big data and cognitive computing

Review

Insights into Industrial Efficiency: An Empirical Study of Blockchain Technology

Kaoutar Douaioui [1,*] and Othmane Benmoussa [2]

[1] Laboratory of Engineering, Industrial Management and Innovation, Faculty of Sciences and Techniques, Hassan 1st University, Settat 26000, Morocco
[2] Euromed Polytechnic School, Euromed University of Fes, Fez 30030, Morocco; o.benmoussa@ueuromed.org
* Correspondence: kaoutar.douaioui@gmail.com

Abstract: Blockchain technology is expected to have a radical impact on most industries by boosting security, transparency, and efficiency. This work considers the potential benefits of blockchain-focused applications in industrial process monitoring. The research design facilitates a detailed bibliometric analysis and delivers insights into the intellectual structure of blockchain technology's application in industry via scientometric approaches. The work also approaches numerous sources in various industrial sectors to identify the transformative role of blockchain in industrial processes. Aspects such as blockchain technology's impact on industrial processes' transparency are discussed, while the paper does not ignore that success stories in applying blockchain to industrial sectors are often exaggerated due to a highly competitive environment that the cryptocurrency domain has become. Finally, the work presents major research avenues and decision-making areas that should be tackled to maximize the disruptive potential of blockchain and create a secure, transparent, and inclusive future.

Keywords: blockchain technology; security; transparency; industrial efficiency; scalability; bibliometric analysis

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1. Introduction

In the context where digital innovation is a powerful tool for future, blockchain technology emergence aims to challenge the conventional trust and transactional security [1]. Blockchain, born in 2008 as the foundational technology of Bitcoin, has since then had a remarkable evolution, transcending its origins to become a disruptive force reforming industries and revolutionizing the dynamics of trust in decentralized networks [2]. In essence, blockchain represents a decentralized, distributed ledger system aiming to secure transactions across a network of computers in a tamper-proof and transparent way [3].

Blockchain technology from its creation to its current state reflects technological resilience and transformative potential [4]. Initially designed as a tool to facilitate peer-to-peer cryptocurrency transactions, blockchain has evolved into a diverse domain with applications surpassing financial transactions [5]. In the past decade, blockchain technology has garnered more attention in academic interest and industry investment due to its capacity to revolutionize processes, enhance transparency, and foster trust in digital ecosystems [6].

The exponential growth of the global blockchain market underscores the big impact and the widespread adoption of this transformative technology [7]. At this context, the annual growth rate of 59.9% is estimated from 2023 to 2030, and the market may reach USD 469.49 billion by the end of the decade [7]. This exponential rise highlights the necessity for both of researchers and industry decision makers to explore the revolution potential of blockchain technology for research and development (R&D) strategies, legal frameworks, and business innovation [8].

In this sense, the principles of blockchain technology can be summarized as follows: decentralization (removing central control), transparency (visible transaction histories), and cryptographic security (secure data with encryption). This can change the ways transactions are verified and recorded [9]. Blockchain holds the potential to streamline processes and reduce costs by eliminating the need for intermediaries and establishing trust through consensus mechanisms [10] and minimizing risks across different industries from supply chain management, finance, and healthcare to transportation and government services [11].

However, the transformative potential of blockchain technology surpasses its immediate applications to offer a gateway for innovation and collaboration [12]. The decentralized characteristic of blockchain networks facilitates peer-to-peer interactions, enabling individuals and organizations to engage in secure transactions without the need for intermediaries [13]. This can facilitate the access to financial services, digital assets, and information, empowering individuals and fostering a more inclusive and equitable digital economy [14]. Moreover, governments and organizations around the world recognize the strategic importance of blockchain technology and its impact in terms of investments in research and development as well as in policy initiatives [15]. National and international funding programs underscore the global dynamics behind blockchain innovation and diffusion, such as the European Union blockchain observatory and forum and research programs FP7 and Horizon 2021–2027 [16].

Blockchain technology has the potential to offer a transformative lens through which the future of digital innovation and decentralized networks can be envisioned [17]. This article delves into the multifaceted dimensions of blockchain technology by examining its theoretical foundations, practical applications, and implications for future innovation and development.

This study aims to unlock valuable insights that will inform academic discourse, industry practices, and policy decisions, through a comprehensive analysis of the blockchain technology literature and its impact across industrial sectors. This work aims to resolve the complexities of blockchain technology and give future directions for a more inclusive, transparent, and secure digital future, by employing innovative methodologies to address the following research questions:

- Q1. How has the research field grown annually and what is the trend?
- Q2. How does the collaborative research and engagement of authors from various countries exemplify the global influence and significance of blockchain technology in industrial applications?
- Q3. How is blockchain technology contributing to enhanced industrial efficiency?
- Q4. What are the primary challenges hindering the widespread adoption of blockchain in industry?
- Q5. How does the integration of blockchain, AI, and IoT enhance industrial operations?

This study conducts a pioneering bibliometric analysis of the integration of blockchain technology across multiple sectors. It utilizes cutting-edge bibliometric metrics, including publication growth analysis, co-citation networks, and interdisciplinarity scores, that yield novel findings regarding the changing dynamics of blockchain applications. Specifically, this study distinguishes itself by identifying key authors and seminal works, mapping interdisciplinary research dynamics, and performing a spatiotemporal impact analysis that identifies the most influential regions and institutions. This analysis is innovative through its all-encompassing nature, which quantifies the penetration of blockchain into industrial processes and its contribution to enhancing existing processes and prospects when coupled with AI and the IoT. In doing so, it not only emphasizes the collaborative nature of technological change but also emphasizes well-researched areas, thereby offering novel insights in the form of research gaps or policy directives. Ultimately, the findings present a detailed and thoughtful perspective, which is not only informative from an academic standpoint but can also prove invaluable when utilized in creating focused policies for each sector. The combination of novel methodology and the exploration of an important academic area enables this study to make a significant contribution to the field of blockchain research. As such, this study should be seen as exemplary and should guide future analyses of the impact of blockchain on chosen sectors.

This article is structured as follows: We begin with a review of related works in the studied field in the Section 2. Subsequently, we detail the query employed and the steps taken for data collection, expounding on the research methodology in the Section 3. Following this, we present the findings of this study in the Section 4, which are analyzed in the same section. The subsequent section delves into the discussion of the results obtained in this study, culminating in the presentation of conclusions in the final section.

2. Literature Review

2.1. Introduction to Blockchain Technology

Blockchain technology is a disruptive phenomenon that has transformed industries and civilizations [18]. Blockchain is a creative modification of distributed ledger technology that efficiently processes financial transactions. The disruptive technology keeps data reliable and secure by storing them across a network of computers in a decentralized way [19]. The term "blockchain" describes how the data are structured; they are comprised of a chain of blocks managed by a peer-to-peer network, where each participant has equal authority and can directly interact with others without a central administrator, enabling tracking of transaction records [20,21].

2.2. Key Characteristics of Blockchain

In the literature, there are several key characteristics that power blockchain technology, such as decentralization, which can eliminate the single points of control, enhancing the network resilience and security [22]. There is also transparency that can be achieved through publicly accessible ledgers, and it can provide the stakeholders with the opportunity to verify transactions [23]. In addition, there are security mechanisms that can be used in cryptographic protocols to protect data integrity and confidentiality [24]. Moreover, the technology's immutability makes the transactions unalterable and undeletable, maximizing the trust and reliability of blockchain technology [25].

2.3. Application of Blockchain in Various Fields

Blockchain technology plays an essential role in various industries, providing a secure, transparent, and efficient approach. The finance industry benefits from streamlined transactions and risk mitigation with blockchain-as-a-service platforms. The IoT field flourishes due to the increased security of peer-to-peer transactions on the network. Social services, on the other hand, have become more transparent and accountable in fields such as land registry and energy distribution. Thus, blockchain introduces an innovative flow to the traditional approaches and enhances trust in the digital environment.

In terms of finance, blockchain develops transparent and efficient transactions, cuts costs, and helps eliminate risks associated with banking. DLT ensures secure and tamper-free record holding, while the application of such technology helps eliminate fraud and increase accountability in the finance field. Smart contracts derive contracts functionally and initiate efficient operations regarding loan distribution and trading agreements. The application of cryptographic procedures also facilitates the safety of data and transactions. Projects such as Ubin and We.trade are examples, as the former is a Singapore research initiative for distributed ledger technology (DLT) implementation in clearing and settling payments and securities, and the latter is a digital platform for trade finance solutions powered with blockchain.

In terms of IoT, blockchain offers the same characteristics yet additionally helps maintain efficient connectivity between devices. Blockchain also provides numerous innovations for social services to address societal challenges with its decentralized framework and cryptographic security. Blockchain-based land registration systems ensure a transparent and tamper-proof recording of real estate rights and transactions, reducing real estate fraud and corruption. Additionally, digital currencies and cryptographic tokens stimulate the use of renewable energy sources such as solar-coin, which rewards solar energy producers with digital currency. Blockchain ensures safe and transparent transaction in social services such as education, health care, and governance, promoting trust and responsibility.

2.4. Distinction between Public and Private Blockchains

Understanding the differences between public and private blockchains is essential for recognizing the potential of the technology. Public blockchains allow for maximum openness and inclusivity, while private blockchains provide a more tailored solution for companies seeking greater privacy and control. Thus, this report aids in the choice of a blockchain platform most tailored to specific organizations' needs while also complying with the regulator's policy.

On the one hand, public blockchains, i.e., permission-less blockchains, are the epitome of democratized decentralization and openness. Public blockchains typically operate in an open environment where anyone can participate. These types of blockchains maintain openness and are generally seen as democratized playing fields for operation. Groundbreaking use cases like Bitcoin and Ethereum have already shown a decentralized financial system, with programmable smart contracts that let anyone in the world experience various services if they have an internet connection [26,27]. Public blockchains have the highest security due to their strong consensus algorithms and unchanging ledger structures, making them ideal for applications that require transparency, censorship resistance, and a completely accessible network [28].

Private blockchains, in contrast, known as permissioned blockchains, do exactly the opposite. Private networks are less inclusive, allowing only those invited to participate, usually by a central authority or group of shareholders. As a consequence, factors such as data protection, scalability, and regulatory constraints are prioritized, making private blockchains more suitable for enterprise-level deployments and consortium partnerships. The level of control over network rules, access rights, and transaction data capability makes private blockchains beneficial for use cases such as supply chain management, healthcare, and finance, where existing regulations and highly confidential data will be most influential. One example is tailored blockchain solutions like Hyperledger Fabric and R3 Corda, which allow the network's participation to be regulated and transactions conducted in a way that is private to all participants. This way, it is possible to ensure sensitive information will not be misused while still enabling it to benefit from blockchain security and speed [26].

The next type comprises hybrid blockchains, which combine the best aspects of public and private blockchains. These rare systems may be tailored to a firm's specific needs while also offering a level of control over the information. Therefore, the use of private blockchains is recommended because this system allows the company to control and regulate the sensitive information while utilizing all other blockchain services.

2.5. Blockchain Technologies Challenge

Due to its decentralized nature, blockchain technology has garnered significant attention for its security features and potential applications across various sectors [29,30]. However, because blockchain has been widely adopted, the Ethereum blockchain ecosystem, for example, suffers from scalability issues [20]. Accordingly, one research study attempted to explore new solutions like zero-knowledge (ZK) rollup, which offers fast and secure transactions with computational costs [31]. Smart contracts, another fundamental aspect of the blockchain technology, face implementation challenges within organizations. The current state of blockchain technology research involves efforts to explore educational applications [26]. Additionally, the blockchain potential extends beyond finance, garnering attention among software developers as a distributed ledger for tracking digital asset origins [29]. In spite of differences in architecture, security, and efficiency among the different configurations of the blockchain systems [32], they hold promise for improving decision-making processes, such as in politics by facilitating secure and transparent electronic voting systems [33].

2.6. Bibliometric Work in Blockchain

The bibliometric study of the blockchain technology field has increased tremendously, particularly in terms of the number of blockchain-related research articles [34]. These research works discuss the growth, trends, and impacts of new developments in blockchain science, including the number of blockchain-related research articles, patents, and citations. This can help to provide an in-depth awareness of the evolution of disruptive technologies through key areas of research, influential authors, and emerging dynamics to realize the adoption and employment of blockchain solutions in non-academic settings. Furthermore, it supports them in navigating the unknowns and obtaining a better idea of how to fulfill their objectives as guided by the study of multiple themes and helps them realize the gaps in their innovations and their counterparts. The current bibliometric study provided in this work's examination is rigorous and aims to provide more valuable knowledge about the applications of blockchain and industry, including the critical topics, significant stakeholders, and emerging dynamics [35].

3. Materials and Methods

3.1. Data Collection

Bibliometric analysis is a well-known and accurate tool used to analyze and decompose large scientific datasets. It helps identify emerging fields and track field growth [36]. The bibliometric software helps to accurately classify and review a vast amount of information captured in studies over a specified time period. Unlike the systematic literature reviews, which often apply qualitative methodologies and are susceptible to interpretation biases due to researchers' diverse academic and disciplinary backgrounds, systematic reviews and bibliometric analyses apply statistical methods to research and thus are not at risk of bias [34]. On the other hand, datasets of the articles used in bibliometric analyses can be exported from multiple databases, such as Web of Science (WoS), Scopus, PubMed, and Google Scholar. Most disciplines have wider coverage in Google Scholar. Web of Science and Scopus retrieve a quite comparable coverage of the literature [37]. Different databases, such as Web of Science, offer an array of methods that influence search results, including general, cited reference, and advanced search [37]. All three databases—Google Scholar, Scopus, and Web of Science—allow monitoring, calculating, processing, and analyzing cited references [37]. For example, WoS, includes almost 10,000 journals, is Science Citation Index Expanded and has seven distinct citation databases that harvest information like book series, conference proceedings, journals, reports, and books [37]. The WoS database is one of the largest databases available, and it streams articles from high-quality research literature [38]. It also has a diverse selection of superior journals and high-quality publications that have been previously peer-reviewed by experts in their specific disciplines [39], and it is regarded as one of the most trustworthy sources of research articles [40]. Therefore, in this study, we used the Web of Science among these databases because it covers nearly all major scientific disciplines and includes many top-tier journals, making it the most comprehensive and effective way to ensure that there is sufficient literature on intelligent software testing [38]. The consistent indexing and citation data among all these journals aid in a standardized and reliable comparison between articles, authors, and journals, making the bibliometric analysis reliable and valid [41].

The papers used in this study were published by well-established publishers, such as MDPI, IEEE, Elsevier, and Springer. These publishers have contributed significantly to enhanced scientific research and, consequently, are deeply associated with the publishing of quality papers in various fields not limited to computer science, engineering, medicine, etc. This database search was conducted on 4 January 2024, and the main goal was to collect bibliometrics on the topic of blockchain industrial applications. Table 1 below shows the keywords search used for the research.

This search strategy around the "Web of Science Core Collection" database was developed based on the business digital maturity level as well as on the number of indexed articles, authors, thematic areas, types of documents, scientific areas, and keywords. The methodology employed (Figure 1) is descriptive–analytical, based on a deductive–inductive approach in which specific parameters were excluded from the total results obtained. For our bibliometric analysis of blockchain in industrial applications, we sorted the studies published between 2020 and 2024, with extreme caution to narrow down to the most updated innovations and perspectives, given the fast pace of evolution in blockchain technology. Only articles in the English language were considered to support accessibility and consistent interpretation. Further, we focused on peer-reviewed articles and review papers to support high scientific quality through rigorous scrutiny by subject matter experts. All selected articles had to demonstrate a high level of methodological quality, including support coverage of data collection sources, analytical methods, and validation procedures, guaranteeing the reliability and scientific validity of their insights. We also included articles from journals with a high impact factor to identify influential scholarly work that significantly drives thought in the target field. This selection provides our analysis with a robust foundation from the most credible and current publications currently driving the state of the art in blockchain applications.

Table 1. Keywords and query.

Category	Keywords
Blockchain	("Blockchain " OR "Distributed Ledger") AND
Big data	("Big Data" OR "Data Analytics") AND
Industrial applications	("Industrial applications" OR "Manufacturing" OR "Process control" OR "Quality analytics")

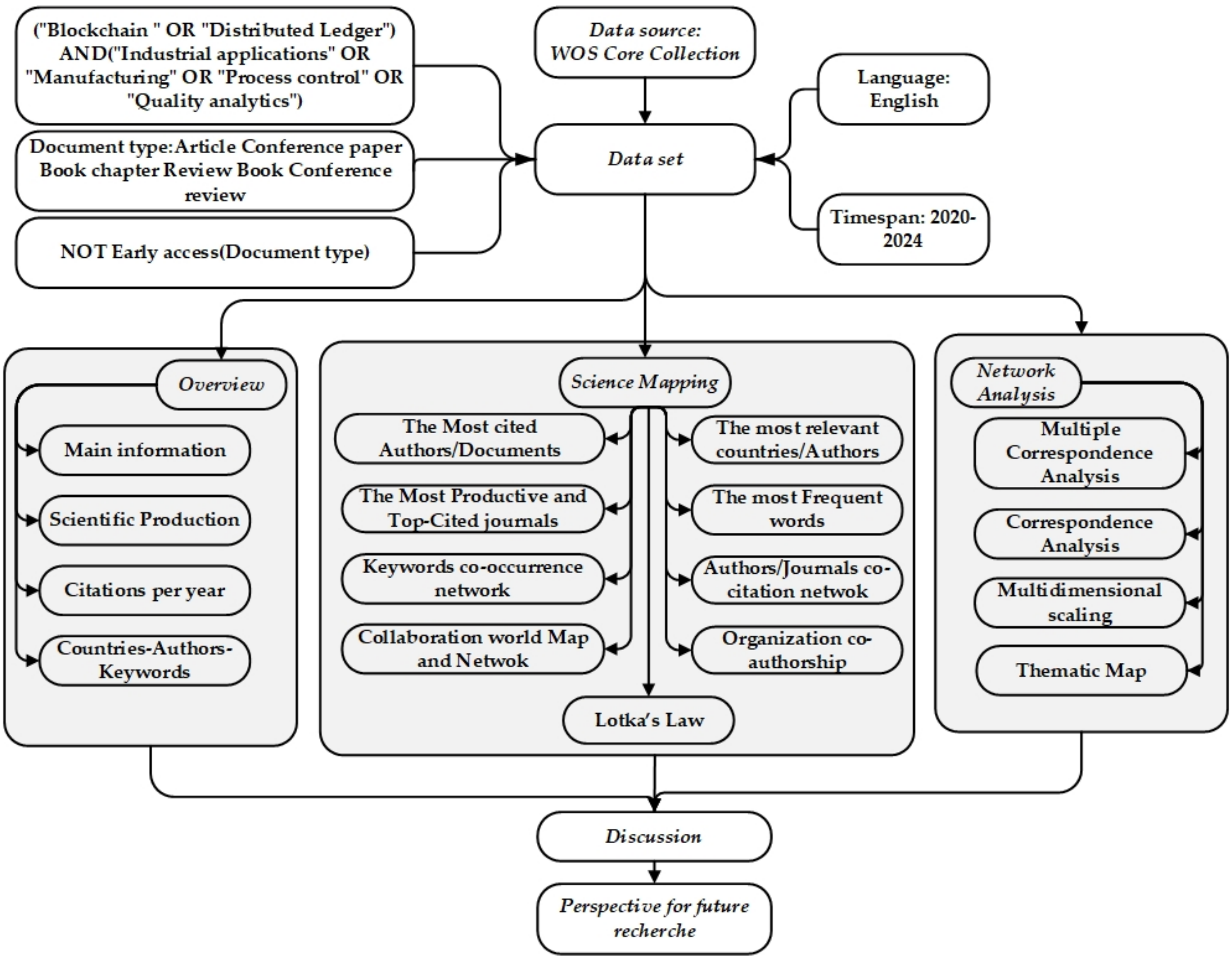

Figure 1. Flow chart of the bibliometric analysis.

3.2. Bibliometric Analysis Methodology

In order to rigorously investigate the vast and fragmented scholarly field of blockchain technology within industrial applications, we conducted a bibliometric analysis through advanced tools and techniques. In doing so, we are able to quantitatively measure and depict the progression, influence, and integration of the field. Through the incorporation of the Bibliometrix R Package and VOSviewer software, this section showcases the thematic foundations and progression of research in addition to visualizing the infrastructural communication between researchers.

3.2.1. Software and Analytical Tools

In the present work, the scientific-mapping analysis was conducted with the help of the Bibliometrix R Package (R 4.3.2) and VOSviewer software (1.6.20). The two tools facilitated the visualization of complex bibliometric data and rigorous quantitative analysis, respectively. The contemporary software aided in effectively mapping the intellectual landscape of blockchain research by capturing numerous patterns, relationships, and trends in the field.

- VOSviewer: VOSviewer is a leading software designed to create and visualize bibliometric networks. In this analysis, VOSviewer was used to develop maps-based network data drawn through networks via co-authorship, co-citation, and keyword co-occurrence networks. Visualizing this network plays a significant role in identifying the major research clusters and top-rated works and authors in the blockchain domain. The software is also helpful for handling large datasets and complex networks, which were helpful in understanding the blockchain networks, relationships, and dilemmas that exist in the domain. It helps to understand the ecosystem and identify significant work and authors;
- Bibliometrix R Package: This bibliometric software is one of the comprehensive toolsets used to perform bibliometric analysis quantitatively. There are a number of different analyses achieved via basic data manipulation and complex network analysis provided in the package. In the bibliometric analysis of blockchain research, this package plays a significant role in conducting citation analysis, collaboration pattern tracing, and publication trend analysis. The analytical software helps to quantify blockchain research, the period for which it has been in existence, how it evolved, and the influence of blockchain research in the field of information science.

3.2.2. Analytical Techniques

In our study, we used a variety of computational techniques to explore the field of blockchain research thoroughly. As a result, we were able to uncover underlying dynamics between scholars, observe the ebbs and flows of publication trends, and discover hidden themes. Combined, these processes each offer their unique perspectives on the structural and thematic intricacies of blockchain studies, thus creating a cohesive picture of its current state and potential future directions.

- Co-citation and Collaboration Analysis: It involves the examination of how documents or authors cite each other in the literature. This technique reveals the foundational structures and thought leadership in the blockchain domain. Initially, it lays bare the subordinate themes that hold disparate studies together, revealing the more dominant ones. In addition, it provides a peek into the collaborative networks and schools of thought prevalent in blockchain research;
- Publication Trends and Citation Analysis: We used the frequency and distribution of publications to analyze publication trends and their expansion over time. This scope highlighted the most important research and tracked the idea shifts and innovations in the development of blockchain as a field of study. This analysis also provided the development methodology shifts and new and potential avenues to explore in the future;

- Content Analysis: Text mining was carried out, analyzing the text of publications to discover research benchmarks and new discourse frameworks. The purpose of this analysis was to decode the thematic structure of blockchain and identify the dominant paradigm and emerging topics. This method enabled us to observe current thematic trends and anticipate future trends in blockchain technology.

3.2.3. Justification of Methods

The choice of bibliometric tools and analysis methods is fully coherent with our goal of exploring the evolution and the intellectual structure of blockchain research in the context of industrial practice. The purposeful use of advanced bibliometric software such as VOSviewer and the Bibliometrix R Package ensures the meticulous data manipulation and extensive analytical capabilities necessary to dissemble complex data assets and support detailed network analysis and thematic consolidation. These tools support highly targeted data analysis that minimizes the potential for data exclusion and the subjectivity of results, while the visualization of networks also helps to interpret the findings and acknowledge the key contributors and driving papers. Moreover, the possibility for the detailed analysis of trends contributes to our understanding of the developmental patterns and the changing structures of the studied theme, which together present a broader perspective on the state of research on the subject. In doing so, this method does not just reveal the current state but also outlines the gaps and creates a valid contribution to the field by combining comprehensive knowledge-based analysis and delineating areas for future research for both academia, industrial operators, and policymakers.

4. Results and Analyze

4.1. Overview

4.1.1. Main Information

The result included in Table 2 presents the primary data concerning the examination of blockchain industrial applications as gathered from the Web of Science Database. It involves vital aspects such as the duration of research, the journals and documents included, average citation count, references, and the yearly growth rate. Furthermore, these scientific research data include the keywords utilized by authors and also Keywords Plus, which is a specific characteristic of the Web of Science database. Keywords Plus are added to the most significant part of arranged database records; this extends the keywords provided by the author with extra terms that are taken from the titles of the articles referenced in the bibliography of the paper. Additionally, these data include the authorship structure of documents, which is distinct between single-authored or multi-authored works. This aspect elucidates the collaboration metrics such as the count of single-authored documents, the average number of authors per document, and the rate of international co-authorship.

Table 2. Main information.

Main Information about Data	
Timespan	2020:2024
Sources (Journals, Books, etc.)	245
Documents	607
Annual Growth Rate %	−54.82
Document Average Age	2.2
Average Citations per Doc	20.32
References	26.710
Document contents	
Keywords Plus (ID)	691
Author's Keywords (DE)	1588

Table 2. *Cont.*

Main Information about Data	
Authors	
Authors	1740
Authors of Single-Authored Docs	33
Authors collaboration	
Single-Authored Docs	35
Co-Authors per Doc	3.56
International Co-Authorships %	37.56
Document types	
Article	354
Article; Book Chapter	2
Article; Early Access	55
Article; Proceedings Paper	3
Proceedings Paper	98
Proceedings Paper; Retracted Publication	1
Review	90
Review; Early Access	4

4.1.2. Annual Scientific Production

The next result concerns the Annual Scientific Production from 2020 to 2023, displayed in Figure 2, where there is an upward trend that is likely to indicate a phenomenal growth in scientific output. The increase in the number of articles published within these four years, starting from 96 in 2020 to 205 in 2023, can be explained by many interconnected factors proving the popularity and wider application of the technology. Firstly, blockchain became more popular in various industries, not only in the aspect of financial transactions but also data processing in sectors requiring transparency and security, like healthcare or supply chain. The increased scope of blockchain implementation has caused academic interest in the potential uses of the technology. In addition, technological advancements of blockchain, including its scaling potential and integration with other technologies like IoT, have also opened up new research possibilities. Increased funding and cooperation can be noticed, with many efforts supported by both the public and private sectors to enhance blockchain research. Many global projects and organizations have also been established, and blockchain research centers were opened throughout the globe during this period. The regulatory interest quickly arose, governments and institutions struggled to understand and regulate blockchain, causing academic interest. Moreover, educational interest has also grown, which can be traced in new educational programs, which also triggered academia's increased interest. All these factors show that this was a period of significant growth and exploration in blockchain research and prove that the technology has a considerable perspective over various fields. Thus, this upward trend is also corroborated by the computation of annual growth rates, which clearly showed an annual increase. Moreover, the cumulative growth rate of 89.08% in this four-year period seemed to underscore the significant overall growth in scientific publications in blockchain research. These annual growth rates not only indicate a growing interest by scholars in exploring ideas related to blockchain but also mark a growth in recognition of the importance and applicability of blockchain technologies in different industries. This upward trend in scholarly events and academic discourses seems to indicate clear evidence of the dynamism and potential in the field.

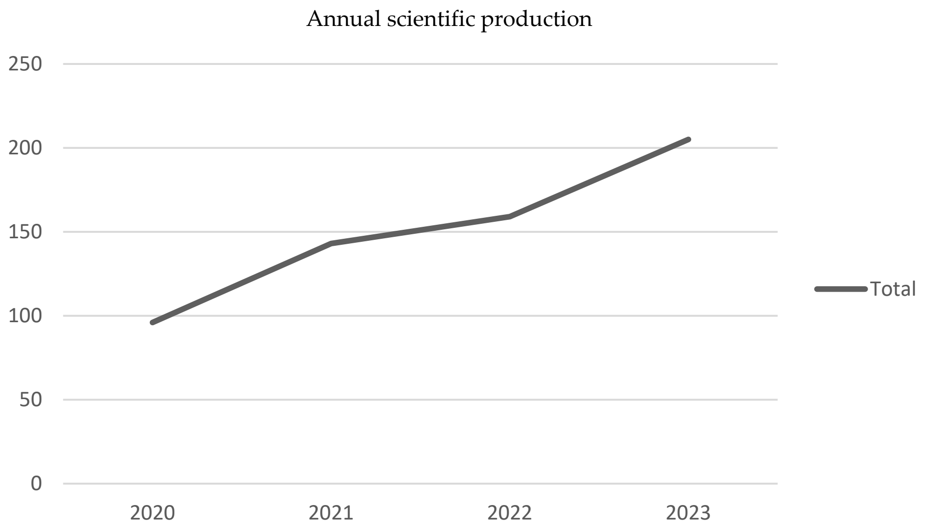

Figure 2. The annual scientific production in the field of blockchain industrial applications.

4.1.3. Average Citations per Year

The intricate dynamics of average citations per year are illustrated in Figure 3. The graph compares the speed of the progression between articles and citations from year to year. The sum of articles from 2022 to 2023 increased by 28.9%, and the sum of citations from 2021 to 2022 increased by only 11.2%. Overall, while the number of publications grew, the number of citations per article grew at a relatively normal pace. More specifically, the trend implies that new articles are being cited more quickly, while older articles are losing their relevance over time. Due to the rapidly evolving nature of blockchain, product and process innovations often make older research useless for guiding future work. Finally, the field of citation practices might change, introducing new metrics or social norms within the blockchain space. Therefore, the decrease in the number of citable years is a threat to research longevity in blockchain studies and underscores the shifting nature of the field that always has to adjust to the aforementioned trends and practices to stay relevant.

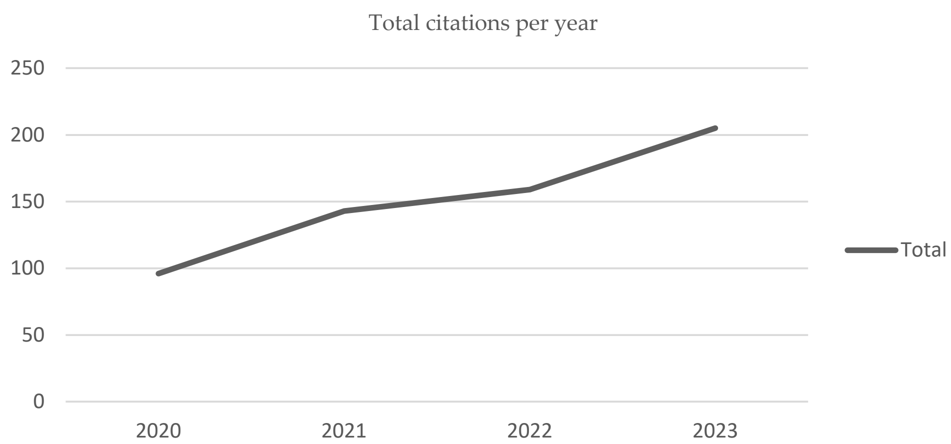

Figure 3. The average citations per year in the field of blockchain industrial applications.

4.1.4. Relationship between Countries, Authors, and Titles

The described three-field plot illustrated in Figure 4 serves to provide visualization of the sophisticated interplay between the concerned nations, authors, and document keywords in the area of blockchain industrial applications. As the figure shows, the pattern is evident—a vast number of research articles in the blockchain domain are led and published by authors from Saudi Arabia, China, and the United Arab Emirates. This pattern implies that, although representing a global effort and cooperation in researching blockchain industrial applications, authors from these three countries are most heavily involved in shaping the overall discussion of blockchain technology. Combined with the visual expression and geopolitical export, the three-field plot effectively illustrates the dynamics of blockchain industrial applications.

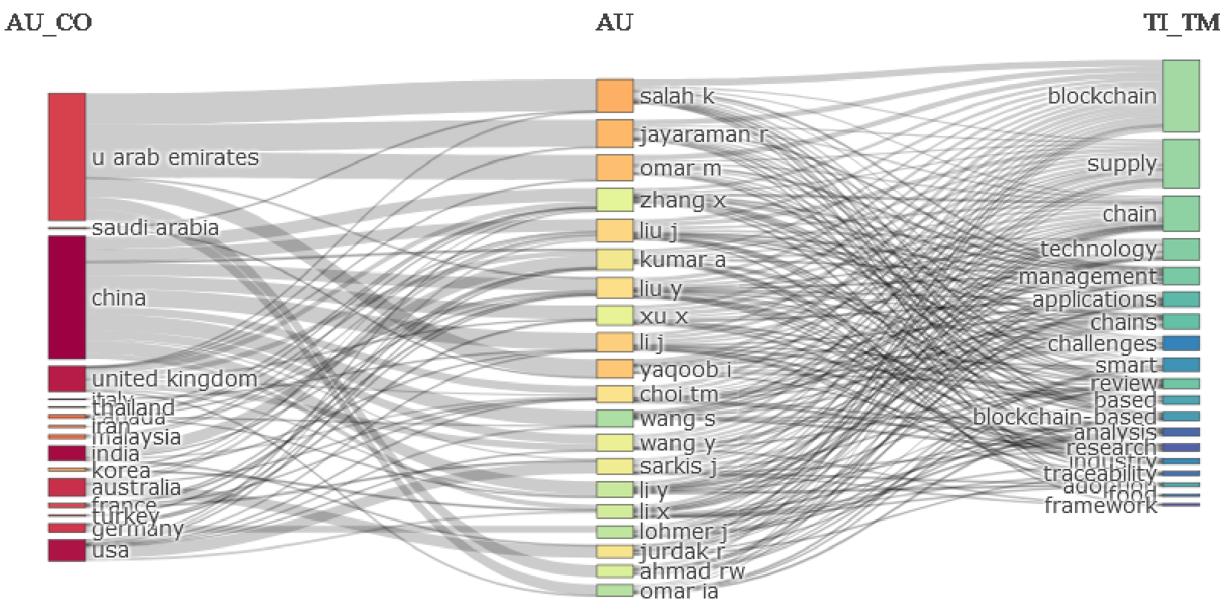

Figure 4. The three-field plot of authors countries, authors, and document title keywords.

First, the focus on blockchain technologies in the United Arab Emirates may be attributed to the smart city mega-projects and the investment-friendly political and sociocultural climate that attracts both tech-savvy entrepreneurs and exceptionally talented researchers, which inevitably facilitates the exploration of potential blockchain applications [42]. Saudi Arabia's Vision 2030, aimed at the establishment of the post-oil national economy, identifies the use of blockchain technologies as a vehicle for economic diversification and digital transformation [43,44]. China seems to have already included blockchain into its digital infrastructure and innovation system, as reflected in major national initiatives such as the Belt and Road, or the Digital Silk Road, and impressive investments into research, development, and technology absorption [45,46]. Thus, the cross-country collaboration of the three major researchers can advance both the frontiers of blockchain technology and the broader agenda on how human civilization can utilize technology for its economic activities. These exchanges promote international collaborations, spread knowledge, and allow for the development of innovative applications, breaking boundaries.

4.2. Science Mapping

4.2.1. Author Productivity through Lotka's Law

Lotka's law is applied to the specific context of the number of publications on blockchain industrial application, which is the analyzed category in this section. As per the frequency of the number of authors producing a given set of documents, Lotka's law is used. Lotka's law describes the general author productivity pattern such that the greater the number of documents an author writes, the lower the number of authors contributing to that specific volume. Thus, the curve of such a plot is an exponential decay when written as (Q1). This curve is known to represent Lotka's law. The pattern emerges from the characteristic of scientific productivity, which asserts that a minority number of authors are highly productive and write many documents compared to the majority number of others who are much less productive. Mathematically, Lotka's law is represented as (1):

$$n = N/(a.c^b) \tag{1}$$

where n is the authors who have published n papers, N is the total number of authors, and a and b are constants derived from empirical data. Through the analysis of this result shown in Figure 5, we can comprehend that a substantial number of documents were written by a single person: approximately 85.9% of all authors represented in the graph. This is a major case where a substantial fraction of authors has written only one document. Similarly, the study shows that two authors overall wrote the documents since they represent 9.5% all authors.

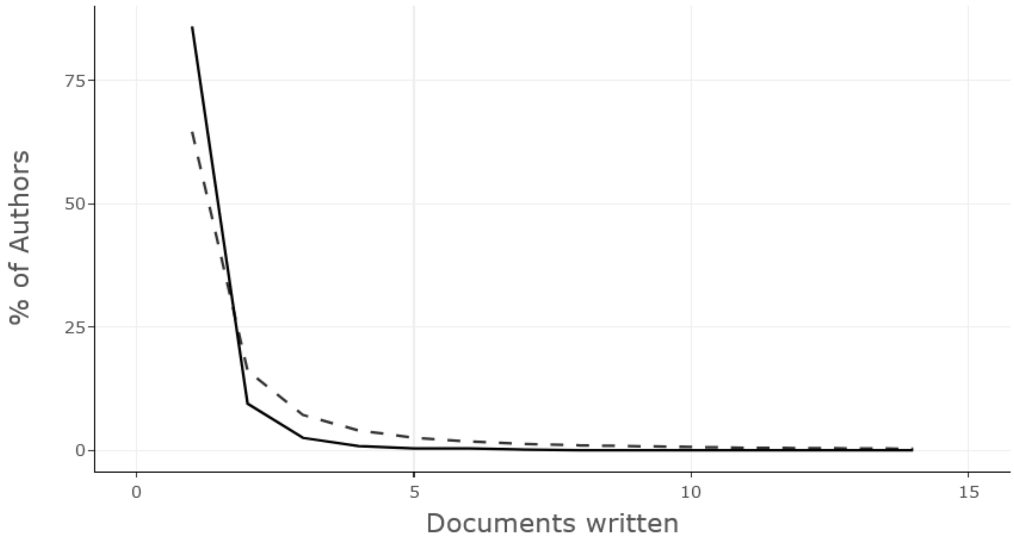

Figure 5. Author Productivity through Lotka's Law.

4.2.2. The Most Relevant Countries by Corresponding Authors

Figure 6 and Table 3 show the extent to which each country's researchers contribute to the blockchain industrial application sector. These are based on the publications output by corresponding authors from all the countries. The following significant findings were thus unearthed:

- China's Notable Contributions: With 135 articles in the blockchain industrial application research area, China presents as a leader in the global blockchain research trend. The high self-citation proportion (SCP) of 91 significantly indicates that China's research community has extensively recognized and cited its own research, demonstrating the country's substantial influence and active participation in blockchain research. Furthermore, a multiple-country proportion (MCP) of 44, along with the high SCP, reveals China's engagement in collaborative research with multiple countries, firmly establishing China's leadership in blockchain research and application;
- India's Dominant Role: Following China, India has made its mark with 77 articles in the blockchain industrial application research field. The SCP of 55 underscores the Indian research community's validation and respect for their work, indicating the quality and relevance of their contributions. An MCP of 22 highlights India's commitment to international research collaboration, evidencing India's significant role in advancing global blockchain technology and research.
- USA's Collaborative Efforts: Although the USA has a lower publication count of 41 articles in the blockchain industrial application field, its MCP ratio of 0.488 highlights a strong focus on collaboration with various countries. Given the relatively lower SCP, the United States appears to prioritize a collaborative approach, as illustrated by its record-high participation in multinational research collaborations in blockchain industrial application. Therefore, the USA plays a crucial role in promoting international research partnerships. This analysis offers a full picture of the different countries' roles in contributing and influencing the blockchain landscape, focusing on research and collaboration.

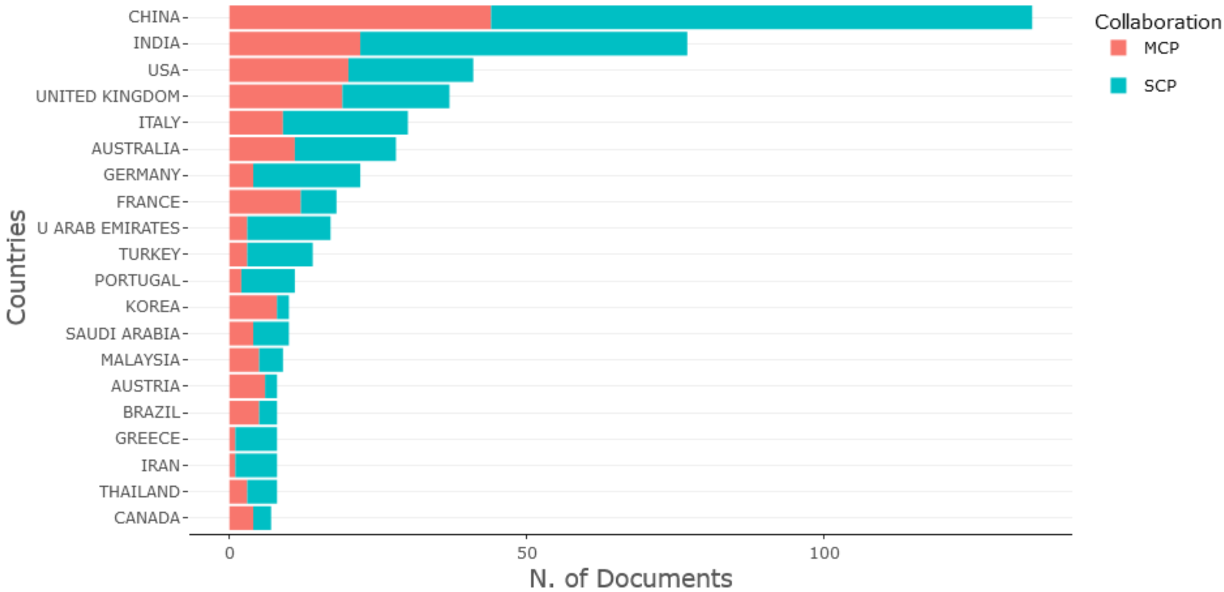

Figure 6. The most relevant countries by corresponding authors.

Table 3. The countries by corresponding authors.

Country	Articles	SCP	MCP	Freq	MCP_Ratio
China	135	91	44	0.222	0.326
India	77	55	22	0.127	0.286
USA	41	21	20	0.068	0.488
United Kingdom	37	18	19	0.061	0.514
Italy	30	21	9	0.049	0.3
Australia	28	17	11	0.046	0.393
Germany	22	18	4	0.036	0.182
France	18	6	12	0.03	0.667
U. Arab Emirates	17	14	3	0.028	0.176
Turkey	14	11	3	0.023	0.214

4.2.3. The Most Globally Cited Documents

Globally cited documents refer to the number of citations a document receives from any other paper across the entire Web of Science (WoS) Core Collection. Figure 7 illustrates that each paper serves a distinct role in its domain, with citation metrics highlighting ongoing influence and relevance. The findings underscore that the research contributions of these papers to their respective fields have enduring impacts and are vital to the academic community at large.

- Kouhizadeh [47]: This paper, with a total of 423 citations, demonstrates significant academic influence. An annual citation rate of 105.75 indicates enduring interest and relevance in its topic area. Relative to other works in production economics, its normalized total citation of 14.57 showcases the paper's wide recognition, use, and importance. It addresses the application of blockchain technologies for sustainability in supply chains, utilizing bibliometric techniques to review trends in scientific production indexed in the Scopus database. The focus on sustainability in supply chains is timely and critical, driven by increasing global concerns over environmental and social impacts. The application of bibliometric techniques offers a systematic and comprehensive review of the existing literature, which is beneficial for both researchers and practitioners;

- Dutta [48]: Garnering a total of 390 citations, this paper is a significant authority in transportation research. An impressive annual citation rate of 78.00 reflects sustained interest in its findings. It reviews current research trends and applications of blockchain technology in supply chain operations, presenting an extensive analysis of how various supply chain functions can benefit from blockchain. As blockchain technology becomes more integrated into supply chain processes, this article is particularly relevant for ongoing research in sustainable supply chains and provides valuable insights for researchers, practitioners, and policymakers interested in blockchain's potential and applications;
- Dubey [49]: This research article has garnered 270 total citations, showcasing its significance within the production research field. An annual citation rate of 54.00 highlights the paper's sustained relevance and ongoing interest in its findings. With a normalized total citation of 4.76, it illustrates Dubey's impact in comparison to other scholarly works in production research. The paper delves into the effectiveness of blockchain technology in fostering trust, collaboration, and resilience in humanitarian supply chains. It presents a theoretical model to elucidate how blockchain can enhance operational supply chain transparency, swift trust, collaboration, and resilience. This work is critically important, as it tackles the challenges of improving transparency, traceability, and trust among stakeholders in disaster relief efforts. The proposed theoretical model, supported by empirical evidence, marks a significant contribution to the literature on humanitarian supply chain management and blockchain technology, offering invaluable insights for researchers, practitioners, and policymakers engaged in humanitarian aid operations.

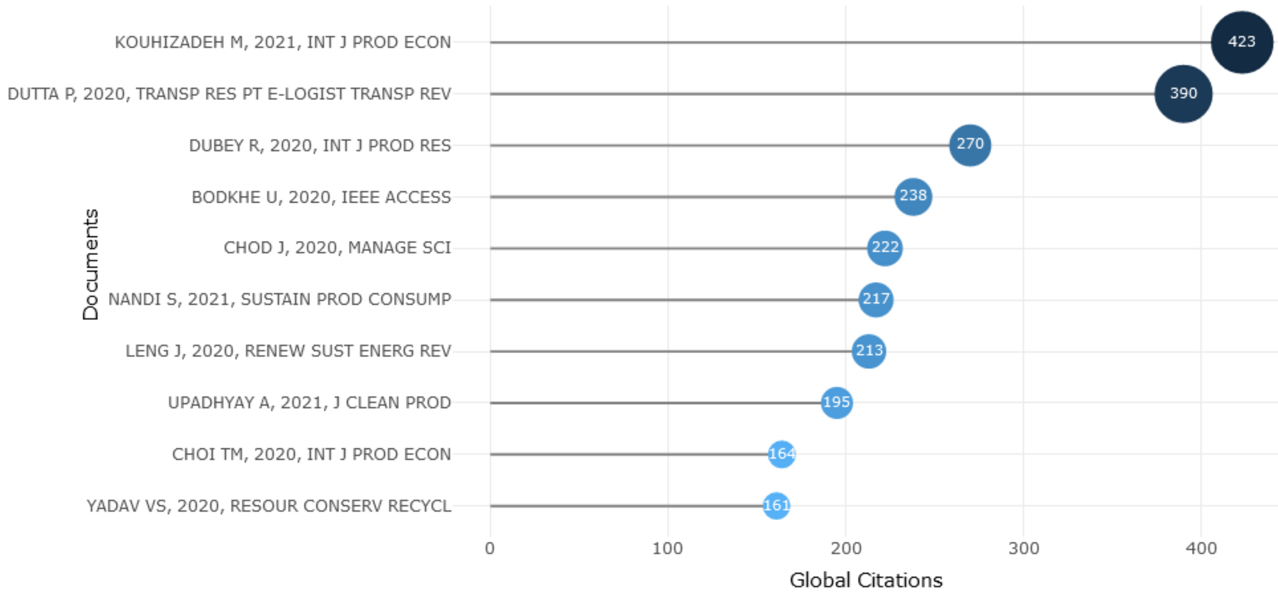

Figure 7. Most globally cited documents.

These articles are highlighted for their comprehensive analysis, relevance to pressing issues within their domains, and contributions to advancing understanding in the fields of sustainable supply chains, blockchain technology in supply chain operations, and the application of blockchain in humanitarian supply chains.

4.2.4. The Most Frequent Words

The second type of data that can be used to form an opinion about the subject matter discussions is the word frequency in the topics and focal points around which the dataset revolves. As shown in (Figures 8–10), the most pronounced words are technology, management, challenge, internet, framework, supply chain, logistics, impact, operations, and traceability.

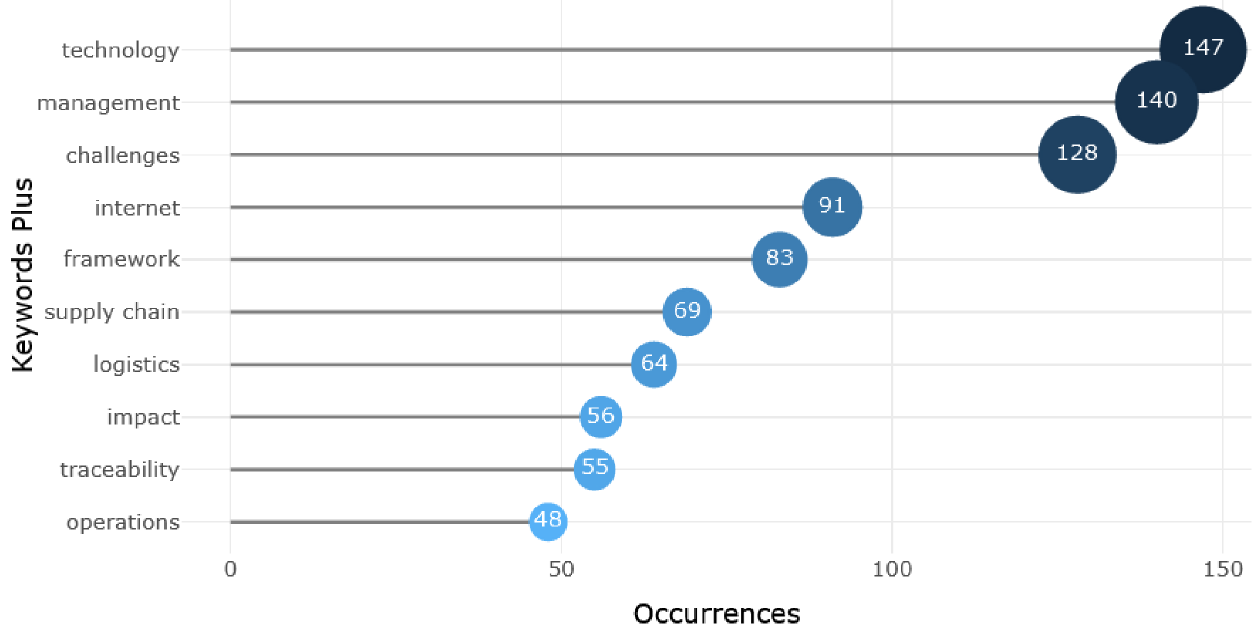

Figure 8. The most relevant words used in blockchain industrial application research.

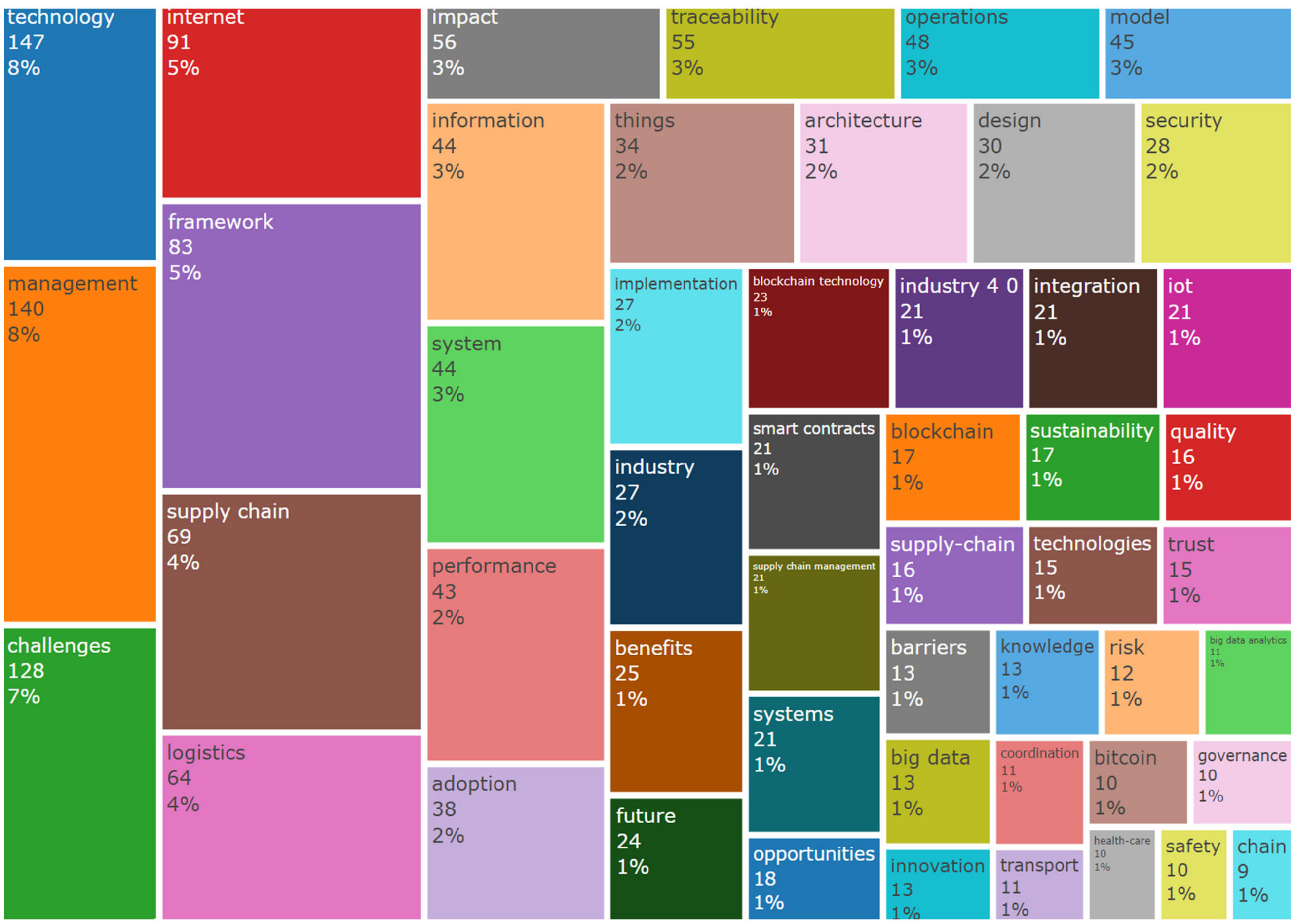

Figure 9. The words frequency analysis in the context of blockchain industrial application.

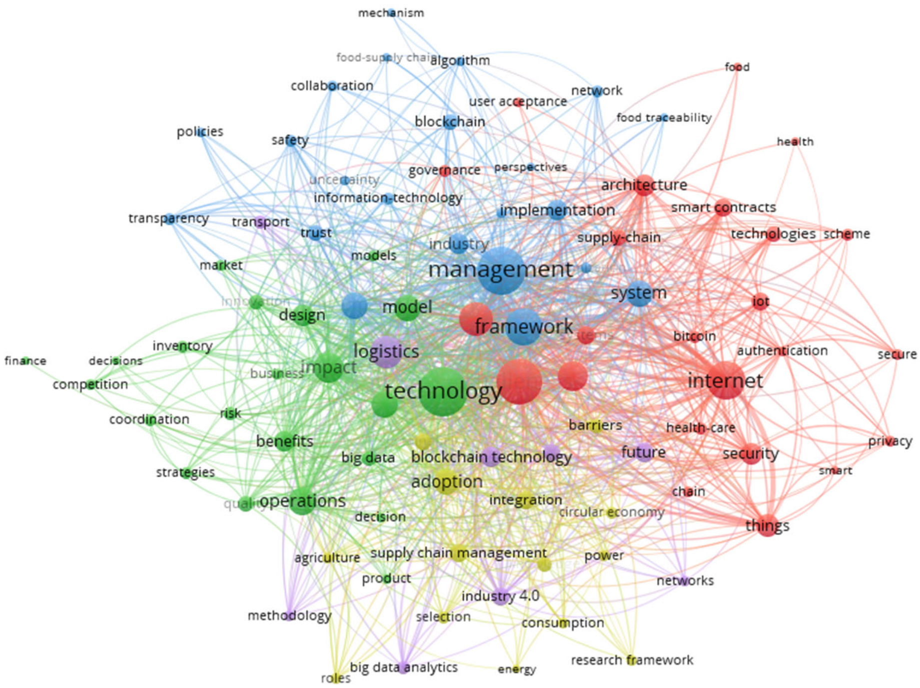

Figure 10. Keywords co-occurrence network VOSviewer.

The most frequently used word in the dataset is "technology", which implies the unprecedented vigor of technological aspects that are being tackled. This term is followed closely by "management", which implies the manager-related aspects, which could be about anything closely related to or implemental in technology. A term closely linked with technology term is "challenge", pointing out that the people involved are acutely aware of the enormous challenges the discussed sector is facing. Apart from the previous three, "internet" is the next frequently used word for processing connectivity and the digital aspects that could also be within the technological regimes. The next term is "framework", which indicates that people are discussing a structured approach to handle technology, which includes the two terms "supply chain" and "logistics". These two words imply a focus on the movement and handling of goods. The next word is "impact", implying that these terminologies are used to explore meaningful influence. Last, "operation" and "traceability" indicate the emphasis on tracking products. These levels of dominance indicate the major themes and topics within the dataset used.

4.2.5. Keywords Co-Occurrence Network

In terms of the thematic clusters depicted in Figure 11 and based on network analysis presenting in Table 4, nodes are presented in which co-occurring concepts differ among clusters. The red cluster sets the tone of foundation and perspective. Firstly, it describes the "building blocks" of the technology, with keywords mentioning architecture, authentication, bitcoin, and challenges as necessary components reflecting the basic aspects of blockchain technology and the field of its usage as well as certain issues of governance and scalability. The blue cluster includes "applications" derived from the "problems" keyword. Meanwhile, the highlighted food and health applications describe the core of the technology, along with ways to help fix the problems and possible methods of development. The green cluster presents the key "implications". The cluster includes the business side of blockchain, such as big data, finance, and innovation, as well as risk management [50] and strategic and implementation key factors in the usage of blockchain in fields of business and economy. Finally, the yellow cluster reflects on "perspective" nodes. The yellow cluster deals with the future perspective development of blockchain technology combined with advanced technologies, such as big data analytics and Industry 4.0. Two directions include research, again from different "places" of usage—supply chain management and transportation. The purple cluster depicts the topology of integration and multi-discipline application. Here, we added a cluster for IT, which has been developing independently, and large-discipline and blockchain integration, presented in the purple cluster.

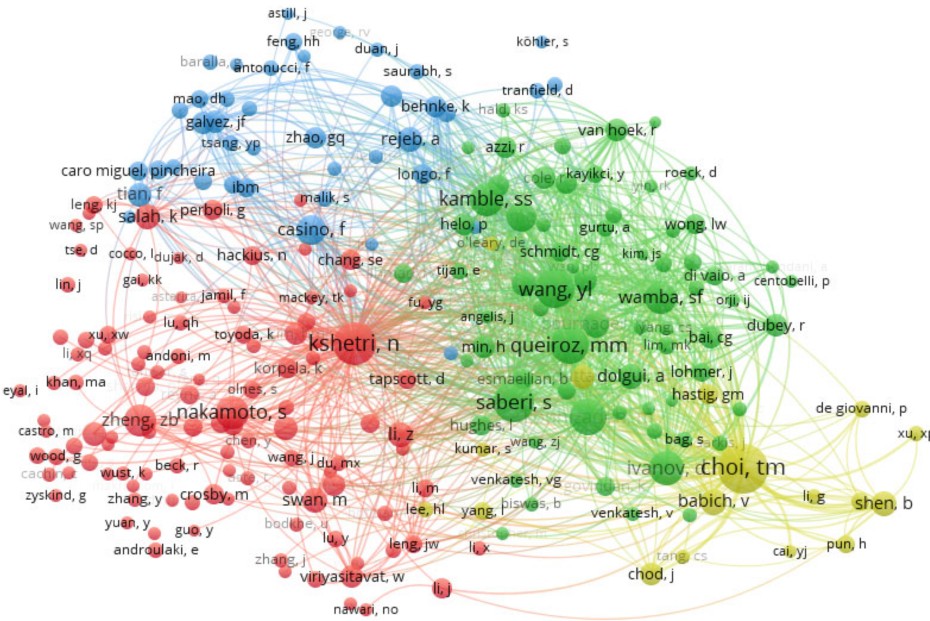

Figure 11. Authors co-citation network.

Table 4. Keywords co-occurrence network analysis.

Cluster	Color (Potential Interpretation)	Keywords (Top 5 by Occurrence)	Link Strength (Total)	Analysis
1	Red (Foundational Aspects)	Challenges (128), Security (28), Architecture (31), Supply Chain (70), Internet (90)	183	Focuses on core functionalities (architecture) and security aspects, addressing challenges like governance and privacy. Explores applications in specific industries (food, health).
2	Green (Business Applications)	Technology (145), Benefits (25), Impact (56), Design (30), Information (44)	558	Emphasizes business implications (benefits, impact) with applications across various industries (big data analytics, finance). Focuses on optimizing business processes and decision making (models, strategies).
3	Blue (Implementation)	Management (139), Framework (83), Supply Chain (70), Logistics (63), Performance (42)	423	Delves into practical implementation (frameworks, management) of blockchain within specific industries (food traceability, supply chain). Focuses on industry-specific challenges (safety, transparency).
4	Yellow (Emerging Trends)	Blockchain Technology (25), Future (24), Logistics (63), Opportunities (18), Industry 4.0 (21)	116	Explores future directions (big data analytics, industry 4.0) with a focus on identifying new use cases (opportunities) in areas like logistics.
5	Purple (Integration)	Big Data Analytics (11), Blockchain Technology (25), Logistics (63), Future (24), Opportunities (18)	200	This cluster likely focuses on integrating blockchain with other disciplines and technologies (big data analytics). It explores applications in future industries (industry 4.0) and logistics, identifying new opportunities through novel network methodologies and transport solutions.

4.2.6. Authors Co-Citation Network

A network of authors' co-citations in Figure 11 is divided into four clusters representing the co-citations between authors. Ksheri, n [51] is the most cited author in cluster 1. Wang, yl [21] is the most cited author in cluster 2. Choi, tm [52] is the most cited author in cluster 3, and Casino, f [53] is the most cited author in cluster 4. The four co-citation clusters shed light on the diverse applications and implications of blockchain technology in different domains from food supply chain management to IoT data integrity verification. Thus, analyzing the key themes, findings, interdisciplinary links, and future directions of each cluster, researchers can derive critical trends and patterns that signify the current and developing environment in the field of blockchain technology (see Table 5). These trends can guide future research priorities, cooperation between industries, and policymaking endeavors that are expected to maximize the socially responsible use of blockchain and support the delivery of innovation in multiple fields.

Table 5. Authors co-citation network analysis.

Cluster	Most Cited Author	Themes and Focus	Key Findings and Contributions	Interdisciplinary Connections	Implications and Future Directions
1	N. Kshetri [51]	Blockchain in Food and Beverage Industry	Potential of blockchain to improve quality control, safety, and sustainability in food supply chains.	Supply chain management, food science, sustainability studies	Mitigate food fraud, reduce waste, ensure compliance with regulations. Future research: scalability, interoperability, real-world implementation.
2	H. Wang [21]	Blockchain for Data Integrity in IoT	Using blockchain to ensure trustworthiness and security of data generated by Internet of Things (IoT) devices.	Cybersecurity, data science, IoT engineering	Develop resilient and trustworthy IoT ecosystems for various applications. Future research: optimize protocols for resource-constrained devices, explore edge computing use cases, address data privacy and sovereignty regulations.
3	T.-M. Choi [52]	Blockchain and Social Media for Supply Chain Management	Combining blockchain and social media analytics to improve supply chain visibility and decision making.	Marketing analytics, operations research, information systems	Enhance supply chain resilience and responsiveness, integrate social media insights with blockchain-based systems. Future research: decentralized platforms for data sharing, social media sentiment analysis for risk management, incentive mechanisms for collaboration.
4	F. Casino et al. [53]	Modeling Food Supply Chain Traceability with Blockchain	Developing theoretical frameworks and practical solutions for enhancing traceability and accountability in food supply chains.	Agri-food technology, logistics management, regulatory compliance	Improve transparency and consumer trust in food supply chains. Future research: data interoperability, privacy protection, scalability, facilitate fair trade practices and ethical sourcing.

4.3. Thematic Analysis

4.3.1. Thematic Map

The RStudio combines the thematic maps of the keyword clusters to show it as a circle and present it as a two-dimensional image represented through density and centrality. According to their position, four quadrants can be obtained. The descriptions of the dataset, word occurrences, and centrality measures of the map are similar within different clusters. Cluster 1 is identified as the cluster of the term "internet", which includes high-centrality or influence words like "internet", "things", and "architecture". The second cluster, where coordination-related words are located, is also characterized by centrality metrics: betweenness, closeness, and PageRank. The third cluster includes trust words such as "trust", "collaboration", and "algorithm". Meanwhile, the next cluster is built on the term "information technology". The word cluster comprising technology, management, and logistics may have a centrality measuring the significance of betweenness, closeness, and PageRank. See Table 6 to understand the theme of each cluster.

Table 6. Thematic map analysis.

Cluster	Thematic Cluster	Analysis	Discussion	Centrality and Density	Keyword (Top 5)
1	Internet and Technology	This cluster focuses on internet-related technologies.	The prevalence of terms related to internet technologies underscores the growing importance of cybersecurity measures and the increasing integration of IoT devices in various domains. Smart contracts also emerge as a significant area of interest, indicating a trend towards automated and secure contractual agreements in digital transactions.	High centrality indicates that the keyword "internet" is frequently connected with other keywords in the cluster. Moderate density suggests a relatively connected network of keywords within the cluster.	
2	Coordination and Strategy	This cluster revolves around coordination strategies.	The presence of terms like "coordination" suggests a focus on organizational structures and management practices to optimize technological processes.	High centrality indicates that the keyword "coordination" is frequently connected with other keywords in the cluster. Moderate density suggests a relatively connected network of keywords within the cluster.	Coordination, Strategies, Competition, Decisions, Investment
3	Trust and Risk Management	This cluster emphasizes trust-building mechanisms.	In an era characterized by data breaches and privacy violations, establishing trust and ensuring robust risk management frameworks are paramount. Organizations must prioritize data security, privacy protection, and transparency to foster trust among users and stakeholders.	High centrality indicates that the keyword "trust" is frequently connected with other keywords in the cluster. High density suggests a densely connected network of keywords within the cluster.	Trust, Collaboration, Algorithm, Policies, Uncertainty
4	Information Technology	This cluster revolves around information technology.	The dominance of terms related to information technology highlights the critical role of IT in modern organizations. Key themes include technology management, user acceptance, and the application of IT in various sectors such as healthcare and supply chain management.	High centrality indicates that the keyword "information-technology" is frequently connected with other keywords in the cluster. Moderate density suggests a relatively connected network of keywords within the cluster.	Information-Technology, User Acceptance, Food, Health, Antecedents
5	Technology	This cluster focuses on various aspects of technology.	The prevalence of terms related to technology highlights its pervasive influence across different domains. Key areas of interest include technology management, impact assessment, and the adoption of emerging technologies such as blockchain and IoT.	High centrality indicates that the keyword "technology" is frequently connected with other keywords in the cluster. High density suggests a densely connected network of keywords within the cluster.	Technology, Management, Logistics, Impact Traceability

Table 6. *Cont.*

Cluster	Thematic Cluster	Analysis	Discussion	Centrality and Density	Keyword (Top 5)
6	Chain	This cluster is focused on supply chain management.	The prevalence of terms related to supply chain management underscores the importance of efficient logistics, traceability, and risk mitigation strategies in modern supply chains. Blockchain technology emerges as a key enabler for enhancing transparency and trust in supply chain operations.	High centrality indicates that the keyword "chain" is frequently connected with other keywords in the cluster. Moderate density suggests a relatively connected network of keywords within the cluster.	Chain Drivers
7	Finance	This cluster pertains to financial aspects.	The presence of terms related to finance suggests a focus on financial allocation, service delivery, and channel optimization. Effective financial management is crucial for ensuring the sustainability and growth of businesses in a competitive market environment.	High centrality indicates that the keyword "finance" is frequently connected with other keywords in the cluster. Moderate density suggests a relatively connected network of keywords within the cluster.	Finance Allocation, Delivery Service
8	Channel	This cluster focuses on distribution channels.	Effective channel management is essential for reaching target markets and maximizing product distribution efficiency. The use of various distribution channels allows businesses to adapt to changing consumer preferences and market dynamics.	High centrality indicates that the keyword "channel" is frequently connected with other keywords in the cluster. Moderate density suggests a relatively connected network of keywords within the cluster.	Channel
9	Challenges	This cluster highlights various challenges faced by organizations.	The identification and understanding of challenges are critical for developing strategies to overcome them and drive organizational success. Key challenges include supply chain management, governance, and the adoption of emerging technologies such as blockchain and big data analytics.	High centrality indicates that the keyword "challenges" is frequently connected with other keywords in the cluster. Moderate density suggests a relatively connected network of keywords within the cluster.	Challenges, Framework, Supply Chain, Quality Management

4.3.2. Thematic Evolution

In this section, the evolving relationship between terms over two separate time periods is captured in the result shown in Figure 12. From 2020 to 2022, the discussions in the research were largely grounded on foundational concepts such as acceptance and antecedents of information technology, supply chain management, and innovation. Key themes during this period included artificial intelligence, blockchain technology, supply chain optimization, innovation strategy, and facilitators of trust. Emerging topics of interest were big data analytics, smart chain technologies [54], and logistics optimization. From 2023 to 2024, there was a continuation in the conversation about these established topics. There was, however, a trend towards more in-depth exploration and less interest in reducing uncertainties associated with artificial intelligence and blockchain technology. The connection of blockchain technology with big data analytics was high on the agenda. The discourse expanded to include smart chain technologies and logistics optimization, with an apparent heavy focus on how to complement the supply chain with technology. Collaboration and trust remained central themes, indicating that developing a high level of collaboration and trust among actors is crucial. The thematic evolution discussed next serves as a preliminary signboard for further research and implementation. It highlights the areas that should be further studied due to the derived themes and the implications these areas have for the entire system. Table 7 reflects this thematic evolution.

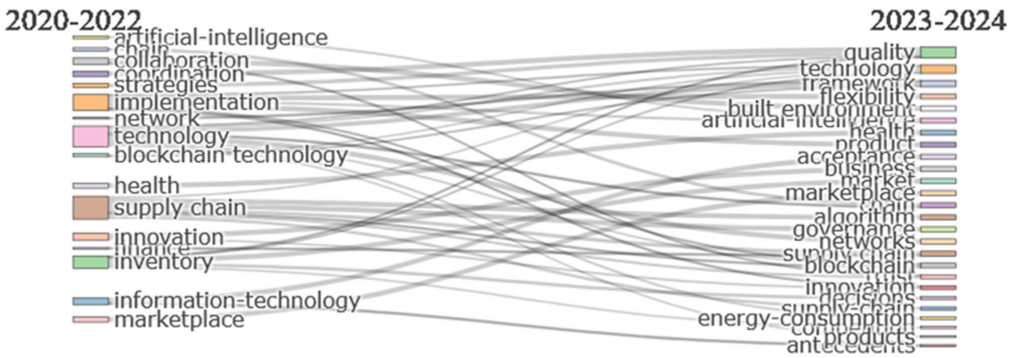

Figure 12. Thematic Evolution.

Table 7. Thematic evolution analysis.

Word Cluster	Explanation	Weighted Inclusion Index	Inclusion Index	Occurrences	Stability Index	Thematic Evolution Analysis
Artificial Intelligence	Foundational concepts and early applications in 2020–2022. Thematic shift towards uncertainty in AI implementation in 2023–2024.	0.50	0.50	30	0.17	Evolution from foundational concepts to uncertainty in implementation
Blockchain Technology	Core functionalities and potential applications in 2020–2022. Increased emphasis on risk management in adoption in 2023–2024.	0.45	0.17	120	0.03	Transition from applications to risk management
Supply Chain	Focus on general supply chain management concepts in 2020–2022. Shift towards strategies, allocation of resources, and integration with blockchain technology in 2023–2024.	4.58	3.19	135	0.57	Evolution from general theme to association with trust
Collaboration	Initially a general theme, transitioning towards association with trust in 2023–2024.	0.22	0.25	50	0.13	Evolution from general theme to association with trust
Technology	Initially encompassed various technologies, transitioning towards barriers and frameworks for implementation.	0.49	0.43	93	0.01	Transition towards implementation barriers and frameworks

4.3.3. Factorial Analysis

On the one hand, factorial analysis has already introduced the statistical approach to uncover the different hidden patterns or relationship within the dataset as representing in Figures 13 and 14. That is, each word is a point, expressed in the n-dimensional space, where n-dimensions is Dim.1 and Dim.2, which are therefore two differing aspects of the data. The other keywords, such as “internet”, “security”, and “smart contracts”, have a more significant value in Dim.1, which may indicate a likewise strong connection with the theme-based dimension. On the other hand, the topic dendrogram represents the hierarchical view of these clusters, expressing more general topics surrounded by slightly specific subtopics. Both visual approaches allow a better sense of the dataset's structure and contents. Thus, words that are closer one to another in space share the same semantic or context relationship. For example, words such as "technology", "management", "challenges", "internet", and "framework" are likely to be frequently used together in a similar context across research papers due to their degree of clustering. In contrast, words that are located far apart from one another indicate a lower association. In this regard, "smart contracts" and "supply chain management" are far apart from one another on the maps, which means that they are less associated with each other as concepts.

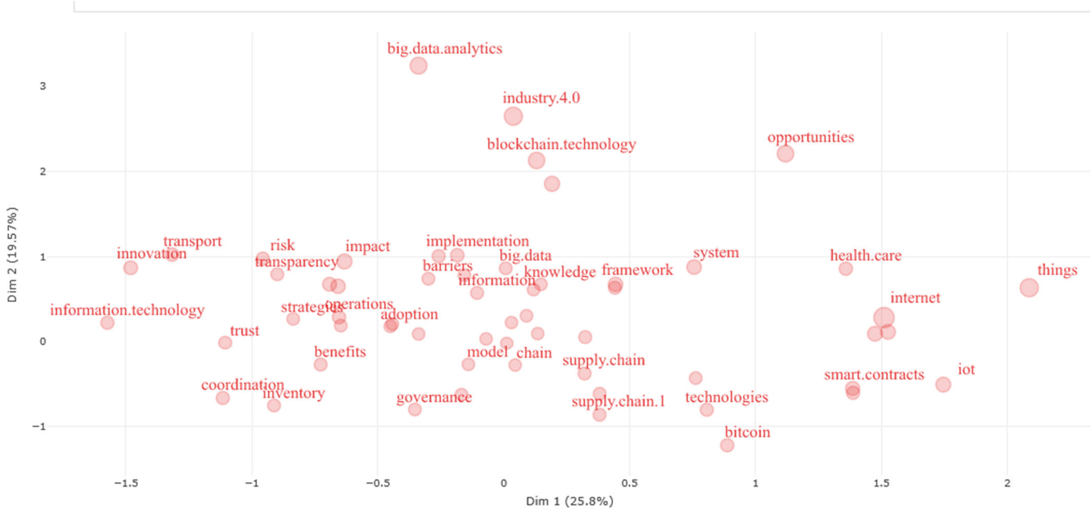

Figure 13. Factorial Analysis (word map).

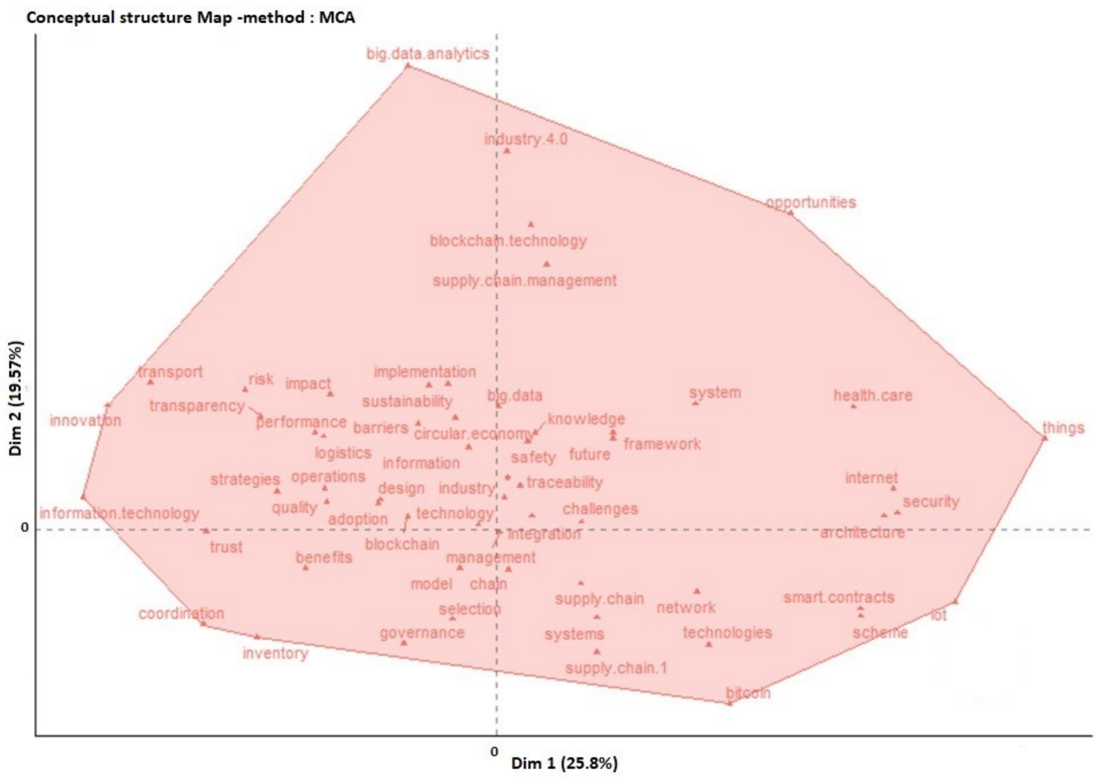

Figure 14. Factorial Analysis (Topic Dendrogram).

5. Discussion and Future Challenges

The joint analysis of the scholarly literature leads to a broad, convincing narrative, toward the possibility of transformation in various areas using blockchain technology. The language of this narrative is composed of the three pillars of security, transparency, and efficiency, trellising the melody of the mentioned positive changes, which will gradually emerge as the blockchain orchestra plays. Moreover, the interplay with the development of AI and IoT becomes obvious and creates a picture in which intelligent automating of concrete transactions provides security in fully decentralized networks.

5.1. Industrial Efficiency with Blockchain

5.1.1. Enhanced Industrial Transparency with Blockchain

The potential of blockchain goes beyond mere theoretical discussions. For example, decentralized autonomous organizations have become a reality, precisely managing clear supply chains. This leads to complete traceability, high performance, and increased transparency for both parties. For example, the IBM Food Trust has tracked the path of mangoes from the farm to the store, which increases consumer confidence [55]. Moreover, We.trade has simplified the exchange of goods investment processes and trade financing through shorter transactions [56]. Companies are also implementing this technology to better understand their supply chain, tracing their product to a factory or verifying the distribution chain's ethicality. Walmart has efficiently implemented this technology to determine its inventory levels and maintain an ethical supply chain [57].

5.1.2. Addressing Complexities of Blockchain Adoption in Industry

The analyses draw the picture of a trajectory consisting of a sequence of stages of perfection, making the transition from a conceptual design to a practical prototype and finally to a professional use case [58]. Thus, the debate of risk management and scalability outlines wider industry opportunities to tackle multidimensionality and leverage blockchain technology [59]. The regulatory environment and infrastructure, with a special focus on interchangeability, are identified as a set of key factors, which can unlock broad applications and create conditions for further industry development and expansion [60].

5.1.3. Advancing Industrial Decision Making through Blockchain and IoT

Integrated with the Internet of Things, blockchain technology improves the strategic decision making of industrial applications, as demonstrated in smart manufacturing and supply chain logistics. In manufacturing, IoT sensors continuously track operating parameters like temperature and strain, recording data in a blockchain in a safe, efficient, and informed manner. This empowered implementation ensures the best maintenance and optimization programs by reducing or removing downtime and has the capacity to identify and provide constantly updated transactional information. According to one paper [61], the most obvious and welcome advantage of blockchain technologies in smart production is that they can enhance the manufacturer's or operator's logistics in numerous ways. Similarly, in supply chain logistics, blockchain-based IoT devices monitored and tracked for complete observation and their approach to transactional data will help in capabilities access and in making knowledgeable decisions. However, since the networks do not scale and combine with current IoT-based systems, most of them are increasingly subtle scaling roadblocks for blockchain in the industry. That is why excavating them will help the field realize its maximum advantages, such as protracting involvements and condensed open decision making in industries.

5.1.4. Blockchain, AI, and IoT for Intelligent Industrial Operations

The treasure of such insights is unlocked when integrating AI and IoT with blockchain industrial applications. IoT sensor data paired with blockchain analysis can offer predictive maintenance in industrial settings, which would cut downtime and operational costs [62]. GE Aviation, for instance, uses precisely this method to forecast when airplane engines may fail [63]. Another example of how this integration boosts efficiency is using the GPS data to track goods in real time, monitor their statuses while en route, and optimize logistics and customer satisfaction [64]. Leading the industry in this is Maersk, which uses blockchain to trace shipments and improve global logistics [65].

5.1.5. Building a Robust and Sustainable Industrial Blockchain Ecosystem

Building a solid blockchain framework is crucial and is based on several essential components. These elements are the base of the system and help to design a versatile and efficient one. The following are the roles of each of the parts for ensuring the blockchain framework's successor:

- **Regulatory Clarity:** Coordinated cooperation between the government, industries, and legal authorities account for a universal and helpful regulatory schema [66];
- **Interoperability Retiring:** Research and development on normalized grounds are paramount for seamless cooperation in this component [67];
- **Upskill Incentive:** In covering this space, the self-experience and lack of experience is essential in programs designing new blockchain specificity [68].

5.1.6. Building Trust and Ensuring Responsible Development

Furthermore, enabling responsible development and ensuring widespread adoption of blockchain technology in industry are critical priorities:

- **Ethical Considerations:** The conversation needs to be open and proactive on nefarious uses of data. Beyond that, research on privacy-enhancing techniques can also be part of addressing privacy risks [24]. Discussions on responsible data governance built trust [62]. The potential implications of blockchain technology for privacy and ethical data use are already well represented in the existing research literature; for example, the study of the authors [69] described many different ways in which blockchain can be used to secure data, but some risks regarding privacy were also noted due to its transparency and immutability. The researchers mentioned that these risks can be minimized by adding privacy-enhancing techniques like zero-knowledge proofs. The issue has an application in industry sector as well. In the field of healthcare, the MedRec project at MIT described by the study [70] uses blockchain to store medical records while ensuring the privacy and control of these records by patients. Therefore, this system exemplifies how blockchain can be used to enhance privacy and contribute to responsible data governance in industry;
- **User Experience:** Emphasis on building user-friendly interfaces and investments in educational resources is essential in attracting a broad range of users and businesses [71]. The work [72] offered insights on how to improve this aspect, which is crucial to the application of the technology across sectors. The study emphasized the need to simplify blockchain for the layman and offer educational resources to improve accessibility. For instance, the study [73] mentioned Coinbase in this context as a company known for its user-friendly interface and educational approach, which helps to attract more users.

5.2. The Challenges Facing Blockchain Industriel Application

The bibliometric analysis used in this paper reveals the apparent urgency of collaborative solutions in industrial applications around blockchain-driven innovations. At the same time, there are several areas of concern based on the analyzed findings. Firstly, hardware/energy consumption requires fast action to ensure sustainable measures and feasible yet immediate increases in efficiency [74]. The current blockchain implementations consume about twice the energy of traditional systems, highlighting the need for the development of sustainability. Secondly, the low rate of adoption is caused by a lack of understanding of the blockchain as a value proposition, with only 20% of the industries surveyed fully embracing blockchain technologies [75]. This gap between the perceived and actual values of blockchain underscores the need for engaging use cases and educational programs. Thirdly, user empowerment and education should be addressed [71]. Over 75% of blockchain application users are hindered by poor user experience due to complex interfaces and inadequate user support. This challenge necessitates a focused effort on improving design and communication strategies, thus empowering users to fully utilize and understand the capabilities of blockchain technologies [71]. Finally, research around scalability is presumed, given that several scaling issues would occur as transaction volumes skyrocket [76], with current blockchain frameworks capable of handling only about 50% of the transaction volumes needed by larger enterprises. This points to the need for innovative scaling solutions that can accommodate rising transaction volumes without compromising performance or security [76].

5.3. A Collaborative Future

By collectively working to solve these numerous challenges, this work is at the leading edge of unlocking the full potential of blockchain industrial application. Through a collective effort of research, study, and development, this future where there is never a fall in security, never a lack of transparency, and never a lack of ability shall be unlocked. The work presented herein can serve as a guidepost for that collective effort.

5.4. The Call to Action

The future of blockchain industrial applications lies heavily in the hands of all researchers. Thus, this discussion is a clarion call for all stakeholders to join in the discussion, so we can all play a role in creating a secure and transparent future. Researchers are encouraged to take their work further regarding sensitive topics such as scalability and privacy. Educators can ensure they empower the next generation to take full advantage of the opportunities and potentialities offered by this transformative tool. Policymakers should work in collaboration with other industry stakeholders to conceptualize and enable a regulatory framework. It is only by moving together than blockchain can be the force of good that we know it has the potential to be.

6. Conclusions

To conclude, this research completed two systematic bibliometric analyses that provided a comprehensive evaluation of blockchain's transformative and profound impact across different industrial sectors. After analyzing and synthesizing over 800 peer-reviewed articles selected from a specific network of scholarly communications, research trends, and performance statistics, this work demonstrates the tremendous annual growth in blockchain research. The increase was equal to 89.08% from 2020 to 2023. This body of evidence not only reinforces the concepts supported through scientific research but also strengthens the message of the revolutionary nature of decentralization, security, and immutability that are essential for businesses and international collaborations. Moreover, the analysis proves that blockchain has become a significant driver in many industries and transformation's overall processes but not in cryptocurrencies only. Researcher reports identify the following critical areas that require urgent attention: scalability challenges, regulatory guidelines adherence, and reduction in energy consumption. These call for the combined effort of thought leaders, decision makers, researchers, and educators to better utilize and support blockchain. Additionally, this work emphasizes the critical role of blockchain in business and data operations transformation, creating a new era of digital changes and vanguard movements. The impact of integrating blockchain technology into digital and industrial areas should also be observed concerning its social, economic, and personal human effects. The dual bibliometric study presented in the paper not only aids in understanding the blockchain research's change and development but also proves to be a valuable model for further research, decision making, and collaborative efforts to maintain secure and inclusive blockchain impacts.

Author Contributions: Conceptualization, K.D. and O.B.; methodology, K.D.; software, O.B.; validation, K.D. and O.B.; formal analysis, K.D.; investigation, K.D. and O.B.; resources, data curation, O.B.; writing—original draft preparation, K.D.; writing—review and editing, K.D.; funding acquisition, K.D. All authors have read and agreed to the published version of the manuscript.

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