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The Application and Ethics of Artificial Intelligence in Blockchain:
A Bibliometric-Content Analysis

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ABSTRACT

AI-enabled blockchain refers to the use of AI to enable the analysis and decision-making processes based on data collected, shared, and stored by blockchain. This helps overcome some of the existing challenges in blockchain applications. Despite the growing number of review papers on blockchain and AI, there is a dearth of literature on AI-enabled blockchain in business scenarios. This study uses bibliometric-content analysis to (1) identify three stages of development of AI-enabled blockchain literature and point out the increasing diversity of technological applications; (2) identify the strongest foci of extant literature; (3) unveil the roles of AI-enabled blockchain in 10 application sectors, and identify the key roles of AI in enabling blockchain applications; (4) conclude the referred ethical issues from three levels and make further discussion. The findings present the trends of AI-enabled blockchain and could help developers and service providers better manage the use and ethical issues of AI in blockchain applications.

KEYWORDS

Artificial Intelligence, Bibliometric Analysis, Blockchain, Business Applications, Content Analysis, Ethical Implications

INTRODUCTION

Blockchain is a shared, immutable ledger that facilitates recording transactions and tracking assets in a business network (Sylim et al., 2018). As a disruptive technology that provides businesses with greater trust, security, and efficiencies. Its applications span various fields, with a market expected to exceed 10 billion US dollars by 2022 (Petroc, 2022).

Despite these advantages, blockchain technology still faces challenges in its business applications (Xing & Marwala, 2018), and Artificial intelligence (AI) may be one of the most important tools to solve these challenges. While blockchain serves as a ledger, it lacks sufficient capabilities to make complex decisions or deal with security threats (Xing & Marwala, 2018). By contrast, AI technologies may extract and transform data into valuable insights (e.g., neural networks, data mining) and

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generative solutions (e.g., genetic algorithm, machine learning) for blockchain applications. AI-enabled blockchain refers to integrating AI and blockchain, where AI enables analytics and decision-making based on data collected, shared, and stored by blockchain (Xiong et al., 2020). The synergy between AI and blockchain is akin to the cooperation between the body and the brain. Blockchain acts as a body, collecting and storing data and sharing it with the AI system, which acts as a brain, performing analysis, deciding, and supporting the operation of the blockchain.

Recently, a growing number of AI-enabled blockchain applications have already been developed in finance (Y. Wang et al., 2022), smart manufacturing (Teng et al., 2022), supply chain (Y. Wang, 2021), healthcare (Al-Otaibi, 2022), transportation (S. Wang et al., 2022), and other business fields, exerting a significant influence over the industries. Despite the growing importance of AI-enabled blockchain, the current literature primarily focuses on the individual applications and ethical considerations of AI in the blockchain. However, AI is an emerging and promising technology that can contribute to blockchain's technological development and empowerment in business. Therefore, it is essential to explore the general business application scenarios of AI-enabled blockchain and understand the role that AI plays in enhancing blockchain applications.

In addition, while AI can enhance blockchain applications by improving sustainability, scalability, risk identification, and business innovation (Alkan, 2022; Wang et al., 2021), developers and service providers across various application scenarios must also consider the potential negative impacts of AI on ethical issues such as privacy, fairness, and dignity. The ethical issues posed by AI have attracted increasing research attention (Kazim & Koshiyama, 2021). For example, AI may violate citizens' dignity (Morse et al., 2021) and privacy (Campbell et al., 2020), and it is prone to algorithm bias (Akter et al., 2022). Integrating AI in commercial blockchain applications raises inevitable ethical concerns. Therefore, besides exploring the business implications, it is critical to better understand the ethical implications of AI-enabled blockchain.

While there are some review papers on the intersection of blockchain and AI, few have focused specifically on AI-enabled blockchain from a business and management perspective. For example, Hussain and Al-Turjman (2021) analyze the technical aspects of AI and blockchain without considering their business implications, while Kumar et al. (2022) provide a general overview of integrating these technologies without a comprehensive analysis of AI's role in blockchain applications. Salah et al. (2019) investigate how blockchain enables AI, rather than how AI enables blockchain applications. In the last five years, this area of research has seen rapid growth, with nearly 100 papers being published annually. Given this substantial body of literature, it is crucial to conduct a systematic review to gain a deeper understanding of the current state of research and identify future research directions.

Therefore, the primary aim of this study is to gain a comprehensive understanding of both the business applications and the ethical implications of AI-enabled blockchain by analyzing a corpus of relevant literature. Specifically, this study seeks to answer the following questions:

RQ1: What is the status quo (i.e., yearly growth, cited papers, countries, institutions, journals) of publications related to AI-enabled blockchain in business?
RQ2: What are the growth trajectories and topical focus of research on AI-enabled blockchain?
RQ3: What roles does AI play in supporting blockchain in its business applications?
RQ4: What are the ethical issues associated with AI-enabled blockchain in its business applications?

A bibliometric-content analysis is performed to evaluate the existing research regarding AI's beneficial effects on blockchain applications. We reviewed the literature from descriptive, bibliometric, and content perspectives. Descriptive analysis helps uncover the development trends of this research stream. Bibliometric analysis is used to unveil objective correlations in the existing literature and to identify new knowledge. In contrast, content analysis is used to identify the business areas that adopt AI-enabled blockchain, the roles of AI within blockchain applications, and the associated ethical implications. Such analysis would assist us in understanding the status quo and development trends regarding the topic, shedding light on future research.

The remainder of this paper is structured as follows. First, we describe the data collection and analysis methods. We then present the analysis and results of the study. Finally, we summarize the key findings, implications, and limitations of the research.

DATA COLLECTION AND METHODOLOGY

Data Collection

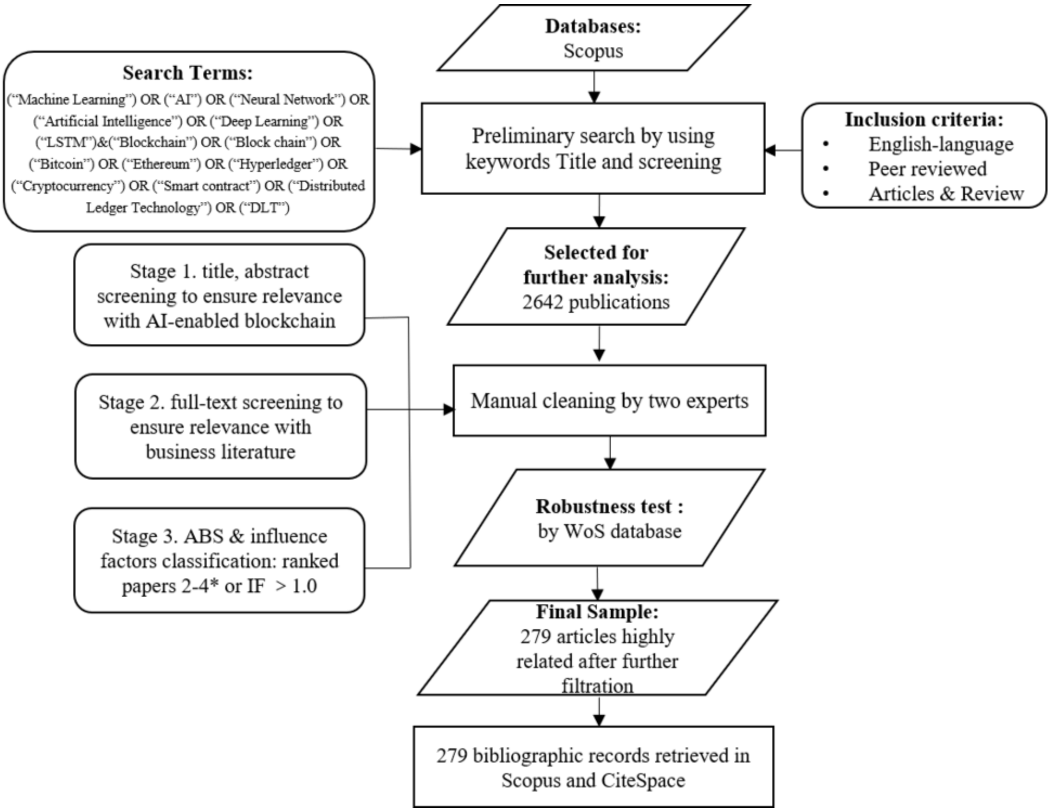
Based on previous literature (Khlystova et al., 2022; Rocha & Pinheiro, 2021; Verma & Gustafsson, 2020), multiple databases (i.e., Scopus and Web of Science) are adopted in this work. Scopus, a robust and inclusive database that owns the world's largest amount of peer-reviewed literature (Boyle & Sherman, 2006) and meets the stringent indexing requirements (Lim et al., 2022), is a suitable source for bibliographic data retrieval (Anand et al., 2021; Donthu, Kumar, Pandey, et al., 2021). Web of Science, a database widely used in the bibliometric analysis (Hota et al., 2020), is adopted for robustness check since it ensures the widest time span of literature and high quality of journals (Poje & Zaman Groff, 2022).

Using the Advanced Search function of Scopus, we used Boolean operators and performed nesting based on field labels (Burnham, 2006). Based on the study of Krishen et al. (2021), the authors construct a detailed list of keywords for retrieval to cover the research field as much as possible. For the two central elements, *AI* and *blockchain*, the authors use a variety of synonyms during the search, such as "*deep learning*" and "*artificial intelligence*" for "*AI*" and "*smart contract*" or "*bitcoin*" for "*blockchain*." During retrieval, the search query is augmented using the following restrictions: (1) Only formal journals are considered. Since journals are rigorously peer-reviewed (Lim et al., 2022) as opposed to conference proceedings or other types of manuscripts, the quality is assured (Tranfield et al., 2003) and the findings can be trusted by researchers (Obregon et al., 2022). (2) Search terms that appear in the title, abstract, or keywords of the publications are all counted to ensure the coverage of the search. (3) Only publications from 2008 to January 2023 are considered, as blockchain was first proposed in 2008. (4) Since VOSviewer can only process English inputs, only English articles or reviews were analyzed (Tiwary et al., 2021).

After an initial search, 2642 publications have been identified. A three-stage pretreatment is conducted by two professional researchers to screen out papers that are of high quality and high relevance to the topic (Verma & Gustafsson, 2020). First, to ensure the relevance of the data, one researcher reviews the title and abstract of the papers and retains those related to AI-enabled blockchain rather than those discussed AI or blockchain only. During this step, 1985 pieces of literature were removed. Second, two researchers clean the data independently to ensure preciseness. Any disagreements have been discussed until a consensus is reached based on the following criteria: (1) the article should focus on business applications rather than technology features only; (2) only papers on AI-enabled blockchain are included, and those on the relationships between these two technologies are removed. Third, to ensure the quality of data, only journals that have been rated as 2-star or higher by the 2018 or 2021 AJG (ABS) list and those not on the AJG (ABS) list yet have an impact factor of over 1 are included in this study (Khlystova et al., 2022). In this vein, 279 bibliographic records are imported from Scopus, including author names (all authors for each paper), countries/regions of the authors, article titles, and journal titles.

Following Aramo-Immonen et al. (2020), the authors conduct a robustness test based on complementary analysis using Web of Science, the same procedure as Scopus, to verify the results of Scopus. Although results from the first two steps of the three-stage pretreatment indicate that two additional papers are not included in the filtered list, their impact factors are less than one, suggesting that the literature coverage filtered from Scopus is sufficient. We show the entire process of data acquisition and processing in Figure 1.

Figure 1. Flow chart of the data collection process



Analysis Method and Technical Principles

Bibliometric Tools and Analysis

VOSviewer and CiteSpace have been widely used in literature reviews for subjects including e-commerce (Ding & Yang, 2020), innovation research (Xu & Talib, 2020), social studies (Contreras et al., 2022), and journal studies (Donthu et al., 2020). Using VOSviewer, overlay maps and density maps can be generated in a readable manner (Donthu et al., 2020), enhancing the visualization for various purposes. CiteSpace can calculate Betweenness Centrality (BC), degree, and other quantitative data to create a visual map (Zhou & Song, 2021), facilitating further in-depth quantitative analysis of existing publications. In this vein, CiteSpace 6.1.R6 Advanced and VOSviewer version 1.6.18 are chosen as the tools for conducting scientometric analysis.

To better understand the dynamic evolution of the research field's development and untangle the research stream's current focus, progress, and future orientations, the authors conduct both a timeline view and a cross-sectional view of keyword co-occurrence analysis. Co-citation clusters are used to uncover the hidden relationships between different pieces of literature, revealing new knowledge structures and assisting in creating maps. The above methods are further elaborated as follows.

First, the keywords of papers are chosen as they reflect the focus and concerns of relevant studies. As a textual analysis technology, a keyword co-occurrence network is an effective tool for exploring the topics of research in the literature library (Fang et al., 2017). We generated the network using keyword pairs from the collected literature. When two or more keywords appear in one article, we established a link between them. The more often they occur together, the stronger the link is (Wu

& Zhang, 2019). In each map, each node represents a keyword, and the lines connecting the nodes represent co-occurrences.

Second, the timeline view and cross-sectional view are adopted for bibliometric analysis to present longitudinal details, including historical origins, recent flourishing periods, and future trends, as well as cross-sectional messages involving different research angles and relationships between them. VOSviewer, which is used to generate cross-sectional views, creates a two-dimensional map based on Euclidean norms by calculating the similarity between terms. The distance between them reflects the correlation between words on the map. Significant terms are located in the middle of the map, while color distinguishes different clusters of terms on the map (van Eck & Waltman, 2010). Using this method, the distance between cluster positions implies the relationship between clusters. To sum up, a three-dimensional perspective of literature is developed for comprehensive analysis through the timeline and cross-sectional view.

Third, co-citation analysis is used to identify classical literature in each field of research. Co-citation can be defined as "n papers citing the same paper have a co-citation relationship," where n denotes the co-cited times of a paper. As long as n is high enough, the paper co-cited by n papers can be classical literature. Metrology software can present clusters of visualized results based on the semantic similarity between text segments (Shiau et al., 2017). Also, the software can automatically tag the clustered results based on the titles, keywords, and abstracts of the cited articles within each cluster. Based on the labels of the clusters, we can identify the themes of the articles. Besides, papers with high BC values play a more critical role in current literature. CiteSpace is used to calculate the BC of all cited papers, identifying the landmark publications that have contributed the most to the development of AI-enabled blockchain in business. The content analyzed in this study is shown in Table 1.

Content Analysis

Content analysis, a systematic coding and classification method for analyzing large amounts of text data (Vaismoradi et al., 2013), is employed in this study. This method combines qualitative methods that retain rich meaning and perform robust quantitative analysis (Duriau et al., 2007), supplementing the bibliometric analysis. Previous literature reviews have applied content analysis to various topics, such as supply chain management (Seuring & Gold, 2012) and librarianship research (Koufogiannakis et al., 2004). We conducted the following efforts based on the general content analysis (Gaur & Kumar, 2017).

Table 1. Application of scientometric analysis

Science Mapping Technique	Usage Context	Analysis Unit	Data Requirements
Keyword co-occurrence (CiteSpace)	Timeline view of keyword	Keyword	All the filtered bibliographic records
Keyword co-occurrence (VOSviewer)	Cross-sectional view of keyword	Keyword	All the filtered bibliographic records; Minimum of co-occurrence of keywords: 3; Number of keywords selected: 56; Counting method: full counting
Co-citation analysis (CiteSpace)	Themes	Titles, keywords, and abstracts	All the filtered bibliographic records
Betweenness centrality (BC) calculated (CiteSpace)	Landmark publications discovery	Cited papers	All the cited papers from the dataset

First, the authors select a sample based on the review objectives, namely business applications and ethical implications of AI-enabled blockchain, as shown in the data collection section. Second, a feasible coding scheme is determined through consistent discussions. The business applications and criteria for ethical implications are defined, and several examples are given based on the existing literature. For business applications, (1) the study should name at least one application case; (2) the newly proposed business application should be able to meet a specific and unresolved demand, reduce costs, or enhance efficiency. Regarding the ethical implications, according to Ashok et al. (2022), the influence of each application should be described at individual, corporate, or social levels. Third, we performed corpus coding. After discussing the above definitions, two coders read the selected manuscript in depth and code independently (Bartikowski et al., 2019; Seuring & Müller, 2008). Following the general routine (Tranfield et al., 2003) and the definition/standard built in the second stage, the authors include the paragraphs and articles that describe business applications and ethical implications in the appropriate categories for analysis. To ensure the consistency of codes, we should make further discussions to resolve disagreements and reach consensus. Fourth, the authors summarize the coded results and draw conclusions, and the detailed results are presented in the findings section.

ANALYSIS AND RESULTS

Descriptive Analysis of the Current Research Progress

In this part, statistical and descriptive methods are used to examine the research performance of AI-enabled blockchain studies from various perspectives, including yearly growth of publications, top 15 cited papers, top 10 productive countries, top 12 productive institutions, top 10 productive journals, and top 10 cited journals. The statistical performance helps us better understand the current research progress on AI-enabled blockchain in business.

As a brand-new research field, the earliest business research on AI-enabled blockchain, titled "Blockchain thinking: the brain as a decentralized autonomous corporation" in 2015, discussed the implementation of friendly AI into the blockchain (Swan, 2015). Since then, the research on AI-enabled blockchain in business has experienced rapid development, as evidenced by the fast-increasing publications shown in Figure 2.

To identify the most important papers in the focal research area, Table 2 lists 15 publications with the highest total citations (TC). Scopus provided the data sources. We can observe it from the statistics that nine of the top 15 papers are related to cryptocurrency through the title messages.

Figure 2. Annual publications (until January 2023)

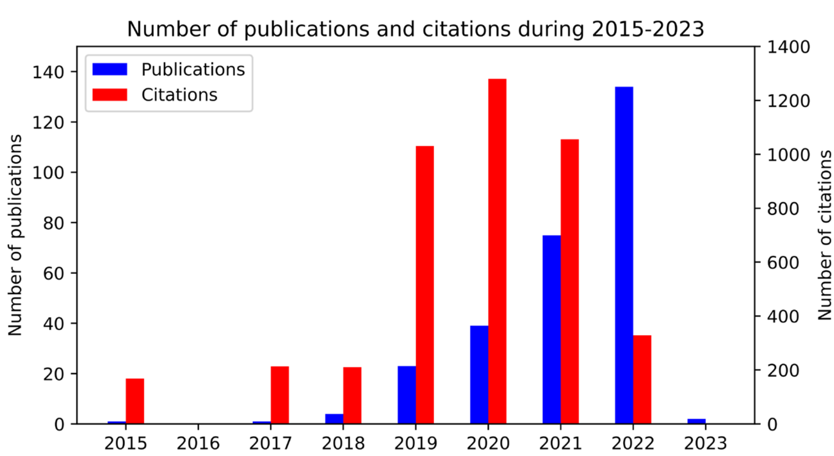


Table 2. 15 top cited papers on AI-enabled blockchain in business

Ranking by TC	Title	Year	Journal	Total Citation (TC)
1	An Empirical Study on Modeling and Prediction of Bitcoin Prices with Bayesian Neural Networks Based on Blockchain Information	2017	IEEE Access	213
2	Block IoT Intelligence: A Blockchain-enabled Intelligent IoT Architecture with Artificial Intelligence	2020	Future Generation Computer Systems	197
3	Performance optimization for blockchain-enabled industrial Internet of things (IIoT) systems: A deep reinforcement learning approach	2019	IEEE Transactions on Industrial Informatics	182
4	Blockchain Thinking: the Brain as a Decentralized Autonomous Corporation [Commentary]	2015	IEEE Technology and Society Magazine	168
5	Machine Learning Adoption in Blockchain-Based Smart Applications: The Challenges, and a Way Forward	2020	IEEE Access	147
6	Cryptocurrency forecasting with deep learning chaotic neural networks	2019	Chaos, Solitons and Fractals	139
7	Prediction of the price of Ethereum blockchain cryptocurrency in an industrial finance system	2020	Computers and Electrical Engineering	107
8	Bitcoin price forecasting with neuro-fuzzy techniques	2019	European Journal of Operational Research	98
9	Regulating Cryptocurrencies: A Supervised Machine Learning Approach to De-Anonymizing the Bitcoin Blockchain	2019	Journal of Management Information Systems	94
10	Predicting the direction, maximum, minimum and closing prices of daily Bitcoin exchange rate using machine learning techniques	2019	Applied Soft Computing Journal	90
11	A Deep Blockchain Framework-Enabled Collaborative Intrusion Detection for Protecting IoT and Cloud Networks	2021	IEEE Internet of Things Journal	79
12	Anticipating Cryptocurrency Prices Using Machine Learning	2018	Complexity	79
13	Bitcoin technical trading with artificial neural network	2018	Physica A: Statistical Mechanics and its Applications	74
14	A comparative study of bitcoin price prediction using deep learning	2019	Mathematics	70
15	Machine learning based privacy-preserving fair data trading in big data market	2019	Information Sciences	66

As a typical application of blockchain technology, cryptocurrencies, such as bitcoin, have received considerable interest from practitioners and researchers. The most cited work is “An Empirical Study on Modeling and Prediction of Bitcoin Prices with Bayesian Neural Networks Based on Blockchain Information,” which uses a Bayesian neural network to select information from the blockchain that is most relevant to the supply and demand of bitcoins to train the model, improving the performance of the price prediction model (Jang & Lee, 2017).

The productivity of a country or region partially reflects the degree of devotion to the chosen topic. The top 10 most productive countries or regions (all authors’ countries/regions are considered for each paper) are selected for comparison, as shown in Table 3. That Asia, rather than Europe with more developed countries/regions, has emerged as the research center of AI-enabled blockchain technology in business is surprising, with China, India, Taiwan (China), and South Korea together contributing more than half of the research (62.3%).

The affiliates of the authors (all the authors’ institutions are considered for each paper) are shown in Table 4. Fifty pieces (17.9%) are from the top 12 contributors, with Beijing University of Posts and Telecommunications and Seoul National University of Science and Technology contributing the most, yet only with seven papers. Such a result shows that the current research in this field lacks

Table 3. Number of publications by country or region

Ranking	Country/Region	Amount	Percentage
1	China	87	31.2%
2	India	45	16.1%
3	South Korea	33	11.8%
4	United States	28	10.0%
5	Saudi Arabia	21	7.5%
6	Canada	19	6.8%
7	United Kingdom	15	5.4%
8	Australia	13	4.7%
9	Taiwan (China)	9	3.2%
10	Egypt	9	3.2%

Table 4. Number of publications by institution

Ranking	Institution	Amount	Percentage
1	Beijing University of Posts and Telecommunications	7	2.5%
2	Seoul National University of Science and Technology	7	2.5%
3	Carleton University	6	2.2%
4	Institute of Technology, Nirma University	6	2.2%
5	Chinese Academy of Sciences	5	1.8%
6	Beijing University of Technology	5	1.8%
7	Jeju National University	5	1.8%
8	Sun Yat-Sen University	4	2%
9	King Abdulaziz University	4	1.4%
10	Sungkyunkwan University	4	1.4%
11	King Khalid University	4	1.4%
12	Guangzhou University	4	1.4%

concentrated and potent attention from institutions, resulting in a relatively dispersed research effort. This study is extensive, as 68 countries/regions and 160 institutions have contributed.

The top ten journals with the highest productivity in the specified research field are listed in Table 5. Regarding the number of articles, the series journals under IEEE are the most influential, with the IEEE Access ranking first (16 articles). Articles in this field have been primarily published in journals specialized in IoT and information science (IS) technology, including IEEE Internet of Things Journal (10 articles), Applied Soft Computing (9), and Expert Systems with Applications (9).

By further examining the citations of the journals using data sources from Scopus, the dominance of the IEEE series is the most pronounced (see Table 6). With 589 citations, IEEE Access is by far the most cited journal. Different from the table of the most productive journals, the table of the most cited journals illustrates the subdivided fields, such as computer systems (Future Generation Computer Systems), technology and society direction (IEEE Technology and Society Magazine), and operational research (European Journal of Operational Research). It is noteworthy that most of these journals

Table 5. Top 10 productive journals

Ranking	Source Journal	Total Publications	Total Citations
1	IEEE Access	16	589
2	IEEE Internet of Things Journal	10	159
3	Electronics (Switzerland)	9	122
4	Applied Sciences (Switzerland)	9	53
5	Expert Systems with Applications	7	93
6	Applied Soft Computing	6	60
7	Future Generation Computer Systems	6	278
8	IEEE Transactions on Network Science and Engineering	6	85
9	Mathematics	6	96
10	Sensors	6	20

Table 6. Top 10 cited journals

Rank by Citations	Source Journal	Total Publications	Total Citations
1	IEEE Access	16	589
2	IEEE Transactions on Industrial Informatics	5	295
3	Future Generation Computer Systems	6	278
4	IEEE Technology and Society Magazine	1	168
5	IEEE Internet of Things Journal	10	159
6	Chaos, Solitons and Fractals	1	139
7	Applied Soft Computing Journal	2	129
8	Electronics (Switzerland)	9	122
9	Computers and Electrical Engineering	4	112
10	European Journal of Operational Research	2	104

are top journals. Although the total publications of the journals are not among the top 10, their total citations have all entered the list of the top 10, demonstrating their leading role in the research fields.

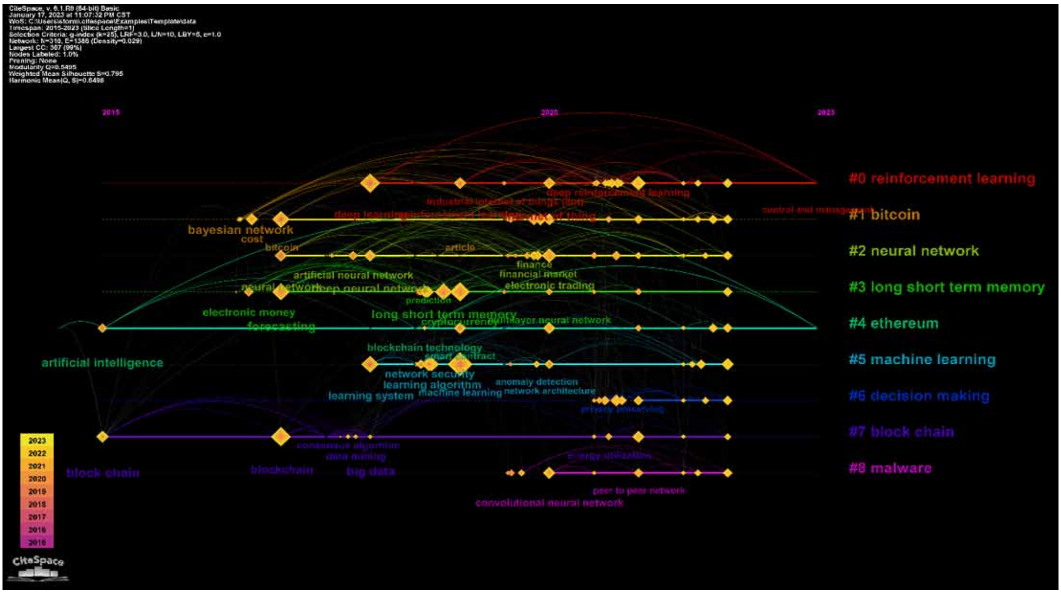
Bibliometric Analysis of Research Trends

Apart from statistical methods, bibliographic techniques help further identify the development trends of the research. Therefore, keyword co-occurrence analysis and co-citation analysis are conducted in this part to clarify the historical evolution of this line of research. Moreover, bibliographic coupling (Figure 6), citation sources (Figure 7), and co-authorship analysis (Figure 8) are supplemented in appendixes.

Timeline View of Keywords

The timeline view of the keyword co-occurrence network, created by CiteSpace, automatically generates labels (i.e., clusters) as time passes, enabling us to map the intellectual structure and reveal patterns and trends of the research (Ding et al., 2001). As shown in Figure 3, the time of the keywords increases sequentially from left to right, while the keywords within the same column

Figure 3. Timeline view of keyword co-occurrence



refer to studies conducted concurrently. On the right of the figure, we generated 9 clusters this way, with the keywords that appeared from 2005 to 2023 identified. Since the first article on AI-enabled blockchain was published in 2015, several AI algorithms and AI-enabled blockchain applications have been developed. Specifically, many intelligent AI algorithms have been implemented in the usage of blockchain technologies since 2017, including Bayesian neural networks, deep learning, artificial neural network, and learning systems. Big data, data mining, and consensus algorithms have been applied as complementary technologies. Bitcoin appears in the network as the earliest application scenario of AI-enabled blockchain.

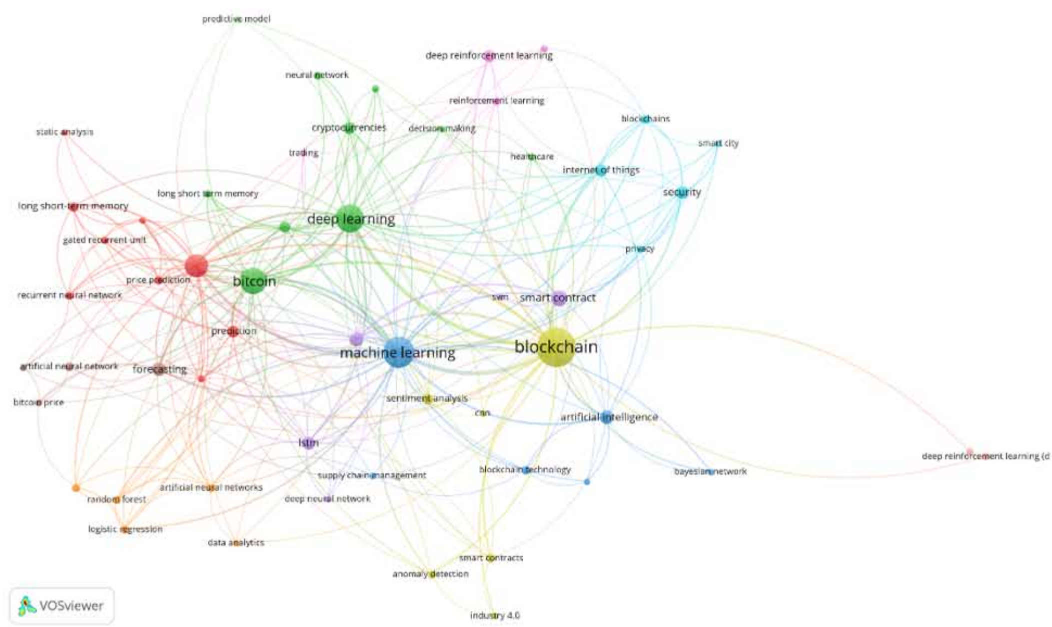
The research field has entered a new development phase with diverse business applications. Complex and novel AI-enabled blockchain applications blossomed in 2019, especially in the industrial Internet of Things, the financial market, electronic trading, and anomaly detection. Several future challenges have also been posed, including coordinating the relationship between AI and personal privacy and managing complex networks.

Cross-Sectional Analysis of Keywords

Keyword co-occurrence analysis at a cross-sectional level via VOSviewer (as shown in Figure 4) is widely used in various disciplines as a statistical technique (Rodriguez & Laio, 2014). It determines the main research directions in a particular field by analyzing the literature in a bibliometric way.

The lower-left corner involves the research of technologies, such as logistic regression, random forest, artificial neural networks, and LSTM, as well as its close relationship with prediction models and machine learning. Strong co-occurrences are identified between the research on healthcare and decision-making. In the center of the map, the co-occurrence links between “blockchain,” “deep learning,” and “machine learning” are the strongest, which reflects the high applicability of deep learning, a classical AI algorithm. Bitcoin is also in a prominent position, reflecting the upsurge in research related to cryptocurrency. The position of deep reinforcement learning in the lower right corner indicates it is a relatively marginalized field. However, in the upper right corner, the authors observe that deep reinforcement learning is often associated with IoT and smart cities through AI.

Figure 4. Author keyword co-occurrence in the current literature



Co-Citation Analysis

The authors use CiteSpace's built-in spectral clustering algorithm to cluster co-citations and draw the clustering analysis chart, as shown in Figure 5. Their relativity revealed the semantic relationship between different clusters. We can see it from the map that the citations of papers in the AI-enabled blockchain field are classified into 11 categories. Among them, the most heated research area is artificial intelligence. It has also established close links with other clusters, such as Ethereum price, cryptocurrency return, and artificial neural network. In contrast, the research on blockchain technology using a dual deep Q-learning approach is relatively isolated and has few connections with other clusters. Following Krishen et al. (2021), the authors further trace the dynamic evolution of research after co-citation analysis, with results shown in Figure 9.

Then, to discover the landmark publications that have contributed most to the research stream, CiteSpace is used to calculate the BC value of all cited papers. BC measures the extent to which a node is located in the center of other "node pairs" (centrality) in the graph (Freeman, 1978). In a group of nodes, nodes with a high BC value are more likely to act as mediators (namely clusters). Papers with a high BC value play a more critical role in the literature library. Table 7 shows the 10 articles with the highest BC value among all 279 cited for analysis. The TC of each paper is also counted.

Instead of merely using TC, calculating the BC value of each cited article can better reflect the article's contribution to the research field. According to the results, "Bitcoin price prediction using machine learning: An approach to sample dimension engineering," an article by Chen et al. (2020), has the highest BC value. This paper's investigation of Bitcoin price prediction can be considered a pilot study of the importance of the sample dimension in machine learning techniques. It inspires many researchers to predict cryptocurrency prices using AI, for example, in Bitcoin technical trading with artificial neural networks (Nakano et al., 2018). Generally, earlier articles are more likely to be cited and have a higher intermediary centrality, as shown in Table 7. Two papers with the highest BC value do not have the highest citations. Some articles published later have also played an important role in the research field. "IoT Security: Review, Blockchain Solutions, and Open Challenges" has the highest total citations. It presents and surveys major security issues for IoT (Khan & Salah, 2017),

Figure 5. Co-citation clusters of literature on AI-enabled blockchain in business

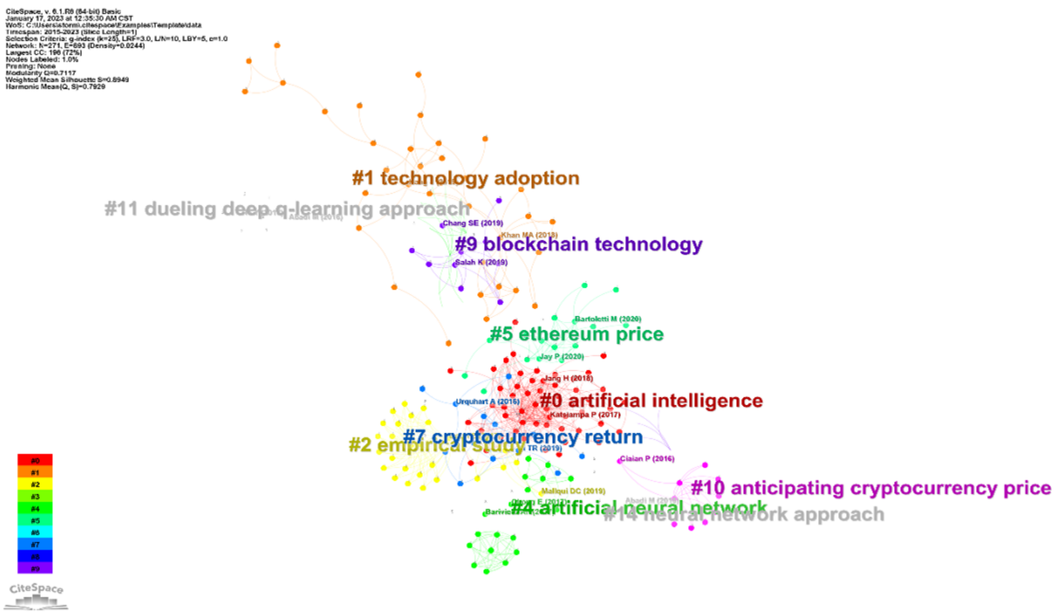


Table 7. Top 10 articles with the highest BC values

Author(s)	Year	BC	Title	TC
Chen et al.	2020	0.28	Bitcoin price prediction using machine learning: An approach to sample dimension engineering	102
Bouri et al.	2017	0.22	On the Hedge and Safe Haven Properties of Bitcoin: Is it Really More than a Diversifier?	560
Khaled & Salah	2018	0.14	IoT Security: Review, Blockchain Solutions, and Open Challenges	1343
Janssen et al.	2020	0.12	A framework for analysing blockchain technology adoption: Integrating institutional, market and technical factors	155
Jang & Lee	2018	0.10	An Empirical Study on Modeling and Prediction of Bitcoin Prices with Bayesian Neural Networks Based on Blockchain Information	214
Ciaian et al.	2016	0.10	The economics of Bitcoin price formation	466
Liu et al.	2019	0.10	Performance Optimization for Blockchain-Enabled Industrial Internet of Things (IIoT) Systems: A Deep Reinforcement Learning Approach	182
Dinh et al.	2018	0.09	Untangling Blockchain: A Data Processing View of Blockchain Systems	561
Ali et al.	2019	0.09	Applications of Blockchains in the Internet of Things: A Comprehensive Survey	379
Corbet et al.	2018	0.09	Datestamping the Bitcoin and Ethereum bubbles	308

with a BC value ranking third in Table 7. Surprisingly, the papers with the most contributions are cited the least, according to the table, showing that even papers with lower citations can still significantly contribute to the research field.

Content Analysis of the AI-Enabled Blockchain Application Literature

While the scientometric analysis presented in Section 3.2 summarizes the existing literature, it does not present the literature. Thus, the authors conduct a supplementary content analysis (Donthu et al., 2021). The authors analyze the extant literature and identify the main areas from technical and business perspectives, namely focusing on the technological development (i.e., the role of AI in enabling blockchain applications) and the business problems (i.e., ethical implications of the application of AI-enabled blockchain).

Roles of AI in Enabling Blockchain Applications

According to the literature, AI-enabled blockchain has a variety of business applications, which can be further categorized into 10 sectors, i.e., finance, manufacturing, transportation, healthcare, supply chain, social media, program monitoring, marketing, enterprise management, and Internet of Things (IoT) security. AI-enabled blockchain has showed or is expected to penetrate extensively in some sectors (e.g., finance, supply chain, and enterprise management) while performing more specialized roles in other sectors (e.g., software monitoring on the user side, copyright protection, and user recommendation). To understand the technical development of AI-enabled blockchain, the authors first discuss the role (i.e., function) of AI in enabling blockchain applications in different application sectors (see Table 8), and further summarize six key roles of AI in enabling blockchain applications (see Table 9).

In the financial sector, AI can facilitate the transaction and management of cryptocurrencies, a typical financial application of blockchain. Considering the volatility of cryptocurrency prices, it is difficult to gauge the trends and the extent of the changes. Several AI algorithms (e.g., recursive networks and CNN) have been used to forecast cryptocurrency price trends by analyzing characteristics of the cryptocurrency market (such as information awareness, investor sentiment, and the number of market investors) (Critien et al., 2022; Y. Wang et al., 2022). A previous study has compared different AI algorithms to determine the one with the best performance in predicting cryptocurrency prices (Hansun et al., 2022). In addition, AI can analyze market risks (Liu & Yu, 2022), detect financial fraud (Mazorra et al., 2022), and optimize mining strategies (Wang et al., 2021).

In the manufacturing industry, blockchain technology is expected to make manufacturing processes more flexible and imaginative as compared with cloud-based manufacturing. However, its application brings new challenges. The manufacturing industry requires a large production scale, high efficiency, and fast response, while blockchain throughput is limited and the block generation process is time-consuming. To realize large-scale and flexible manufacturing, firms can adopt deep learning to optimize block size, supply, and demand configurations, as well as maximize net profits (Teng et al., 2022). Similarly, deep reinforcement learning can improve the performance of IoT systems by leveraging the efficiency of the consensus mechanism in the blockchain (Yang et al., 2021).

As for the transportation industry, vehicles can be grouped into different trust levels by using intelligent transportation systems based on blockchain technology (e.g., Internet of vehicles). In this way, people can realize trust management (TM) of vehicles and save costs of operation and maintenance. However, false information poses a threat to such systems. A malicious upload of incorrect information may burden the blockchain and destroy the trust management mechanism. By calculating information credibility using deep learning, false statements can be pre-screened to a certain extent (S. Wang et al., 2022). In addition, the intelligent transportation system proposes a real-time traffic management scheme based on traffic information, and AI evaluates the feasibility of this traffic scheme after training (Masuduzzaman et al., 2022).

Table 8. Key areas of AI-enabled blockchain's technical applications

No.	Area	Application	Description	Source
1	Finance	Cryptocurrency price prediction	Using deep learning and other AI algorithms, researchers can predict the price of cryptocurrencies based on the changes in factors inside and outside the market.	(Wang et al., 2022)
		Market risk analysis	Risks of the financial market under the blockchain can be mined using decision trees and machine learning.	(Liu & Yu, 2022)
		Financial fraud detection	Financial transactions are anonymous with the use of blockchain technology; machine learning can compensate for the deficiencies of existing regulatory mechanisms.	(Mazorra et al., 2022)
		Optimal mining strategy	Reinforcement learning is adopted to dynamically learn mining strategies with the best performance on a time-varying blockchain network.	(Wang et al., 2021)
2	Manufacturing	Mass customization	A mass customization production framework based on blockchain technology and using artificial intelligence methods to optimize the process.	(Yetis et al., 2022)
		Smart manufacturing	AI and DQN algorithms are used to solve critical problems in an intelligent manufacturing system based on blockchain.	(Teng et al., 2022)
3	Transportation	Vehicle networking	A distributed trust mechanism is established for the Internet of vehicles based on the blockchain, and AI is used to assess the reliability of the information provided by vehicle nodes.	(Wang et al., 2022)
		Automatic traffic real-time management	In real-time traffic management, blockchain technology optimized by deep learning is used to store and use traffic flow information.	(Masuduzzaman et al., 2022)
4	Healthcare	Medical consultation	A blockchain-based consultation framework for small-scale medical consultations is established, which uses ML-based smart contracts to evaluate doctors and their consultations.	(Hassija et al., 2022)
		Security of medical Internet of Things	The security and privacy of the medical Internet of Things is improved using blockchain technology, and AI methods for security verification are adopted to improve safety and reduce delay.	(Al-Otaibi, 2022)
		Medical insurance fraud detection	The blockchain-based medical insurance database is traceable, and the use of deep learning methods in data transmission can improve the efficiency of searching fraud cases.	(Zhang et al., 2022)
5	Supply chain	Pharmaceutical cold chain management	Blockchain technology is used to manage the pharmaceutical supply chain, in which deep learning is used to establish a demand forecasting model for improving economic efficiency.	(Zhang et al., 2021)
		Risk control of supply chain finance	A fuzzy neural network is used to evaluate the financial credit risks of the blockchain supply chain.	(Wang, 2021)
6	Social media	Fake news detection	A machine learning method under the blockchain framework is used to detect fake news.	(Waghmare & Patnaik, 2021)
		False information dissemination control	Blockchain is used to control false information on Twitter, and machine learning is used as a classifier to replace the manual optimization process.	(Vignesh, 2019)

continued on following page

Table 8. Continued

No.	Area	Application	Description	Source
7	Cybersecurity	Smart contract vulnerability detection	Integrated learning is used to train multiple neural networks for vulnerability detection of smart contracts.	(Zhang et al., 2022)
		Malicious mining software detection	Deep learning is leveraged to detect encrypted malicious mining software by using static and dynamic analysis methods.	(Darabian et al., 2020)
		Smart home network security	A smart home network security architecture based on blockchain technology and using deep learning for intrusion detection has been developed.	(Farooq et al., 2022)
		Smart city network security	In terms of data transmission and IoT architecture, blockchain is adopted to ensure the network security of smart cities, and AI is used for intrusion detection.	(Al-Qarafi et al., 2022)
8	Marketing	Recommendation	A classification system based on blockchain technology and a machine learning training model for individuals are established, which can effectively process a large amount of user data and boost the accuracy of recommendations.	(Mann et al., 2022), (Bosri et al., 2021)
9	Organizational management	Performance evaluation of blockchain applications in small and micro enterprises	Machine learning is used to unveil the influencing factors of enterprises that have adopted blockchain technology and provide business leaders with recommendations on whether or not to adopt this technology.	(Hamdan et al., 2022)
		Performance evaluation of blockchain applications in real economy enterprises	The neural network is adopted to analyze and detect the vulnerabilities of smart contracts based on blockchain technology and reveal the role of blockchain technology in the development of the real economy.	(Shi & Huang, 2022)
10	Copyright	Detection of forged diplomas	Natural language processing technology and blockchain technology are used together to verify the authenticity of the diplomas and improve security.	(Kim, 2022)

In the healthcare industry, blockchain can reshape the old ways of establishing and organizing electronic medical records of patients, better protect patient privacy and enable smoother medical data sharing and medical cooperation. However, to meet practical needs, blockchain technology must be combined with big data and AI to sort out the data chain and mine the medical data pool for maximum value. By combining blockchain technology with AI, limited medical resources can fully cater to the increasing medical demand. For instance, AI and blockchain are used in medical consulting to establish an intelligent consulting system. While blockchain technology is used to create a personal account for everyone who enters the network, NLP is used to evaluate doctor consulting services (Hassija et al., 2022). Machine learning is used in the identity verification system for stronger patient privacy protection during the use of blockchain-based medical systems by providing authentication services with strong stability, high speed, and high accuracy (Al-Otaibi, 2022). To reduce medical insurance frauds, deep learning can improve the accuracy of text classification of insurance case data and reduce the workload of manual auditing (Zhang et al., 2022).

Traceability and visualization are the two prominent features of blockchain technology. Using a supply chain based on blockchain technology, the full life-cycle supervision of products can be realized, which is especially suitable for food, medicine, and other products that need to be traced back to their source. A large amount of data was generated during the supply chain operation, resulting in a burden on the blockchain storage system. AI can manage data through algorithms while reducing

Table 9. Key roles of AI in enabling blockchain applications

No.	Role	Interpretation	Performance	Reference
1	Prediction	AI makes use of existing knowledge or data to help predict the future trends of a specific business field.	In the financial field, AI is used to predict the return of cryptocurrencies using informed transactions.	(Wang et al., 2022)
			In the supply chain, machine learning is used to predict the adoption of blockchain technology.	(Kamble et al., 2021)
2	Optimization	With original constraints remaining unchanged, AI is an effective method for achieving better business objectives, including reducing time, money, and error costs.	As for a blockchain-based medical system, the use of machine learning for face recognition can improve the speed and accuracy of user security authentication.	(Al-Otaibi, 2022)
			In smart manufacturing, deep reinforcement learning (DRL) is used to optimize the allocation of equipment and reduce the weighted system cost for the IoT system.	(Yang et al., 2021)
			In finance, for tasks that consume a large amount of energy (such as mining), machine learning is adopted to improve efficiency and reduce energy consumption.	(Wang et al., 2021)
3	Value creation	In business, AI is used to realize a series of business activities for products or services required by customers.	In the marketing field, deep learning and knowledge map are combined with blockchain technology to process authorized data of customers and provide recommendations.	(Zhang & Kim, 2022)
			In medical consulting, two AI technologies, word vector and deep learning are used to evaluate the performance of doctors and provide services in the blockchain-based consultation framework.	(Hassija et al., 2022)
4	Forgery prevention	AI is used to improve the verifiability and realize anti-counterfeiting.	In the field of copyright protection, NLP and other technologies are applied to online diploma verification to prevent diploma forgery and protect intellectual property rights.	(Kim, 2022)
5	Risk identification	Based on existing data, various methods are used to comprehensively identify and objectively evaluate potential risks in the commercial field.	The vulnerability prediction method based on ensemble learning (EL) can accurately identify the vulnerabilities of smart contracts.	(Zhang et al., 2022)
			In finance, the identification and prediction of financial risks related to bitcoin investment can help relieve the anxiety about bitcoin investment and make rational decisions.	(Aljojo, 2022)
			In finance, unsupervised machine learning is applied to the cryptocurrency framework to combat cryptocurrency money laundering and strengthen risk management of the cryptocurrency market.	(Shahbazi & Byun, 2022)
6	Evaluation	AI is used to replace the existing AHP, TOPSIS, and other traditional evaluation methods for comprehensive evaluation based on big data;	The deep learning model is employed in transportation to comprehensively evaluate the real-time transportation scheme enabled by the blockchain technology, such as energy consumption, throughput, authentication time, and complexity.	(Masuduzzaman et al., 2022)
			In enterprise management, neural networks and deep learning are used to measure and evaluate the benefits of enterprises adopting blockchain technology.	(Hamdan et al., 2022)

supply chain costs and risks. For example, an excessive supply of goods in the cold chain transportation of pharmaceutical products is likely to cause a waste of storage costs. By contrast, insufficient supply could cause a shortage of drugs, posing a potential threat to life (Hosseini Bamakan et al., 2021). In a previous study (Zhang et al., 2021), demand forecasting was conducted through deep learning to develop procurement schemes and improve the response speed of the cold chain. With the development of supply chain finance, enterprises are now exposed to credit risks. By integrating financial information into the blockchain and using a fuzzy neural network for risk assessment, Wang (2021) effectively improved the risk management performance.

In the realm of social media, AI-enabled blockchain can be leveraged to combat the spread of false information. Specifically, as a blockchain-based social media framework is decentralized, the costs of revoking false news can be reduced. Machine learning techniques can also be applied to the framework to minimize human labor for detecting fake news, significantly saving money and time (Waghmare & Patnaik, 2021). Similar approaches have been adopted by Twitter (Vignesh, 2019).

In the cybersecurity industry, AI plays a critical role in various contexts of blockchain applications. However, as blockchain applications have become more widespread, cybersecurity issues have been more prevalent than ever, posing new challenges to management. For instance, blockchain data is extremely unstructured, making it hard to obtained; the data types are complex and challenging to process; conventional methods cannot detect the vulnerabilities of smart contracts effectively. Consequently, AI has become a critical tool for ensuring the security of blockchain applications. AI, for example, can detect vulnerabilities in smart contracts (Zhang et al., 2022) and malicious mining software (Darabian et al., 2020) more accurately and sensitively. Moreover, in the context of smart cities, where blockchain technology is often used to ensure smooth data transmission, reliable resource mobilization, and the data privacy protection, AI is critical in ensuring timely response and necessary resource allocation in cases of emergency (Sanghami et al., 2022). In addition, a series of AI techniques (such as deep learning and HBO algorithm) can detect database intrusions and protect smart cities from cyberattacks (Al-Qarafi et al., 2022; Farooq et al., 2022).

In the marketing industry, while the application of blockchain technology provides a more personalized and private user experience in transmitting and leveraging user data, AI is also critical in mining user information in the data stream, which allows firms to better understand users' needs, provide accurate services, and enhance personalization capabilities. For example, AI can build stronger recommendation systems for a wide range of products, from specific dietary programs (Mann et al., 2022) to items on e-commerce platforms (Bosri et al., 2021).

In terms of organizational management, AI facilitates the evaluation and key decision-making processes on blockchain adoption. Despite blockchain's ability to foster inter-organizational collaborations by reducing trust costs, it is still not a straightforward decision to adopt the technology because of the high operation and maintenance costs, as well as the high complexity of the business environment. At this point, AI may help make better decisions regarding blockchain applications. For instance, by conducting neural network analysis and Bayesian network analysis of firm data, the authors can be able to identify the key factors that influence firms to make use of blockchain technology (Faasolo & Sumarliah, 2022; Hamdan et al., 2022). Several AI algorithms (such as DL and NN) have been employed to demonstrate the critical role of blockchain in enterprise financing under this stream of research (Shi & Huang, 2022).

Finally, in the copyright industry, blockchain has been widely used in the storage and verification of copyright data. Although there are problems, such as low storage efficiency and a limited scope of applicable copyrights, adopting AI can save time costs, improve scalability, and strengthen copyright protection. As an example, in blockchain diploma applications, AI techniques (NLP and DL) can be used to improve the efficiency of detecting fake diplomas and enhance the verifiability of copyrights (Kim, 2022).

Ethical Implications of the Application of AI-Enabled Blockchain

Besides identifying the domains that can adopt AI in blockchain applications and revealing the role AI plays in each domain, our content analysis presents increased research attention and concerns regarding ethical issues related to the applications, such as privacy, fairness, and dignity. These ethical implications are sorted out in this sub-section based on Ashok's conceptual framework (Ashok et al., 2022), which divides digital ethical issues into 14 categories. Drawing upon this typology, we identified the referred ethical issues at three levels: individual, firm, and societal (see Table 10). In this manner, ethical implications are objective and comprehensive, covering both advantages and disadvantages.

Table 10. Ethical issues in the current literature

No.	Level of Analysis	Referred Ethical Issues
1	Individual level	Privacy concerns (Kim et al., 2019) (Yin et al., 2019); Autonomy (Yetis et al., 2022); Intelligibility (Dolatsara et al., 2022); dignity and well-being (Al-Otaibi, 2022; Hassija et al., 2022)
2	Firm level	Algorithm bias (Wu et al., 2021); higher prosperity (Hamdan et al., 2022; Yetis et al., 2022; Zhang & Kim, 2022; L. Zhang et al., 2022); sustainability (Otoum & Mouftah, 2021)
3	Societal level	Harm for regulators (Yetis et al., 2022); convenience for regulators (Zhao et al., 2022); carbon neutralization (Calvo-Pardo et al., 2022); privacy protection (Farooq et al., 2022); sustainability (Sharma et al., 2021); security (Singh et al., 2021)

At the individual level, the extant literature has showed mixed ethical implications of using AI in blockchain applications. On the one hand, there are several positive moral implications, such as increased intelligibility (Dolatsara et al., 2022), autonomy (Yetis et al., 2022), and dignity and well-being (Al-Otaibi, 2022; Hassija et al., 2022). There are also negative moral implications, including increased privacy disclosure (Kim et al., 2019; Yin et al., 2019).

There are positive moral implications at the firm level, such as higher prosperity (Hamdan et al., 2022; Yetis et al., 2022; Zhang & Kim, 2022; L. Zhang et al., 2022) and improved sustainability (Otoum & Mouftah, 2021). Dark sides also exist, such as algorithm bias and reduced levels of fairness (Wu et al., 2021).

There is an extensive discussion on the ethical implications at the societal level. On the positive side, using AI in blockchain applications may improve cybersecurity status and prevent data leakage (Farooq et al., 2022; Singh et al., 2021), enhance sustainability through energy conservation and emission reduction (Calvo-Pardo et al., 2022; Sharma et al., 2021), and strengthen market supervision by using AI for data mining (Zhao et al., 2022). However, several new regulatory challenges associated with the use of AI and blockchain applications (Yetis et al., 2022) have been presented to the legislative departments.

In addition to the above analysis, the authors further conclude the existing literature from micro-, meso-, and macro-levels to develop a deeper understanding of AI and its corresponding ethical implications.

Micro-Level: The application of AI may violate citizens' privacy. Anonymity is an essential feature of blockchain, which is one reason why it is widely used in electronic voting. The irreversibility and anonymity of blockchain technology protects voters' privacy and voting rights, enhancing people's willingness to vote. However, the AI algorithm developed to strengthen the supervision of cryptocurrency transactions can, to some extent, crack the anonymity of the blockchain and reveal the addresses of the nodes. Although the current cracking rate is not high, once this technology is further developed and maliciously applied to many blockchain-based information storage systems, citizens' privacy will be highly at risk.

Another privacy risk is that a large amount of real-world data is required prior to the deployment and application of AI. Users' behavior data is often extracted directly from blockchain nodes for model training in many existing blockchain-based IoT systems. This practice has not yet been restricted by legislation, but citizens would be concerned about potentially misusing their personal information.

Meso-Level: Applying AI to the blockchain may raise concerns regarding employee dignity and welfare. AI technology in an industrial IoT maximizes economic benefits through the rational arrangement and scheduling of various resources, including human resources (Teng et al., 2022). In addition, as AI algorithms focus too much on quantitative information, they may exert excessive pressure on employees. It may be detrimental we ignore to the dignity and welfare of employees if their feelings and motivations.

Algorithmic discrimination is another primary concern. For example, AI and NLP are now commonly used to assess the performance of doctors via a blockchain-based medical consultation system in healthcare (Hassija et al., 2022); however, a few silent and poor people will get conclusions that do not conform to their actual situation when browsing the comprehensive assessments of the doctors, whose customers are relatively wealthy in the past. Thus, such a consultation program's assessment may incur algorithmic bias because the data source for the training itself carries a particular bias.

Macro-Level: AI ethical issues pose many challenges to legislation, mainly due to AI algorithms' lack of accountability and transparency. The AI algorithms are black boxes. Even developers may not be aware of how data train AI models to think. Interpretability is essential to build people's trust in technology. In recent years, AI and blockchain technologies have been put into practice too quickly, resulting in a gap between legislative requirements and technological advancements. Some businesses may hesitate to use such technologies because of the absence of laws. Some may risk potential violations to gain considerable profits during the transitional period when policies are not formulated, leading to unfairness. To ensure more accountable applications of AI in the blockchain, it is necessary to put an effective human monitoring mechanism in place. The first step is to define the rights and responsibilities of each party. We should hold human users accountable when applying such digital technologies.

DISCUSSIONS

This study presents a systematic bibliometric-content analysis on AI-enabled blockchain in business. The findings, implications for theory and practice, and limitations of this work will be discussed below.

Key Findings

Through a descriptive analysis, the authors uncover the current status of this brand-new research field. The number of publications on AI-enabled blockchain in business is growing steadily (see Figure 2). Moreover, the citations of papers show that "cryptocurrency" is a heated research area currently (see Table 2). Instead of Europe with more developed countries and regions, Asia has become the center for research on AI-enabled blockchain in business (see Table 3). According to Table 4, different countries and regions have focused on various aspects of the research stream and made original contributions. Table 5 and 6 show that relevant research is now heavily oriented towards technology and engineering, based on the list of key outlet journals (e.g., IEEE series journals). It is expected that journals and scholars from diverse backgrounds would be involved in this academic conversation, just like what happened with many other important technologies.

Second, this research area's development is driven by AI's advancement and the enrichment of blockchain application scenarios. Results of the timeline view of keywords and descriptive analysis unveil the development stages and trends of this line of research: (1) Initial stage (2015-2017): the idea of combining AI and blockchain was first proposed in 2015, and a number of AI algorithms and applications have been developed since then; (2) Rapid development (2018-2019): publications in the Scopus database increased rapidly every year, and various AI technologies emerged; (3) Diversified application scenarios (2020-): rather than specific technologies, the application scenarios of AI-enabled blockchain technology dominate the center of the map, demonstrating that the applications of the technology are increasingly diverse. A cross-sectional view of keywords further identifies that "blockchain," "deep learning," and "machine learning" are the strongest foci, all of which have strong connections to specific techniques and applications (i.e., strong co-occurrences).

Third, through content analysis, this study reveals the 10 key areas for the application of AI-enabled blockchain, namely finance (Liu & Yu, 2022; Mazorra et al., 2022; Wang et al., 2021; Wang et al., 2022) smart manufacturing (Teng et al., 2022; Yetis et al., 2022), supply chain (Wang, 2021; Zhang et al., 2021), healthcare (Al-Otaibi, 2022; Hassija et al., 2022; G. Zhang et al., 2022), transportation (Masuduzzaman et al., 2022; S. Wang et al., 2022), social media (Vignesh, 2019; Waghmare & Patnaik, 2021), cybersecurity (Darabian et al., 2020; Farooq et al., 2022; L. Zhang et al., 2022), marketing (Bosri et al., 2021; Mann et al., 2022), organizational management (Hamdan et al., 2022; Shi & Huang, 2022), and copyright protection (Kim, 2022). It is also revealed that AI mainly plays six roles in applications: prediction (Kamble et al., 2021; Y. Wang et al., 2022), optimization (Al-Otaibi, 2022; Wang et al., 2021), value creation (Hassija et al., 2022; Zhang & Kim, 2022), forgery prevention (Kim, 2022), risk identification (Aljojo, 2022; Shahbazi & Byun, 2022; Zhang et al., 2022), and assessment (Hamdan et al., 2022; Masuduzzaman et al., 2022). The combination of AI and blockchain is significantly beneficial to business applications by improving efficiency, reducing costs, and creating value. For future research, the authors expect to explore a broader range of AI-enabled blockchain applications.

Fourth, through content analysis, the ethical issues associated with AI-enabled blockchain technology in business are discussed mainly at three levels (individual, firm, and societal). Based on Ashok's conceptual framework (Ashok et al., 2022), we categorize the issues into 14 groups. Besides, AI's role and the corresponding ethical concerns are analyzed from micro, meso, and macro levels. Citizens' privacy may be violated because of the misuse of AI supervision at the micro level; employees' dignity and welfare may be at risk because of algorithmic discrimination at the meso level; legislation challenges exist at the macro level, as current AI algorithms are black boxes because of low accountability and transparency.

Theoretical and Practical Implications

Theoretically, this study identifies the dominant themes, most contributing authors, influential papers, and the distribution of journal publications in the discussed research field, allowing readers to track the evolution of literature. Specifically, the authors discuss the status quo (i.e., yearly growth, cited papers, countries/regions, institutions, journals), growth trajectories, and topical focus of AI-enabled blockchain. Undoubtedly, AI-enabled blockchain in business is a potential topic of interest currently. From the timeline view, three development stages are identified. Besides, the three key focuses, namely "blockchain," "deep learning," and "machine learning," are revealed by the cross-sectional view. "Cryptocurrency" is also found to be a heated topic at present.

Practically, the authors reveal ten areas and scenarios in which AI is used to support blockchain applications in business, as well as the six roles AI plays in such applications. Our findings can help developers and service providers better adapt applications to different scenarios regarding such technological development. The ethical issues associated are also discussed from micro-, meso-, and macro-levels, providing developers and service providers with ethical implications (e.g., take precautions according to the potential cause).

Limitations and Recommendations for Future Research

There are still limitations to this study, which invite further investigation and research. First, this research only examines formal literature reviews during the data retrieval. Other sources like conference proceedings, monographs, and book chapters can be considered as more diversified clues in the future. Second, we only unveil AI's roles in business settings and the corresponding ethical concerns, leaving the question of how to solve the problems open for further exploration.

CONFLICT OF INTEREST

The authors of this publication declare there are no competing interests.

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REFERENCES

Abbas, K., Afaq, M., Ahmed Khan, T., & Song, W. (2020). A blockchain and machine learning-based drug supply chain management and recommendation system for smart pharmaceutical industry. *Electronics (Basel)*, *9*(5), 852. doi:10.3390/electronics9050852

Aboamer, M. A., Sikkandar, M. Y., Gupta, S., Vives, L., Joshi, K., Omarov, B. S., & Singh, S. K. (2022). An investigation in analyzing the food quality well-being for lung cancer using blockchain through CNN. *Journal of Food Quality*, *5845870*, 1–11. Advance online publication. doi:10.1155/2022/5845870

Adel, K., Elhakeem, A., & Marzouk, M. (2022). Decentralizing construction AI applications using blockchain technology. *Expert Systems with Applications*, *194*, 116548. doi:10.1016/j.eswa.2022.116548

Akter, S., Dwivedi, Y. K., Sajib, S., Biswas, K., Bandara, R. J., & Michael, K. (2022). Algorithmic bias in machine learning-based marketing models. *Journal of Business Research*, *144*, 201–216. doi:10.1016/j.jbusres.2022.01.083

Al-Otaibi, Y. D. (2022). K-nearest neighbour-based smart contract for Internet of medical things security using blockchain. *Computers & Electrical Engineering*, *101*, 108129. doi:10.1016/j.compeleceng.2022.108129

Al-Qarafi, A., Alrowais, F. M. S., Alotaibi, S., Nemri, N., Al-Wesabi, F. N., Al Duhayyim, M., Marzouk, R., Othman, M., & Al-Shabi, M. (2022). Optimal machine learning based privacy preserving blockchain assisted internet of things with smart cities environment. *Applied Sciences (Basel, Switzerland)*, *12*(12), 5893. doi:10.3390/app12125893

Ali, M. S., Vecchio, M., Pincheira, M., Dolui, K., Antonelli, F., & Rehmani, M. H. (2019). Applications of blockchains in the internet of things: A comprehensive survey. *IEEE Communications Surveys and Tutorials*, *21*(2), 1676–1717. doi:10.1109/COMST.2018.2886932

Aljojo, N. (2022). Predicting financial risk associated to bitcoin investment by deep learning. *Advances in Distributed Computing and Artificial Intelligence Journal*, *11*(1), 5–18. doi:10.14201/adcaij.27269

Alkan, B. Ş. (2022). How blockchain and artificial intelligence will effect the cloud-based accounting information systems? In S. Bozkuş Kahyaoğlu (Ed.), The impact of artificial intelligence on governance, economics and finance (vol. 2, pp. 107-119). Springer Nature Singapore. doi:10.1007/978-981-16-8997-0_6

Anand, A., Argade, P., Barkemeyer, R., & Salignac, F. (2021). Trends and patterns in sustainable entrepreneurship research: A bibliometric review and research agenda. *Journal of Business Venturing*, *36*(3), 106092. doi:10.1016/j.jbusvent.2021.106092

Aramo-Immonen, H., Carlborg, P., Hasche, N., Jussila, J., Kask, J., Linton, G., Mustafee, N., & Öberg, C. (2020). Charting the reach and contribution of IMP literature in other disciplines: A bibliometric analysis. *Industrial Marketing Management*, *87*, 47–62. doi:10.1016/j.indmarman.2020.02.022

Ashok, M., Madan, R., Joha, A., & Sivarajah, U. (2022). Ethical framework for artificial intelligence and digital technologies. *International Journal of Information Management*, *62*, 102433. doi:10.1016/j.ijinfomgt.2021.102433

Bartikowski, B., Laroche, M., & Richard, M. (2019). A content analysis of fear appeal advertising in Canada, China, and France. *Journal of Business Research*, *103*, 232–239. doi:10.1016/j.jbusres.2019.01.049

Bosri, R., Rahman, M. S., Bhuiyan, M. Z. A., & Al Omar, A. (2021). Integrating Blockchain with artificial intelligence for privacy-preserving recommender systems. *IEEE Transactions on Network Science and Engineering*, *8*(2), 1009–1018. doi:10.1109/TNSE.2020.3031179

Bouri, E., Molnár, P., Azzi, G., Roubaud, D., & Hagfors, L. I. (2016). On the hedge and safe haven properties of Bitcoin: Is it really more than a diversifier? *Finance Research Letters*, *20*, 192–198. doi:10.1016/j.frl.2016.09.025

Boyle, F., & Sherman, D. (2006). Scopus™: The product and its development. *The Serials Librarian*, *49*(3), 147–153. doi:10.1300/J123v49n03_12

Burnham, J. F. (2006). Scopus database: A review. *Biomedical Digital Libraries*, *3*(1), 1. doi:10.1186/1742-5581-3-1 PMID:16522216

Calvo-Pardo, H. F., Mancini, T., & Olmo, J. (2022). Machine learning the carbon footprint of bitcoin mining. *Journal of Risk and Financial Management*, *15*(2), 71. doi:10.3390/jrfm15020071

Campbell, C., Sands, S., Ferraro, C., Tsao, H. Y., & Mavrommatis, A. (2020). From data to action: How marketers can leverage AI. *Business Horizons*, *63*(2), 227–243. doi:10.1016/j.bushor.2019.12.002

Chen, Z., Li, C., & Sun, W. (2020). Bitcoin price prediction using machine learning: An approach to sample dimension engineering. *Journal of Computational and Applied Mathematics*, *365*, 112395. doi:10.1016/j.cam.2019.112395

Ciaian, P., Rajcaniova, M., & Kancs, D. (2014). The economics of BitCoin price formation. *Applied Economics*, *48*(19), 1799–1815. doi:10.1080/00036846.2015.1109038

Contreras, F., & Abid, G. (2022). Social sustainability studies in the 21st Century: A bibliometric mapping analysis using VOSviewer Software. *Pakistan Journal of Commerce and Social Sciences*, *16*(1), 167–203.

CorbetS.LuceyB. M.YarovayaL. (2017). Datestamping the bitcoin and ethereum bubbles. *ERN: Other Econometric Modeling: Capital Markets - Asset Pricing (Topic).* https://doi.org/10.2139/ssrn.3079712

Critien, J. V., Gatt, A., & Ellul, J. (2022). Bitcoin price change and trend prediction through Twitter sentiment and data volume. *Financial Innovation*, *8*(1), 1–20. doi:10.1186/s40854-022-00352-7

Darabian, H., Homayounoot, S., Dehghantanha, A., Hashemi, S., Karimipour, H., Parizi, R. M., & Choo, K. K. R. (2020). Detecting cryptomining malware: A deep learning approach for static and dynamic analysis. *Journal of Grid Computing*, *18*(2), 293–303. doi:10.1007/s10723-020-09510-6

Ding, X., & Yang, Z. (2020). Knowledge mapping of platform research: A visual analysis using VOSviewer and CiteSpace. *Electronic Commerce Research*, *22*, 1–23. doi:10.2991/aebmr.k.191225.081

Ding, Y., Chowdhury, G. G., & Foo, S. (2001). Bibliometric cartography of information retrieval research by using co-word analysis. *Information Processing & Management*, *37*(6), 817–842. doi:10.1016/S0306-4573(00)00051-0

Dinh, T. T., Liu, R., Zhang, M., Chen, G., Ooi, B. C., & Wang, J. (2017). Untangling Blockchain: A data processing view of blockchain systems. *IEEE Transactions on Knowledge and Data Engineering*, *30*(7), 1366–1385. doi:10.1109/TKDE.2017.2781227

Dolatsara, H. A., Kibis, E., Caglar, M., Simsek, S., Dag, A., Dolatsara, G. A., & Delen, D. (2022). An interpretable decision-support systems for daily cryptocurrency trading. *Expert Systems with Applications*, *203*, 117409. doi:10.1016/j.eswa.2022.117409

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research*, *133*, 285–296. doi:10.1016/j.jbusres.2021.04.070

Donthu, N., Kumar, S., Pandey, N., Pandey, N., & Mishra, A. (2021). Mapping the electronic word-of-mouth (eWOM) research: A systematic review and bibliometric analysis. *Journal of Business Research*, *135*, 758–773. doi:10.1016/j.jbusres.2021.07.015

Donthu, N., Kumar, S., & Pattnaik, D. (2020). Forty-five years of Journal of Business Research: A bibliometric analysis. *Journal of Business Research*, *109*, 1–14. doi:10.1016/j.jbusres.2019.10.039

Duriau, V. J., Reger, R. K., & Pfarrer, M. D. (2007). A content analysis of the content analysis literature in organization studies: Research themes, data sources, and methodological refinements. *Organizational Research Methods*, *10*(1), 5–34. doi:10.1177/1094428106289252

Faasolo, M. B., & Sumarliah, E. (2022). An artificial neural network examination of the intention to implement blockchain in the supply chains of SMEs in Tonga. *Information Resources Management Journal*, *35*(1), 1–27. Advance online publication. doi:10.4018/IRMJ.287907

Fang, Y., Yin, J., & Wu, B. (2017). Climate change and tourism: A scientometric analysis using CiteSpace. *Journal of Sustainable Tourism*, *26*(1), 1–19. doi:10.1080/09669582.2017.1329310

Farooq, M. S., Khan, S., Rehman, A., Abbas, S., Khan, M. A., & Hwang, S. O. (2022). Blockchain-based smart home networks security empowered with fused machine learning. *Sensors (Basel)*, *22*(12), 4522. doi:10.3390/s22124522 PMID:35746303

Freeman, L. C. (1978). Centrality in social networks conceptual clarification. *Social Networks*, *1*(3), 215–239. doi:10.1016/0378-8733(78)90021-7

Gaur, A., & Kumar, M. (2017). A systematic approach to conducting review studies: An assessment of content analysis in 25 years of IB research. *Journal of World Business*, *53*(2), 280–289. doi:10.1016/j.jwb.2017.11.003

Hamdan, I. K. A., Aziguli, W., Zhang, D., Sumarliah, E., & Fauziyah, F. (2022). A machine learning method to predict the technology adoption of blockchain in Palestinian firms. *International Journal of Emerging Markets*, *17*(4), 1008–1029. doi:10.1108/IJOEM-05-2021-0769

Hansun, S., Wicaksana, A., & Khaliq, A. Q. M. (2022). Multivariate cryptocurrency prediction: Comparative analysis of three recurrent neural networks approaches. *Journal of Big Data*, *9*(1), 50. doi:10.1186/s40537-022-00601-7

Hassija, V., Ratnakumar, R., Chamola, V., Agarwal, S., Mehra, A., Kanhere, S. S., & Binh, H. T. T. (2022). A machine learning and blockchain based secure and cost-effective framework for minor medical consultations. *Sustainable Computing: Informatics and Systems*, *35*, 100651. doi:10.1016/j.suscom.2021.100651

Hosseini Bamakan, S. M., Ghasemzadeh Moghaddam, S., & Dehghan Manshadi, S. (2021). Blockchain-enabled pharmaceutical cold chain: Applications, key challenges, and future trends. *Journal of Cleaner Production*, *302*, 127021. doi:10.1016/j.jclepro.2021.127021

Hota, P. K., Subramanian, B., & Narayanamurthy, G. (2020). Mapping the intellectual structure of social entrepreneurship research: A citation/co-citation analysis. *Journal of Business Ethics*, *166*(1), 89–114. doi:10.1007/s10551-019-04129-4

Hussain, A. A., & Al-Turjman, F. (2021). Artificial intelligence and blockchain: A review. *Transactions on Emerging Telecommunications Technologies*, *32*(9), e4268. doi:10.1002/ett.4268

Jang, H., & Lee, J. (2017). An empirical study on modeling and prediction of bitcoin prices with bayesian neural networks based on blockchain information. *IEEE Access : Practical Innovations, Open Solutions*, *6*, 5427–5437. doi:10.1109/ACCESS.2017.2779181

Janssen, M., Weerakkody, V., Ismagilova, E., Sivarajah, U., & Irani, Z. (2020). A framework for analysing blockchain technology adoption: Integrating institutional, market and technical factors. *International Journal of lnformation. International Journal of Information Management*, *50*, 302–309. doi:10.1016/j.ijinfomgt.2019.08.012

Kamble, S. S., Gunasekaran, A., Kumar, V., Belhadi, A., & Foropon, C. (2021). A machine learning based approach for predicting blockchain adoption in supply Chain. *Technological Forecasting and Social Change*, *163*, 120465. doi:10.1016/j.techfore.2020.120465

Katsiampa, P. (2017). Volatility estimation for Bitcoin: A comparison of GARCH models. *Economics Letters*, *158*, 3–6. doi:10.1016/j.econlet.2017.06.023

Kazim, E., & Koshiyama, A. S. (2021). A high-level overview of AI ethics. *Patterns (New York, N.Y.)*, *2*(9), 100314. doi:10.1016/j.patter.2021.100314 PMID:34553166

Khan, M. A., & Salah, K. (2017). IoT security: Review, blockchain solutions, and open challenges. *Future Generation Computer Systems*, *82*, 395–411. doi:10.1016/j.future.2017.11.022

Khlystova, O., Kalyuzhnova, Y., & Belitski, M. (2022). The impact of the COVID-19 pandemic on the creative industries: A literature review and future research agenda. *Journal of Business Research*, *139*, 1192–1210. doi:10.1016/j.jbusres.2021.09.062 PMID:34629569

Kim, H., Kim, S. H., Hwang, J. Y., & Seo, C. (2019). Efficient privacy-preserving machine learning for blockchain network. *IEEE Access : Practical Innovations, Open Solutions*, *7*, 136481–136495. doi:10.1109/ACCESS.2019.2940052

Kim, S. K. (2022). Blockchain smart contract to prevent forgery of degree certificates: Artificial intelligence consensus algorithm. *Electronics (Basel)*, *11*(14), 2112. doi:10.3390/electronics11142112

Koufogiannakis, D., Slater, L., & Crumley, E. (2004). A content analysis of librarianship research. *Journal of Information Science*, *30*(3), 227–239. doi:10.1177/0165551504044668

Krishen, A. S., Dwivedi, Y. K., Bindu, N., & Kumar, K. S. (2021). A broad overview of interactive digital marketing: A bibliometric network analysis. *Journal of Business Research*, *131*, 183–195. doi:10.1016/j.jbusres.2021.03.061

Kumar, S., Lim, W. M., Sivarajah, U., & Kaur, J. (2022). Artificial intelligence and blockchain integration in business: Trends from a bibliometric-content analysis. *Information Systems Frontiers*, *25*, 871–896. doi:10.1007/s10796-022-10279-0 PMID:35431617

Lahmiri, S., & Bekiros, S. (2019). Cryptocurrency forecasting with deep learning chaotic neural networks. *Chaos, Solitons, and Fractals*, *118*, 35–40. doi:10.1016/j.chaos.2018.11.014

Lim, W. M., Rasul, T., Kumar, S., & Ala, M. (2022). Past, present, and future of customer engagement. *Journal of Business Research*, *140*, 439–458. doi:10.1016/j.jbusres.2021.11.014

Liu, M., Yu, F. R., Teng, Y., Leung, V. C., & Song, M. (2019). Performance optimization for blockchain-enabled industrial internet of things (IIoT) systems: A deep reinforcement learning approach. *IEEE Transactions on Industrial Informatics*, *15*(6), 3559–3570. doi:10.1109/TII.2019.2897805

Liu, T., & Yu, Z. (2022). The analysis of financial market risk based on machine learning and particle swarm optimization algorithm. *EURASIP Journal on Wireless Communications and Networking*, *2022*(1), 31. doi:10.1186/s13638-022-02117-3

Mann, S., Balyan, A., Rohilla, V., Gupta, D., Gupta, Z., & Rahmani, A. W. (2022). Artificial intelligence-based blockchain technology for skin cancer investigation complemented with dietary assessment and recommendation using correlation analysis in elder individuals. *Journal of Food Quality*, *3958596*, 1–7. Advance online publication. doi:10.1155/2022/3958596

Masuduzzaman, M., Islam, A., Sadia, K., & Shin, S. Y. (2022). UAV-based MEC-assisted automated traffic management scheme using blockchain. *Future Generation Computer Systems*, *134*, 256–270. doi:10.1016/j.future.2022.04.018

Mazorra, B., Adan, V., & Daza, V. (2022). Do not rug on me: Leveraging machine learning techniques for automated scam detection. *Mathematics*, *10*(6), 949. doi:10.3390/math10060949

Morse, L., Teodorescu, M. H. M., Awwad, Y., & Kane, G. C.(2021). Do the ends justify the means? Variation in the distributive and procedural fairness of machine learning algorithms. *Journal of Business Ethics, 181*(2022), 1083–1095. 10.1007/s10551-021-04939-5

Nakano, M., Takahashi, A., & Takahashi, S. (2018). Bitcoin technical trading with artificial neural network. *Physica A*, *510*, 587–609. doi:10.1016/j.physa.2018.07.017

Nooy, D. W., Mrvar, A., & Batagelj, V. (2018). *Exploratory social network analysis with Pajek* (3rd ed.). Cambridge University Press. doi:10.1017/CBO9780511806452

Obregon, S. L., Lopes, L. F., Kaczam, F., da Veiga, C. P., & da Silva, W. V. (2021). Religiosity, spirituality and work: A systematic literature review and research directions. *Journal of Business Ethics*, *179*(2), 573–595. doi:10.1007/s10551-021-04856-7

Otoum, S., & Mouftah, H. T. (2021). Enabling trustworthiness in sustainable energy infrastructure through blockchain and AI-assisted solutions. *IEEE Wireless Communications*, *28*(6), 19–25. doi:10.1109/MWC.018.2100194

Petroc, T. (2022, May 23). *Blockchain technology market size worldwide from 2017 to 2027*. Statistics. https://www.statista.com/statistics/1015362/worldwide-blockchain-technology-market-size/

Poje, T., & Zaman Groff, M. (2021). Mapping ethics education in accounting research: A bibliometric analysis. *Journal of Business Ethics*, *179*(2), 451–472. doi:10.1007/s10551-021-04846-9 PMID:34127872

Poongodi, M., Sharma, A., Vijayakumar, V., Bhardwaj, V., Sharma, A. P., Iqbal, R., & Kumar, R. (2020). Prediction of the price of Ethereum blockchain cryptocurrency in an industrial finance system. *Computers & Electrical Engineering*, *81*, 106527. doi:10.1016/j.compeleceng.2019.106527

Rocha, R. G., & Pinheiro, P. G. (2020). Organizational spirituality: Concept and perspectives. *Journal of Business Ethics*, *171*(2), 241–252. doi:10.1007/s10551-020-04463-y

Rodriguez, A., & Laio, A. (2014). Clustering by fast search and find of density peaks. *Science*, *344*(6191), 1492–1496. doi:10.1126/science.1242072 PMID:24970081

Salah, K., Rehman, M. H. U., Nizamuddin, N., & Al-Fuqaha, A. (2019). Blockchain for AI: Review and open research challenges. *IEEE Access : Practical Innovations, Open Solutions*, *7*, 10127–10149. doi:10.1109/ACCESS.2018.2890507

Sanghami, S. V., Lee, J. J., & Hu, Q. (2022). Machine learning enhanced blockchain consensus with transaction prioritization for smart cities. *IEEE Internet of Things Journal*, *10*(8), 6661–6672. doi:10.1109/JIOT.2022.3175208

Seuring, S., & Gold, S. (2012). Conducting content - Analysis based literature reviews in supply chain management. *Supply Chain Management*, *17*(5), 544–555. doi:10.1108/13598541211258609

Seuring, S., & Müller, M. (2008). From a literature review to a conceptual framework for sustainable supply chain management. *Journal of Cleaner Production*, *16*(15), 1699–1710. doi:10.1016/j.jclepro.2008.04.020

Shahbazi, Z., & Byun, Y. C. (2022). Machine learning-based analysis of cryptocurrency market financial risk management. *IEEE Access : Practical Innovations, Open Solutions*, *10*, 37848–37856. doi:10.1109/ACCESS.2022.3162858

Sharma, A., Podoplelova, E., Shapovalov, G., Tselykh, A., & Tselykh, A. (2021). Sustainable smart cities: Convergence of artificial intelligence and blockchain. *Sustainability (Basel)*, *13*(23), 13076. doi:10.3390/su132313076

Shi, W., & Huang, Q. (2022). The blockchain technology applied in the development of real economy in Jiangsu under deep learning. *Computational Intelligence and Neuroscience*, *3088043*, 1–12. Advance online publication. doi:10.1155/2022/3088043 PMID:35571683

Shiau, W. L., Dwivedi, Y. K., & Yang, H. S. (2017). Co-citation and cluster analyses of extant literature on social networks. *International Journal of Information Management*, *37*(5), 390–399. doi:10.1016/j.ijinfomgt.2017.04.007

Singh, S. K., El Azzaoui, A., Kim, T. W., Pan, Y., & Park, J. H. (2021). DeepBlockScheme: A deep learning-based blockchain driven scheme for secure smart city. *Human-centric Computing and Information Sciences*, *11*, 12. doi:10.22967/HCIS.2021.11.012

Singh, S. K., Rathore, S., & Park, J. H. (2020). BlockIoTIntelligence: A blockchain-enabled intelligent IoT architecture with artificial intelligence. *Future Generation Computer Systems*, *110*, 721–743. doi:10.1016/j.future.2019.09.002

Swan, M. (2015). Blockchain thinking: The brain as a decentralized autonomous corporation [Commentary]. *IEEE Technology and Society Magazine*, *34*(4), 41–52. doi:10.1109/MTS.2015.2494358

Sylim, P. G., Liu, F., Marcelo, A. B., & Fontelo, P. A. (2018). Blockchain technology for detecting falsified and substandard drugs in distribution: Pharmaceutical supply chain intervention. *JMIR Research Protocols*, *7*(9), e10163. doi:10.2196/10163 PMID:30213780

Teng, Y., Li, L., Song, L., Yu, F. R., & Leung, V. C. M. (2022). Profit maximizing smart manufacturing over AI-enabled configurable blockchains. *IEEE Internet of Things Journal*, *9*(1), 346–358. doi:10.1109/JIOT.2021.3098917

Tiwary, N. K., Kumar, R. K., Sarraf, S., Kumar, P., & Rana, N. P. (2021). Impact assessment of social media usage in B2B marketing: A review of the literature and a way forward. *Journal of Business Research*, *131*, 121–139. doi:10.1016/j.jbusres.2021.03.028

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British Journal of Management*, *14*(3), 207–222. doi:10.1111/1467-8551.00375

Vaismoradi, M., Turunen, H., & Bondas, T. (2013). Content analysis and thematic analysis: Implications for conducting a qualitative descriptive study. *Nursing & Health Sciences*, *15*(3), 398–405. doi:10.1111/nhs.12048 PMID:23480423

van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, *84*(2), 523–538. doi:10.1007/s11192-009-0146-3 PMID:20585380

Verma, S., & Gustafsson, A. (2020). Investigating the emerging COVID-19 research trends in the field of business and management: A bibliometric analysis approach. *Journal of Business Research*, *118*, 253–261. doi:10.1016/j.jbusres.2020.06.057 PMID:32834211

Vignesh, A. (2019). Diminishing spread of false message in twitter using block chain and machine learning. *International Journal of Engineering and Advanced Technology*, *9*, 4933–3937. doi:10.35940/ijeat.A2083.109119

Waghmare, A. D., & Patnaik, G. K. (2021). Fake news detection of social media news in blockchain framework. *Indian Journal of Computer Science and Engineering*, *12*(4), 972–980. doi:10.21817/indjcse/2021/v12i4/211204151

Wang, S., Hu, Y., & Qi, G. (2022). Blockchain and deep learning based trust management for Internet of Vehicles. *Simulation Modelling Practice and Theory*, *120*, 102627. doi:10.1016/j.simpat.2022.102627

Wang, T., Liew, S. C., & Zhang, S. (2021). When blockchain meets AI: Optimal mining strategy achieved by machine learning. *International Journal of Intelligent Systems*, *36*(5), 2183–2207. doi:10.1002/int.22375

Wang, Y. (2021). Research on supply chain financial risk assessment based on blockchain and fuzzy neural networks. *Wireless Communications and Mobile Computing*, *5565980*, 1–8. Advance online publication. doi:10.1155/2021/5565980

Wang, Y., Wang, C., Sensoy, A., Yao, S., & Cheng, F. (2022). Can investors' informed trading predict cryptocurrency returns? Evidence from machine learning. *Research in International Business and Finance*, *62*, 101683. doi:10.1016/j.ribaf.2022.101683

Wu, , Wu, , & Zhang, . (1908). Wu, & Zhang. (2019). Development trend and frontier of stormwater management (1980–2019): A bibliometric overview based on citespace. *Water (Basel)*, *11*(9), 1908. Advance online publication. doi:10.3390/w11091908

Wu, Y., Wang, Z., Ma, Y., & Leung, V. C. M. (2021). Deep reinforcement learning for blockchain in industrial IoT: A survey. *Computer Networks*, *191*, 108004. doi:10.1016/j.comnet.2021.108004

XingB.MarwalaT. (2018). The synergy of blockchain and artificial intelligence. *EngRN: Computer Engineering*. https://doi.org/10.2139/ssrn.3225357

Xiong, Y., Xia, S., & Wang, X. (2020). Artificial intelligence and business applications, an introduction. *International Journal of Technology Management*, *84*(1/2), 1–7. doi:10.1504/IJTM.2020.112615

Xu, T., & Talib, N. B. A. (2020). Hot topics and emerging trends in business model innovation research based on citespace. *International Journal of Management*, *11*(12), 2000–2010. doi:10.34218/IJM.11.12.2020.207

Yang, L., Li, M., Si, P., Yang, R., Sun, E., & Zhang, Y. (2021). Energy-efficient resource allocation for blockchain-enabled industrial internet of things with deep reinforcement learning. *IEEE Internet of Things Journal*, *8*(4), 2318–2329. doi:10.1109/JIOT.2020.3030646

Yang, Y., & Yu, D. (2022). Short video copyright storage algorithm based on blockchain and expression recognition. *International Journal of Digital Multimedia Broadcasting*, *8827815*, 1–11. Advance online publication. doi:10.1155/2022/8827815

Yetis, H., Karakose, M., & Baygin, N. (2022). Blockchain-based mass customization framework using optimized production management for industry 4.0 applications. *Engineering Science and Technology, an International Journal, 36,* 101151. https://doi.org/10.1016/j.jestch.2022.101151

Yin, H. H. S., Langenheldt, K., Harlev, M., Mukkamala, R. R., & Vatrapu, R. (2019). Regulating cryptocurrencies: A supervised machine learning approach to de-anonymizing the bitcoin blockchain. *Journal of Management Information Systems*, *36*(1), 37–73. doi:10.1080/07421222.2018.1550550

Zemánková, A. (2019). Artificial intelligence and blockchain in audit and accounting: Literature review. *WSEAS Transactions on Business and Economics*, *16*, 568–581.

Zhang, G., Zhang, X., Bilal, M., Dou, W., Xu, X., & Rodrigues, J. J. (2022). Identifying fraud in medical insurance based on blockchain and deep learning. *Future Generation Computer Systems*, *130*, 140–154. doi:10.1016/j.future.2021.12.006

Zhang, L., & Kim, D. (2022). A peer-to-peer smart food delivery platform based on smart contract. *Electronics (Basel)*, *11*(12), 1806. doi:10.3390/electronics11121806

Zhang, L., Wang, J., Wang, W., Jin, Z., Zhao, C., Cai, Z., & Chen, H. (2022). A novel smart contract vulnerability detection method based on information graph and ensemble learning. *Sensors (Basel)*, *22*(9), 3581. doi:10.3390/s22093581 PMID:35591270

Zhang, P., Liu, X., Li, W., & Yu, X. (2021). Pharmaceutical cold chain management based on blockchain and deep learning. *Wangji Wanglu Jishu Xuekan*, *22*(7), 1531–1542. doi:10.53106/160792642021122207007

Zhao, Y., Yu, Y., Li, Y., Han, G., & Du, X. (2019). Machine learning based privacy-preserving fair data trading in big data market. *Information Sciences*, *478*, 449–460. doi:10.1016/j.ins.2018.11.028

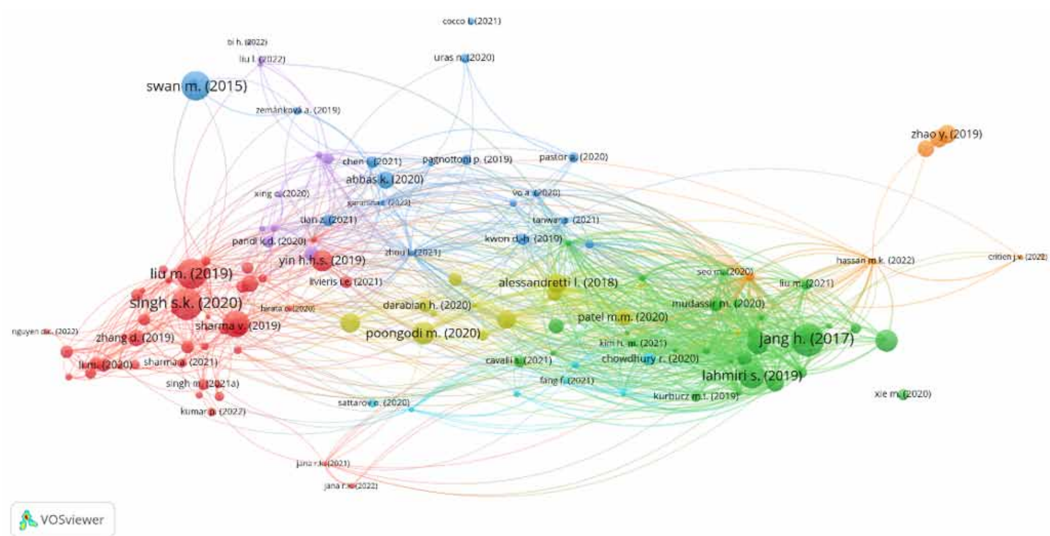
Zhao, Z., Hao, Z., Wang, G., Mao, D., Zhang, B., Zuo, M., Yen, J., & Tu, G. (2021). Sentiment analysis of review data using blockchain and LSTM to improve regulation for a sustainable market. *Journal of Theoretical and Applied Electronic Commerce Research*, *17*(1), 1–19. doi:10.3390/jtaer17010001

Zhou, C., & Song, W. (2021). Digitalization as a way forward: A bibliometric analysis of 20 Years of servitization research. *Journal of Cleaner Production*, *300*, 126943. doi:10.1016/j.jclepro.2021.126943

APPENDIX A

Bibliographic coupling occurs when two documents cite the same third document. Figure 6 presents the bibliographic coupling results generated by VOSviewer, demonstrating the levels of connectivity between different studies in the neighboring research areas. Salient five groups are identified for authors with a minimum of five publications and 159 citations. A higher coupling strength indicates more citations shared by the two target documents. Research with the highest bibliographic coupling activity for the five groups is as follows: Swan (2015), Singh et al. (2020), Lahmiri and Bekiros (2019), Poongodi et al. (2020), Zhao et al. (2019). These studies should be explored in depth to gain a baseline knowledge of AI-enable blockchain research.

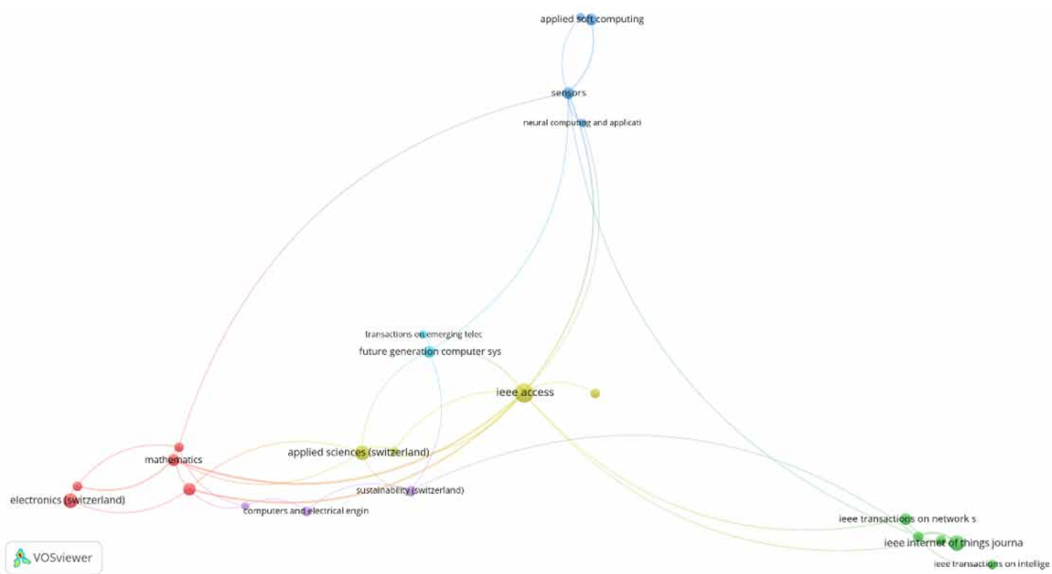
Figure 6. Bibliographic coupling analysis



APPENDIX B

The analysis of citation sources is conducted using VOSviewer, as shown in Figure 7. Salient five groups are generated after setting the threshold as 2. 43 citation sources meet the requirement. Citation journals with the highest activity for each group are shown as follows: IEEE Internet of Things Journal, Applied Soft Computing, IEEE Access, Future Generation Computer System, and Electronics. These journals could be targeted when studying literature on AI-enable blockchain.

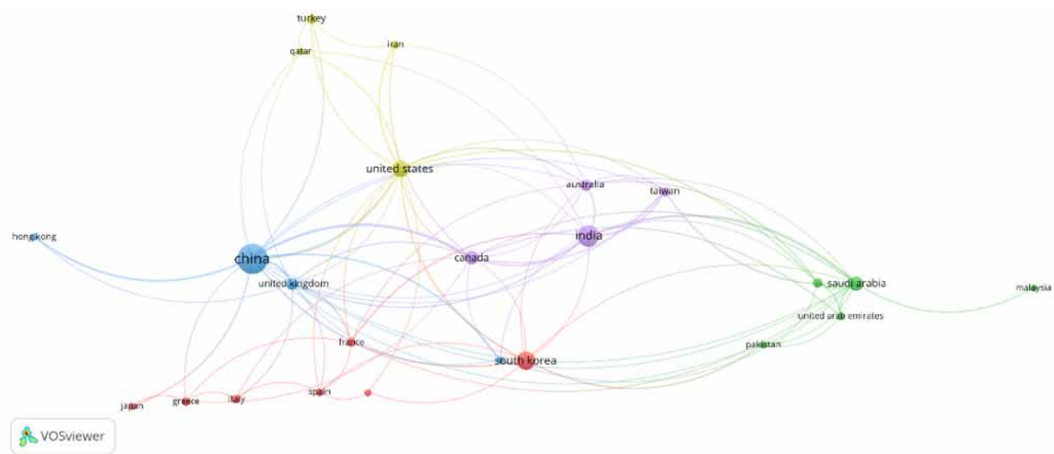
Figure 7. Citation source analysis



APPENDIX C

International country co-authorship network map is developed through VOSviewer, as shown in Figure 8. Each node denotes a country/region. The bigger the node is, the more active the country/region is. Salient five groups are generated after setting the threshold as 5. 24 documents meet the requirement. The countries/regions with the highest activity for each group are shown as follows: China, South Korea, the United States, India, and Saudi Arabia. Both developed countries and developing countries are interested in the application and ethics of using AI in blockchain, and there has been a race for such research.

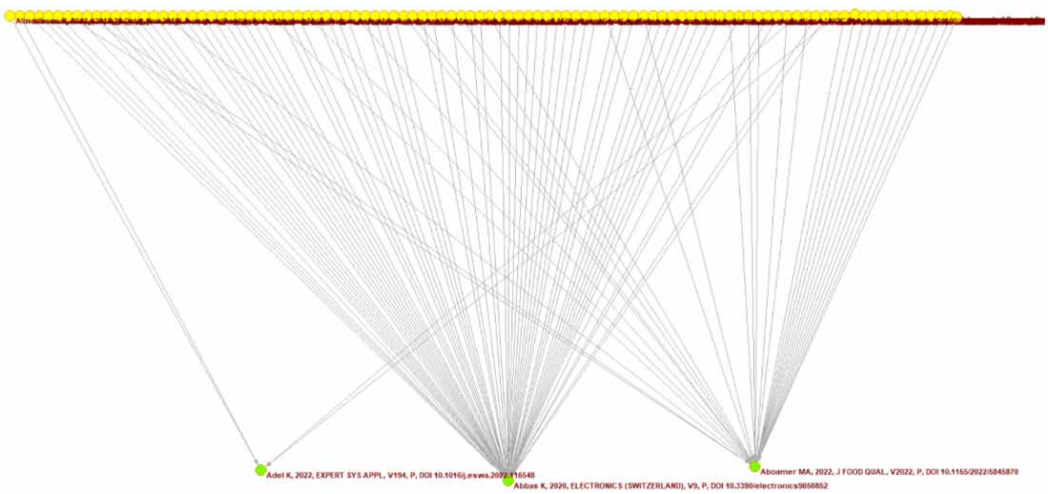
Figure 8. Country co-authorship network map



APPENDIX D

Main Path Analysis is a powerful tool for detecting the most influential articles in a citation network (De Nooy et al., 2018), which is particularly helpful to dig a complete research system and development timeline. Main path analysis is performed in this study using pajek and gephi. However, as this research field is still in its infancy, the authors fail to generate a clear main path, as shown in Figure 9. Three articles have been derived, namely Adel et al. (2022), Abbas et al. (2020), and Aboamer et al. (2022), which may serve as a foundation for future research.

Figure 9. Main path analysis



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