.17
				fast fashion	24	3	0.7%	8.00
	Wood	CC	Wood	wood*	107	29	7.1%	3.69
				paperwork*	107	55	13.4%	1.95
				paper-base*	40	29	7.1%	1.38
	Chemicals	CE		chemical	232	65	15.9%	3.57
	Pharmaceutical	CF		pharma*	132	76	18.5%	1.74
				drug*	779	104	25.4%	7.49
				medicine*	1175	71	17.3%	16.55
	Metal	CH		metal. steel	270	77	18.8%	3.51
	Electronics	CI		electronics	35	20	4.9%	1.75
	Electricity	D		electric*	108	16	3.9%	6.75
				grid	227	47	11.5%	4.83
				energy	314	79	19.3%	3.97

Table A2. *Cont.*

Category	Subcategory	EU Code A*38	Terms	Recording Units	Hits in the Sample	No. of Articles	% of Articles	Hits per Article
	Water supply	E		Water	119	45	11.0%	2.64
				sewerage	679	157	38.3%	4.32
	Construction	F		construction	128	66	16.1%	1.94
	Wholesale	G		wholesale	2	2	0.5%	1.00
				retail	502	99	24.1%	5.07
	Transportation	H		transportation	614	98	23.9%	6.27
				railway	462	125	30.5%	3.70
				train	2378	225	54.9%	10.57
				truck*	15	8	2.0%	1.88
				logistic industry*	795	201	49.0%	3.96
				logistics industr*	249	69	16.8%	3.61
	Financial	K		financial industry*	1	1	0.2%	1.00
				financial institut*	177	39	9.5%	4.54
				insurance	11	11	2.7%	1.00
				bank*	95	38	9.3%	2.50
				trade	189	84	20.5%	2.25
	Real estate	L		real estate	642	160	39.0%	4.01
				housing	1652	255	62.2%	6.48
				land	51	32	7.8%	1.59
	Other	MA	Legal	legal	169	75	18.3%	2.25
				law*	95	50	12.2%	1.90
			Multimedia	media	578	197	48.0%	2.93
			Humanitarian	humanitarian	338	138	33.7%	2.45
	Public administration	O		public service	309	71	17.3%	4.35
				administration	426	22	5.4%	19.36
	Education	P		education	64	12	2.9%	5.33
				school	149	77	18.8%	1.94
	Human health services	QA		health care	143	70	17.1%	2.04
	Arts	R		arts	115	58	14.1%	1.98
				paint*	50	24	5.9%	2.08
	Automotive			car*	111	32	7.8%	3.47
				automotive	97	46	11.2%	2.11
				vehicle*	501	99	24.1%	5.06
				batter*	89	14	3.4%	6.36
	Aeronautics			aeronautic.	2	1	0.2%	2.00
				aerospace	49	13	3.2%	3.77
				aircraft*	102	24	5.9%	4.25
				airplane*	1	1	0.2%	1.00
				drone*	65	17	4.1%	3.82
				space	510	129	31.5%	3.95
				satellite*	23	15	3.7%	1.53
	Defense			defense	27	19	4.6%	1.42
				military	22	15	3.7%	1.47
				firearm	0	0	0.0%	0.00
	Engineering			engineering	503	142	34.6%	3.54
	Maritime			ship*	53	43	10.5%	1.23
				vessel*	66	14	3.4%	4.71
	Petroleum			petrol*	14	8	2.0%	1.75
				oil	220	83	20.2%	2.65
	Postal			postal	15	7	1.7%	2.14
				parcel*	48	16	3.9%	3.00
	Tourism			tourism	57	14	3.4%	4.07
				travel	78	51	12.4%	1.53
Methods	Conceptual research			conceptual	530	167	40.7%	3.17
				framework	2215	308	75.1%	7.19
				content analysis	10	7	1.7%	1.43
				bibliometric*	10	7	1.7%	1.43
	Survey research			survey*	558	135	32.9%	4.13
				questionnair*	193	60	14.6%	3.22
	Qualitative research			empirical	564	128	31.2%	4.41
				interview*	989	78	19.0%	12.68
				Delphi	170	16	3.9%	10.63
				DEMATEL	253	22	5.4%	11.50
				focus group*	82	11	2.7%	7.45
				panel*	189	27	6.6%	7.00

Table A2. *Cont.*

Category	Subcategory	EU Code A*38	Terms	Recording Units	Hits in the Sample	No. of Articles	% of Articles	Hits per Article
	Case study and action research			case stud*	688	150	36.6%	4.59
				action research	25	6	1.5%	4.17
	Archival research			secondary data	29	12	2.9%	2.42
				archival research	0	0	0.0%	0.00
	Simulation			simulation*	423	102	24.9%	4.15
	Optimization			optimization	272	104	25.4%	2.62
				heuristic*	19	6	1.5%	3.17
Theories	Transaction cost theory			transaction cost theor*	37	12	2.9%	3.08
				transaction cost analysis	9	8	2.0%	1.13
				TCT	4	2	0.5%	2.00
				TCA	33	6	1.5%	5.50
	Resource-based view of the firm			resource based*	9	6	1.5%	1.50
				resource-based*	69	26	6.3%	2.65
				RBV	107	18	4.4%	5.94
	Market-based view			market based*	4	3	0.7%	1.33
				market-based*	8	6	1.5%	1.33
				MBV	0	0	0.0%	0.00
	Principal-agent theory			principal agent*	8	5	1.2%	1.60
				principal-agent*	16	11	2.7%	1.45
				PAT	33	8	2.0%	4.13
	Institutional theory			institutional theory	14	9	2.2%	1.56
	Network theory			network theory	34	17	4.1%	2.00
	Information theory			information theory	4	3	0.7%	1.33
	Innovation diffusion theory			innovation diffusion*	9	8	2.0%	1.13
	Dynamic capability theory			dynamic capability*	14	5	1.2%	2.80
	Technology adoption model			technology adoption model	15	11	2.7%	1.36
				TAM	153	22	5.4%	6.95
				TAM2	0	0	0.0%	0.00
	Technology-organization-environment framework			technology-organization-environment	5	4	1.0%	1.25
				TOE	120	16	3.9%	7.50
Interfaces	Internet of Things			Internet of things	582	223	54.4%	2.61
				IoT	2383	248	60.5%	9.61
				smart device*	41	23	5.6%	1.78
	Artificial intelligence			artificial intellig*	134	81	19.8%	1.65
				AI	256	60	14.6%	4.27
				cognitive	82	21	5.1%	3.90
				neural	42	15	3.7%	2.80
	Big data analytics			big data	637	128	31.2%	4.98
				BDA	7	4	1.0%	1.75
				advanced analytic*	3	3	0.7%	1.00
				data mining	23	17	4.1%	1.35
				data science	19	9	2.2%	2.11
	Cloud computing/manufacturing			cloud comput*	168	83	20.2%	2.02
				cloud manufacturing	23	10	2.4%	2.30
				cloud system	10	5	1.2%	2.00
	Additive manufacturing			Additive manufacturing	64	20	4.9%	3.20
				3D print*	69	25	6.1%	2.76
	Cyber-physical systems			cyber physical*	48	32	7.8%	1.50
				cyber-physical*	57	21	5.1%	2.71
				CPS	11	6	1.5%	1.83
	Robotic process automation			robotic process automation	0	0	0.0%	0.00
				RPA	0	0	0.0%	0.00
	Industry 4.0			Industry 4.0	356	83	20.2%	4.29
				machine-to-machine	25	16	3.9%	1.56
				M”M	19	12	2.9%	1.58
	RFID			RFID	94	69	16.8%	1.36
				radio frequency	39	33	8.0%	1.18
				radio-frequency	1357	206	50.2%	6.59

Table A2. *Cont.*

Category	Subcategory	EU Code A*38	Terms	Recording Units	Hits in the Sample	No. of Articles	% of Articles	Hits per Article
	Robots			robots cobots collaborative robots	14 0 0	9 0 0	2.2% 0.0% 0.0%	1.56 0.00 0.00
	Cybersecurity			cybersecurity cyber security	86 24	32 9	7.8% 2.2%	2.69 2.67
Business Areas	Strategic management			strategic management	14	7	1.7%	2.00
	Procurement. logistics and distribution			procurement warehousing inventory management logistics distribution transportation	301 154 79 4558 1288 2378	110 67 51 287 281 225	26.8% 16.3% 12.4% 70.0% 68.5% 54.9%	2.74 2.30 1.55 15.88 4.58 10.57
	Supply chain risk management			supply chain risk* SCRM	103 46	36 5	8.8% 1.2%	2.86 9.20
	Operations			manufacturing production	1909 2856	235 311	57.3% 75.9%	8.12 9.18
	Finance and accounting			finance accounting supply chain finance	663 242 246	167 90 41	40.7% 22.0% 10.0%	3.97 2.69 6.00
	Marketing and sales			marketing sales aftersales	205 577 1	94 178 1	22.9% 43.4% 0.2%	2.18 3.24 1.00
Potential	Trust			trust*	3250	281	88.4%	11.57
	Security			security. immutability	2494	269	84.6%	9.27
	Transparency			transparency	1886	267	84.0%	7.06
	Traceability			trace*. track and trace. tracking	4744	280	88.1%	16.94
	Disintermediation			disintermediat*. intermediar*	645	146	45.9%	4.42
	Cost savings. increased efficiency			costs. efficien*	3466	274	86.2%	12.65
	Collaboration			collaboration. collaborate	530	128	40.3%	4.14
	Information sharing			information sharing	428	110	34.6%	3.89
	Decentralization			decentralization. decentralized. DApp	1380	225	70.8%	6.13
	Tokenization			tokenization	25	12	3.8%	2.08
	Autonomy			autonomy	21	15	4.7%	1.40
	Smart contracts			smart contract*	3322	256	80.5%	12.98
Barriers	Awareness			aware*	406	143	34.9%	2.84
	Network setup			network setup network cost setup cost	2 7 77	2 5 9	0.5% 1.2% 2.2%	1.00 1.40 8.56
	Know-How			know-how expertise skill	19 153 158	12 68 72	2.9% 16.6% 17.6%	1.58 2.25 2.19
	Data disclosure			data disclosure reluctance	6 16	5 11	1.2% 2.7%	1.20 1.45
	Missing management support			top management support	47	14	3.4%	3.36
	Lack of trust			lack of trust	120	67	16.3%	1.79
	Unclear governance			governance	535	129	31.5%	4.15
	Missing standards			missing standard no standard standardization standardisation	7 14 163 51	5 12 72 16	1.2% 2.9% 17.6% 3.9%	1.40 1.17 2.26 3.19
	Legal uncertainties			legal issue* legal uncertain* legal complianc* legal concern*	10 11 4 3	9 4 4 2	2.2% 1.0% 1.0% 0.5%	1.11 2.75 1.00 1.50

Table A2. *Cont.*

Category	Subcategory	EU Code A*38	Terms	Recording Units	Hits in the Sample	No. of Articles	% of Articles	Hits per Article
	Regulatory uncertainties			regulatory*	581	143	34.9%	4.06
Adoption	Proof of concept			proof of concept POC	89 31	42 7	10.2% 1.7%	2.12 4.43
	Use case			use case*	660	145	35.4%	4.55
	Productive application			productive use productive application	11 0	4 0	1.0% 0.0%	2.75 0.00
Consensus	Proof-of-Work			Proof-of-Work POW	92 165	62 69	15.1% 16.8%	1.48 2.39
	Proof-of-Stake			Proof-of-Stake POS	31 97	24 51	5.9% 12.4%	1.29 1.90
	Proof-of-Authority			Proof-of-Authority POA	19 86	8 17	2.0% 4.1%	2.38 5.06
	Byzantine Fault Tolerance			Byzantine Fault Tolerance BFT	87 38	56 24	13.7% 5.9%	1.55 1.58
	Proof-of-Elapsed-Time			Proof of Elaps* POET	14 43	11 14	2.7% 3.4%	1.27 3.07
Platform	Ethereum			Ether*	1656	208	50.7%	7.96
	Bitcoin			Bitcoin*	1038	282	68.8%	3.68
	Hyperledger			Hyperledger	777	141	34.4%	5.51
	Multichain			Multichain	10	9	2.2%	1.11
	R3 Corda			Corda	13	11	2.7%	1.18
	Cardano			Cardano	2	2	0.5%	1.00
	EOS			EOS	10	8	2.0%	1.25
	Iota			Iota	22	10	2.4%	2.20
	OpenChain			OpenChain	1	1	0.2%	1.00
	Tron			Tron	2	2	0.5%	1.00
	Tezos			Tezos	1	1	0.2%	1.00
	Stellar			Stellar	11	8	2.0%	1.38
	BigChainDB			BigChain*	84	15	3.7%	5.60
	Lisk			Lisk	1	1	0.2%	1.00
	Quorum			Quorum	58	20	4.9%	2.90
Network configurations	Public blockchain			public blockchain public chain public system	326 33 3	130 18 3	31.7% 4.4% 0.7%	2.51 1.83 1.00
	Private blockchain			private blockchain private chain private system	378 27 3	106 11 1	25.9% 2.7% 0.2%	3.57 2.45 3.00
	Permissioned			permissioned	554	140	34.1%	3.96
	Permissionless			permissionless	181	65	15.9%	2.78
	Consortium			consort*	749	124	30.2%	6.04
Other	Green			green	629	98	23.9%	6.42
	Sustainability			sustainabil*	1402	152	37.1%	9.22
	Environment			environmental	774	157	38.3%	4.93
	Cryptocurrencies			cryptocurrenc* token*	660 1077	188 118	45.9% 28.8%	3.51 9.13

For some units of analysis, every word ending leads to the expected result. Therefore, we have included all of these word endings by using the word stem combined with an asterisk.

Further Statistical and Bibliometric Analyses

MAXQDA uses classic multidimensional scaling to derive clusters of codes and position them on a map. Therefore, a similarity matrix of codes is calculated and converted into a distance matrix. In the conversion process, column sums are calculated, and the maximum of column sums is defined as a maximum similarity. In each cell, the similarity of two codes is subtracted from this maximum. This calculation means that a distance of

0 indicates that two codes only occur together, i.e., never without the other. A distance corresponding to the maximum means that these codes never occur together. The distance matrix is mapped into two dimensions, where the positions of the clusters are based on a hierarchical cluster analysis of the positions on the two-dimensional surface and unweighted average linkage as the clustering method. Figure A1 indicates the code map of the codes in our literature sample.

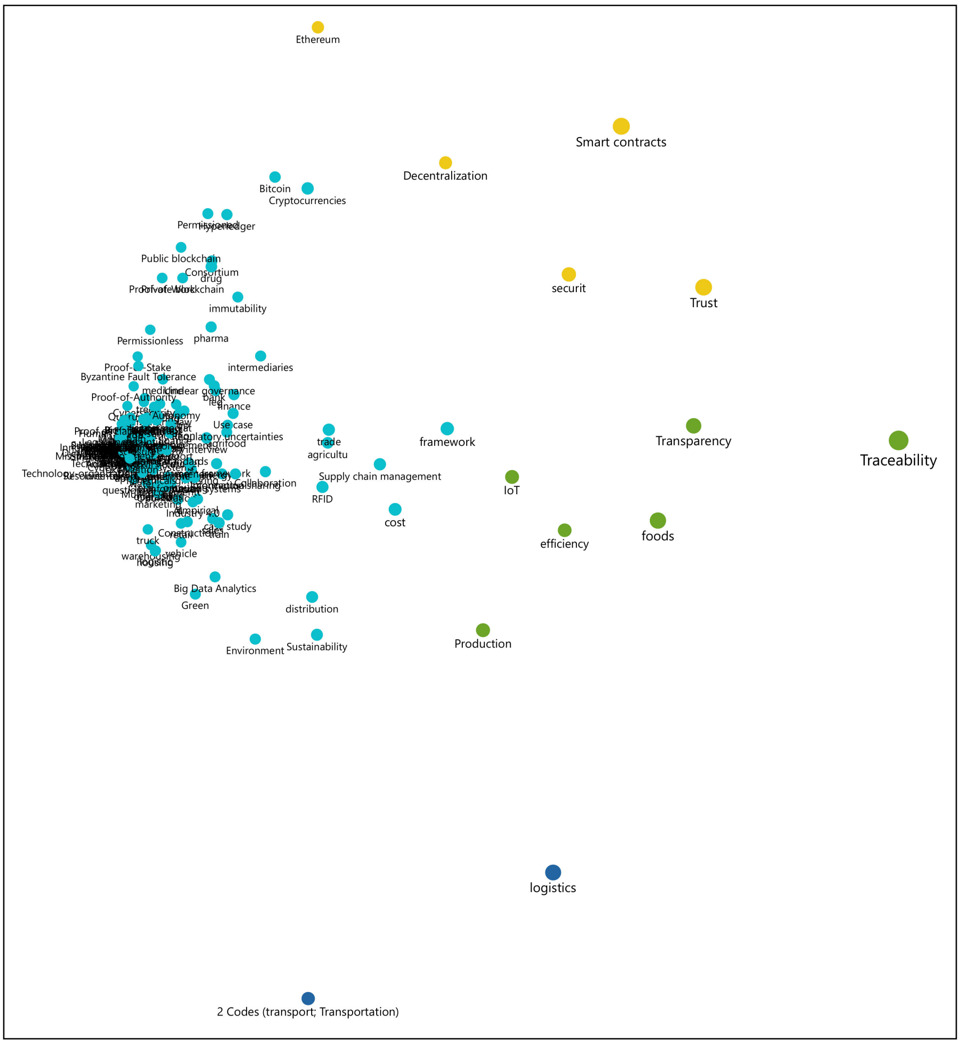

Figure A1. Code map of the proximity of codes in the same document for all recording units and a maximum distance of 2 paragraphs and 4 clusters.

We also used the import feature of the MAXQDA software to analyze the RIS file generated from all 410 documents that includes the keywords of each article. After filtering out single descriptors such as "4.0", the word cloud in Figure A2 was generated. The thickness of the font represents the frequency of the keywords.

Figure A2. Word cloud of keywords used in the literature set.

Bibliometric analysis was conducted using the VOSviewer software [332], where we imported the same RIS file of all 410 articles in our literature set. The co-occurrence of keywords was calculated and mapped, with a threshold of five, i.e., the minimum number of occurrences of each keyword to be included in the map was set to five. Figure A3 shows the generated map, with each node representing one keyword and the scale indicating the frequency of occurrences. Links between the nodes indicate a co-occurrence in the articles. The following clusters were derived by the VOSviewer co-occurrence matrix, with a pre-defined minimum cluster size of four items (see Table A3):

Table A3. Clusters identified in the VOSviewer co-occurrence of keywords result.

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
big data	case study	barriers	digitalization	distributed ledger technology
blockchain	distributed ledger	blockchain technology	industry 4.0	food safety
Hyperledger fabric	Ethereum	dematel	ipfs	food supply chain
IoT	operations management	supply chain finance	smart contract	traceability
literature review	security	supply chain management	supply chain	traceability system
logistics	smart contracts	sustainability		
supply	technology	transparency		
supply chains	visibility			
trust				

Lastly, we calculated the co-authorship of our literature sample for all authors with at least two publications (using "association strength" normalization and weights based on "documents" as the VOSviewer parameters), which is shown in Figure A4.

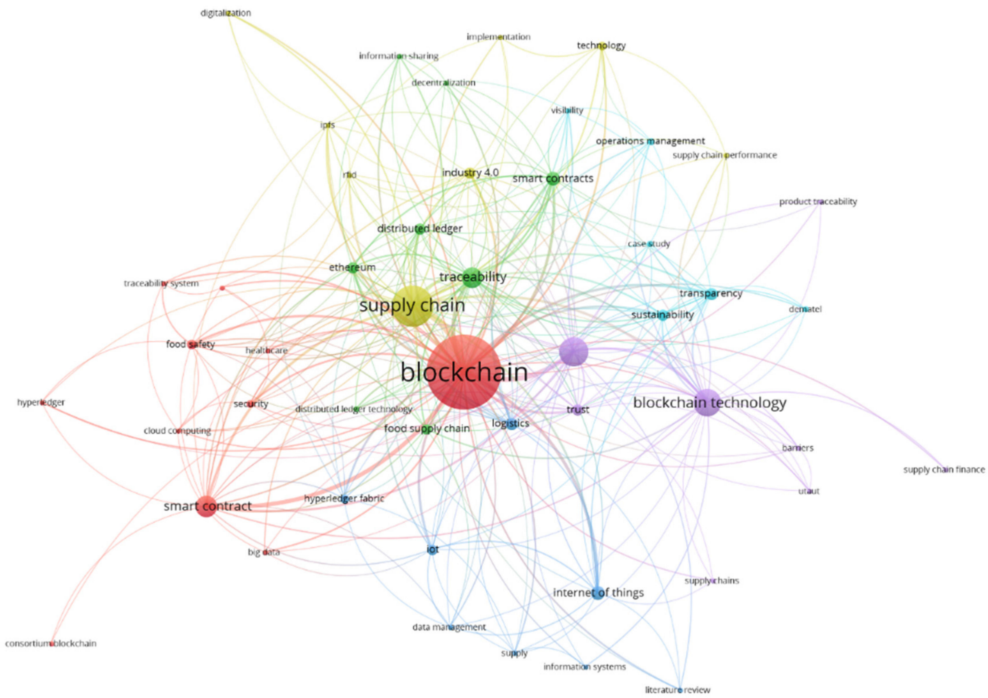

Figure A3. Co-occurrence of keywords in the literature sample (using the VOSviewer software tool).

Figure A4. Co-authorship in the literature sample (using the VOSviewer software tool).

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