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Integrating Blockchain in Scheduling: A Comprehensive Review of Current Trends and Future Directions

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ABSTRACT

This review paper offers a comprehensive exploration of blockchain technology's integration in scheduling activities across various industries. It systematically gathered and analyzed literature, identifying 133 relevant documents through rigorous screening from 2017 till 2023. The bibliometric analysis, including co-authorship and co-occurrence maps, revealed key trends, influential authors, and emerging research areas. Content analysis focused on blockchain applications in service optimization, system and resource planning, management, project and production planning, energy optimization, and security enhancement. The research acknowledged significant advancements in these areas, particularly in terms of improved efficiency, transparency, and security. The findings underscore the potential of blockchain in revolutionizing scheduling and management processes across different sectors, highlighting the need for further exploration of its applications and implications in various professional contexts. The paper aims to bridge the gap in the literature by presenting a holistic view of blockchain's role in advancing scheduling methods, driving innovation, and fostering more robust, efficient, and transparent scheduling systems across industries.

1. Introduction

In the current digital era, the introduction of Bitcoin in the 2010s marked the emergence of a groundbreaking technology known as blockchain [1]. It is perceived as one of the most significant innovations, revolutionizing traditional financial transactions such as interactions, follow-ups, and automatic charges commonly seen in the trading sector [2]. This technology has also influenced how individuals interact with one another. Since its inception, blockchain's popularity has soared, with over 83 million users—accounting for 2.8% of the global population—utilizing it due to its broad range of benefits [3]. Blockchain technology has found applications in a growing list of industries because of its characteristics of decentralization, transparency, enhanced security, cost efficiency, and consensus [1]. These include, but are not limited to, healthcare [4,5], supply chain management [6], energy, the Internet of Things (IoT) [7], manufacturing [8,9], and record management [10].

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Blockchain is a distributed ledger technology that records transactions securely, transparently, and tamper-evidently. The process begins with the submission of a transaction (TRX), which is then broadcast to a Peer-to-Peer network. Nodes within this network run a consensus protocol to validate the TRX, ensuring its legitimacy and compliance with the network's rules. Once validated, the TRX is combined with other transactions to form a new block, which is then appended to the blockchain, creating an indelible link to the previous block. This sequential linking of blocks forms a chain, and each block is immutable once added, making the ledger a trusted and verifiable record of all transactions from inception to the present. The ability to write new transactions to the blockchain can be open to all or restricted to certain authenticated users, depending on whether the blockchain is public or private, as governed by the consensus protocol [11].

Scheduling, broadly defined, is the systematic process of planning, allocating, and managing resources and activities over time to achieve specific objectives efficiently. This process is crucial across various sectors, including production, manufacturing, and services, to ensure optimal operation and customer satisfaction. Over the years, scheduling has taken various forms, ranging from simple to complex techniques, and can range from short-term scheduling that is meant for day-to-day operations to long terms planning for projects with multiple phases and milestones [12]. Traditional scheduling tools that have been circulating include Gantt charts [13], Critical Path Method (CPM) [14], Program Evaluation and Review Technique (PERT) [15], and advanced software solutions for process automation.

The use of scheduling in organizations has a chronological growth that can be traced back centuries, long before project management was first defined [16]. This evolution has occurred in tandem with human civilization and industrial progress. Scheduling problems, which are crucial for optimizing resource allocation and process efficiency, arise in various real-world settings, including manufacturing [17], assembly lines [18], services [19], project management [20] and healthcare [21]. Addressing these challenges requires sophisticated algorithms and strategies to manage timelines and resources effectively, ensuring smooth operations and minimizing delays.

However, traditional scheduling approaches often face certain gaps that can limit their full potential. These gaps include centralized control, lack of transparency, and vulnerability to data tampering [22]. Blockchain technology offers a transformative solution with its principles resulting in robust, secure, and efficient resource management processes, having far-reaching implications across diverse industries. The decentralized nature and transparency of blockchain [1] provide numerous techniques for effectively managing tasks and services [23], allocating resources [24], and meeting deadlines [25].

The implications of integrating scheduling with blockchain technology have widespread effects across various industries and fields. For example, in the traditional supply chain, where improvements such as resource traceability and collaboration within the chain are needed, the combination of blockchain and scheduling can improve the coordination of materials, optimize the overall flow of resources, and enhance efficiency [26]. The healthcare sector also benefits significantly from this intersection, with enhancements in the transparency and security of medical records and the streamlining of patient appointments [27]. Moreover, blockchain addresses several deficiencies found in typical scheduling systems. Its distributed nature allows for reliance on multiple control sources, thereby reducing the risks associated with single points of failure and enhancing the resilience of scheduling networks. Beyond addressing challenges of data authenticity and secure record management, the transparency and immutability of blockchain records increase the reliability and credibility of scheduling data. Furthermore, the automated execution of smart contracts

minimizes the need for human intervention in scheduling processes, offering the potential to reduce errors and improve efficiency [28].

The intersection of scheduling and blockchain technology presents a promising area for research and exploration. In the process of collecting papers prior to conducting an analysis, it was observed that publications spanned across various types of documents, including articles, conference papers, and book chapters. However, there were no literature reviews aimed specifically at exploring the intersection of scheduling and blockchain.

This review paper aims to provide an in-depth and comprehensive analysis of the integration of blockchain technology within the scheduling field across various industries. This paper highlights the prevalent trends in existing research while simultaneously identifying gaps and potential areas for further advancement in this rapidly evolving field. By examining the intersection of blockchain technology and scheduling, the paper aims to offer valuable insights and guide future research directions, fostering a deeper understanding of the applications and implications of blockchain in diverse professional contexts.

The remainder of this paper is organized as follows: Section 2 outlines the research methodology adopted, including statistical analysis. Section 3 presents the results of the bibliometric analysis, while Section 4 conducts an in-depth content analysis to thoroughly explore the diverse applications and transformative impact of blockchain on scheduling across various sectors. Finally, Section 5 concludes the paper by summarizing the key findings and outlining future research avenues based on the identified gaps.

2. Methodology

The methodology of this research employs a systematic approach to gather and analyze literature on the integration of blockchain in scheduling. It includes four main steps, as described below:

a) Literature retrieval

Comprehensive lists of papers exploring the integration of blockchain technology within various scheduling activities were retrieved using the Scopus database. This compilation was achieved by associating 'Blockchain' with relevant keywords such as 'Scheduling,' 'Workflow,' 'Workforce,' 'Planning,' 'Booking,' 'Personnel,' and 'Time Management,' through a systematic pairing process. To ensure higher inclusivity, the keywords were searched within the 'Title, Abstract, and Keywords' sections on Scopus. This process resulted in a total of 192 pre-existing documents, including reviews, papers, and publications, that were published in the time range from 2017 to 2023.

b) Literature screening

In accordance with the guidelines of the PRISMA statement, an esteemed protocol for conducting systematic reviews and meta-analyses [29], a meticulous search and evaluation strategy was employed. This approach ensured a systematic and organized search, appraisal, and selection of significant studies. Initially, the search yielded 192 articles, with no instances of duplication observed. Each article underwent a detailed review process, during which those found to be non-relevant were discarded (as depicted in Figure 1). Through this rigorous filtering mechanism, a curated collection of 133 relevant reviews, articles, and studies was established, all dated between 2017 and July 2023. Figure 2 displays the temporal distribution and increasing interest in the subjects covered by these documents, highlighting the period from 2017 to 2023.

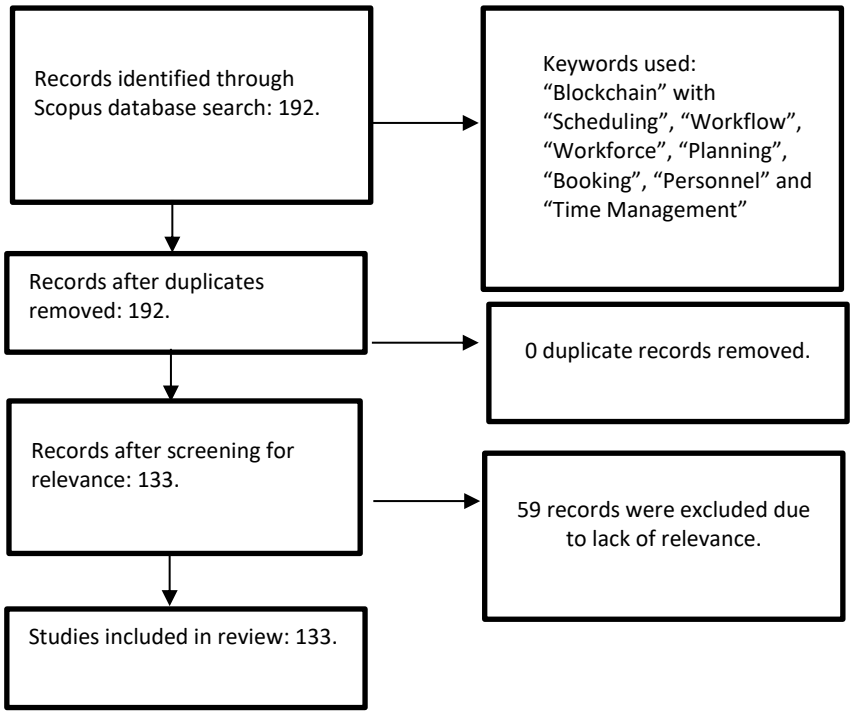

Fig. 1. Literature screening approach

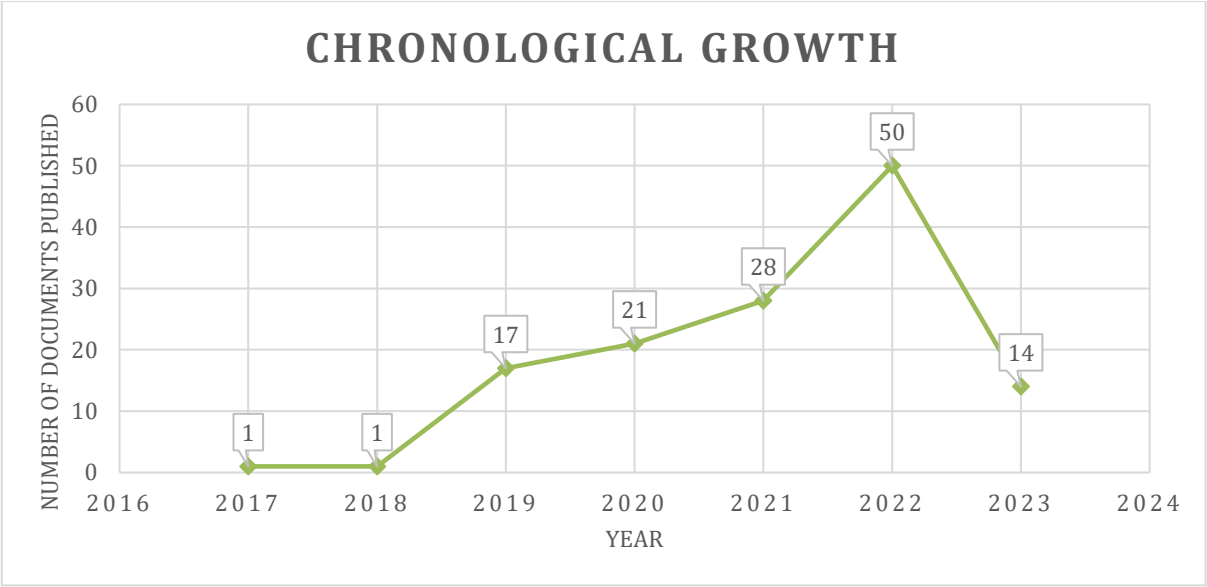

Fig. 2. Chronological Growth of Publications from 2018 till 2023

c) Bibliometric analysis

Bibliometric analysis is a systematic method for evaluating scholarly literature, primarily through examining citations and references in academic papers. This technique plays a crucial role in identifying the impact, emerging trends, and interconnections among various scholarly works. Analyzing citation patterns, co-authorship networks, and prevalent keywords facilitates the identification of leading researchers, pivotal studies, and emerging fields of inquiry. This methodological approach provides valuable insights into the developmental trajectory of research topics, as well as identifying dominant scholars and collaborations within a specific area of study.

d) Content analysis

Content analysis in this context entails a thorough examination and organization of extensive research material, with a particular focus on publications related to the integration of blockchain in scheduling. This process reveals prevalent themes and discernible patterns within the data. The analysis categorizes the research into various themes and sub-themes, facilitating a clearer understanding of the diverse applications of blockchain in scheduling. This systematic organization is crucial for synthesizing the data, enabling the extraction of meaningful conclusions and insights about the impact of blockchain technology in the scheduling domain.

3. Bibliometric analysis

After systematically filtering the papers compiled from Scopus, only the relevant ones were retained, resulting in the creation of a comprehensive CSV file containing all the bibliographic data for each paper. VOSviewer was employed as a tool to generate visualization maps, providing a detailed study of the filtered data through two methodologies: co-authorship and co-occurrence analysis. The results of both analyses are maps that consist of nodes representing various elements such as publications, authors, or organizations. The characteristics of these nodes, such as their size and font, serve as indicators of their level of activity. Additionally, factors such as the distance between these nodes play a role in identifying the strength of their correlation [30].

3.1 Co-Authorship maps based on bibliographic data

Co-authorship maps are types of visualization methods that illustrate the connections between research entities, including authors, organizations, and countries.

3.1.1 Co-Authorship maps for authors

The first part of the co-authorship approach involved conducting an analysis on the authors of the consolidated papers, setting a threshold of a minimum of 2 papers per author. Out of 450 authors, 72 met this criterion and were grouped into 6 clusters, as depicted by Figure 3, which illustrates a network visualization map of the authors.

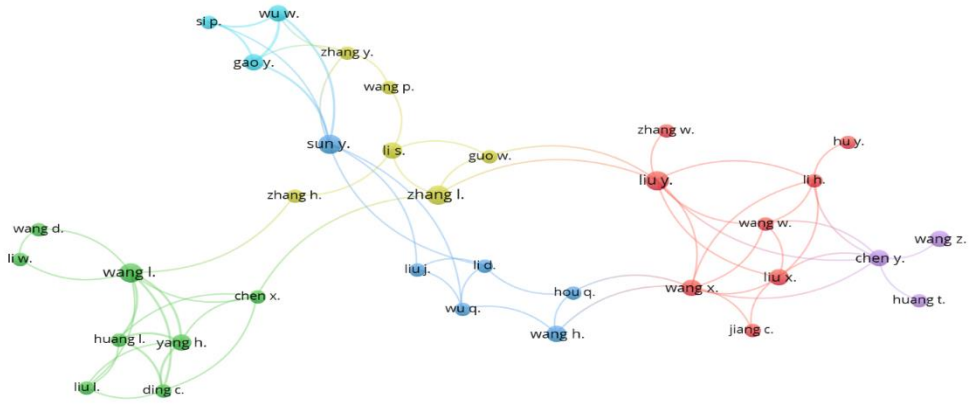

Fig. 3. Network Visualization of Authors Co-Authorship

Using the same analysis, two additional maps were generated to enhance the understanding of the relationships between authors: the overlay visualization, which considers the time factor, and

the density visualization, which provides an overview of the main authors within the bibliographic data. The analysis over the years revealed that the selected papers became particularly attractive topics in 2019 and 2020, coinciding with the period when blockchain significantly gained popularity, as illustrated by the overlay visualization map in Figure 4. The density visualization map, shown in Figure 5, highlights the key authors in the field of the selected papers.

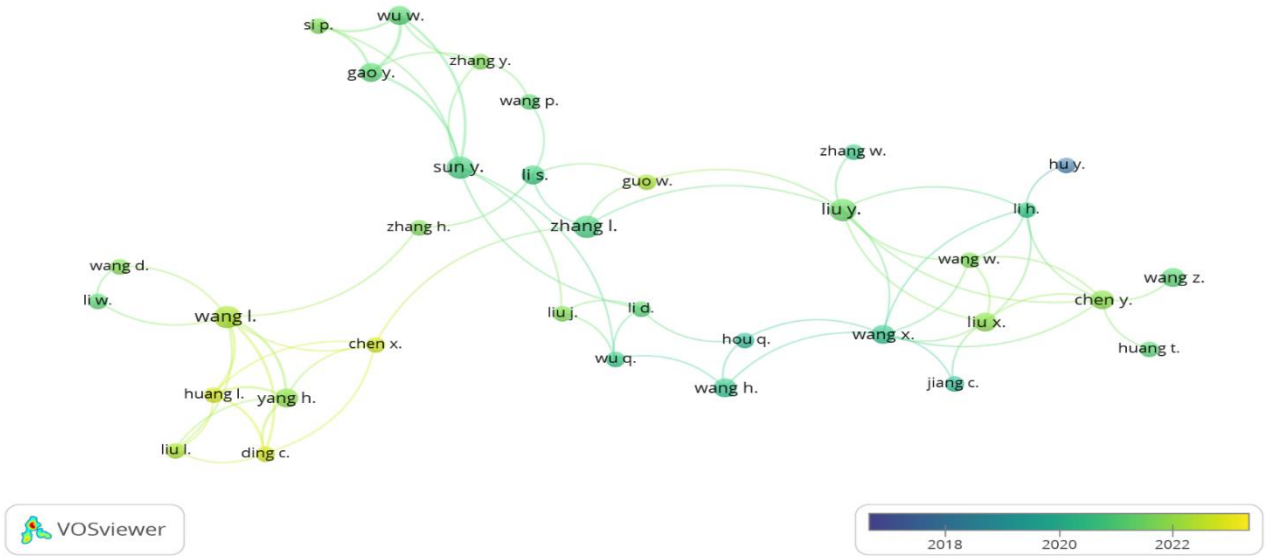

Fig. 4. Overlay Visualization of Authors Co-Authorship

Table 1 was generated based on the number of documents each author published, highlighting the top 10 pioneering authors in the field of Scheduling in Blockchain. According to the analysis, authors Liu Y., Sun Y., Wang L., and Zhang L. have made the most significant contributions, with each being credited in a total of 4 papers. This total reflects the extent of collaboration or co-authorship among these authors across various publications.

Table 1
Highest 10 Occurring Authors based on bibliographic data

Authors No.	Author	Occurrences	Citations	Total link strength
1	Liu y.	4	2	18
2	Sun y.	4	17	22
3	Wang l.	4	0	17
4	Zhang l.	4	12	14
5	Al-hawadi a.	3	1	6
6	Al-refaie a.	3	1	6
7	Bouras a.	3	4	10
8	Chen w.	3	22	17
9	Chen y.	3	23	16
10	Gao y.	3	15	13

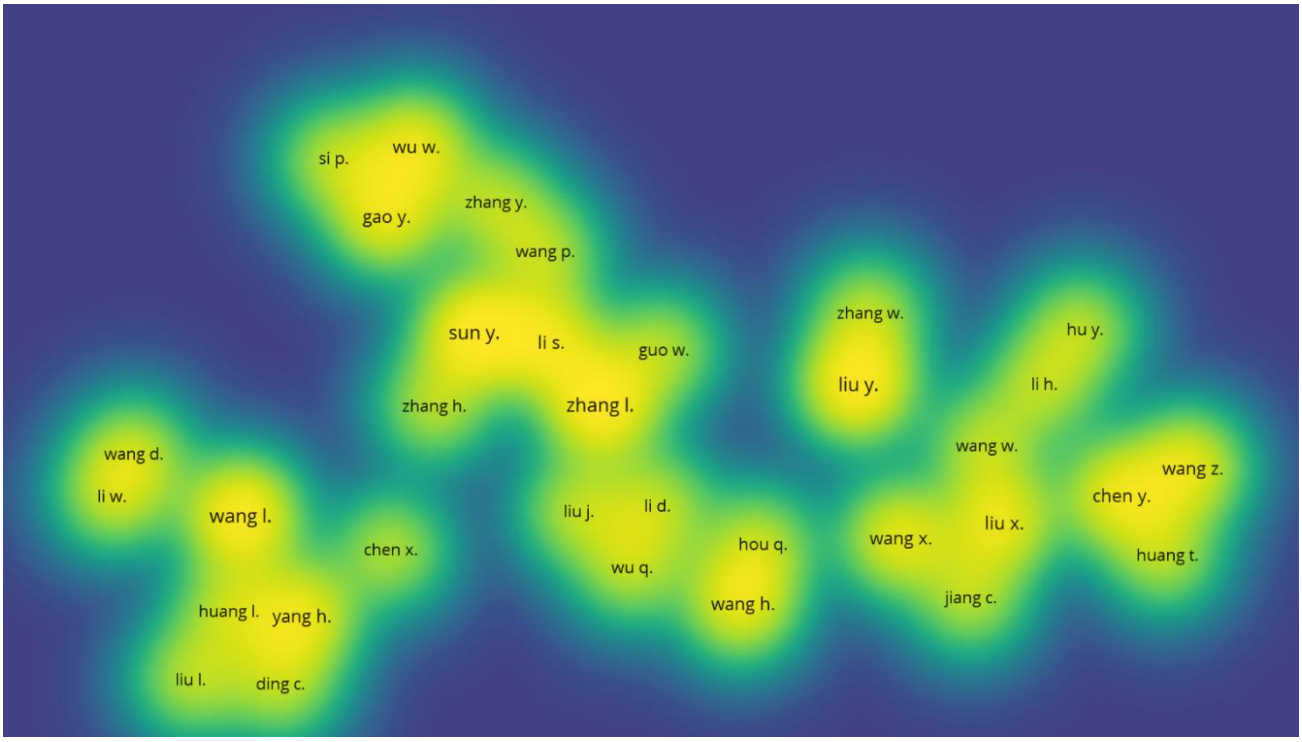

Fig. 5. Density Visualization of Authors Co-Authorship

3.1.2 Co-Authorship maps for organizations

In further analyzing the papers, we explored the organizations associated with the papers retained in the selection process. This analysis helps identify the key organizations that have shown an interest in Blockchain within the scheduling field and to uncover any collaborative efforts among them. Applying a threshold of at least two documents per organization, only 7 out of 298 organizations met the criteria. These organizations hail from regions including China, Jordan, Iraq, and Poland.

As seen in Figure 6, which showcases the network visualization map of the organizations, the 7 organizations show no sign of collaborative work, as no links are visible between any of the nodes. Meanwhile, the overlay visualization map of the organizations in Figure 7 features two main colors highlighting the map, representing the first half of 2021 and the second half of 2022, respectively. This overlay map draws attention to the fact that three of the organizations, colored in blue, are Chinese. This suggests that Chinese organizations have begun exploring such topics earlier than the other 4 organizations located in Jordan, Iraq, and Poland.

When analyzing the popularity of the organizations behind the collected works, the Beijing University of Technology, Faculty of Information Technology in China, as seen in Table 2, appeared 3 times in the dataset. However, the AGH University of Science and Technology, Department of Computer Science in Poland, was the most cited organization among the top 10. The total link strength signifies the degree of collaboration or co-authorship between these organizations across different publications.

Table 2
Highest 10 Occurring Organizations based on bibliographic data

Org's No.	Organization	Occurrences	Citations	Total link strength
1	Beijing university of technology, faculty of information technology, Beijing, China	3	15	3
2	college of agriculture, al-muthanna university, samawah, 66001, Iraq	2	14	16
3	college of computer science and information technology, university of Anbar, Anbar, 31001, Iraq	2	14	16
4	department of engineering processes automation and integrated manufacturing systems, faculty of mechanical engineering, Silesian university of technology, konarskiego 18a str, Gliwice, 44-100, Poland	2	4	0
5	department of industrial engineering, university of Jordan, Amman, 11942, Jordan	2	1	1
6	school of computer science and communication engineering, Jiangsu university, Zhenjiang, 212013, China	2	16	4
7	school of computer science and engineering, sun yat-sen university, Guangzhou, China	2	4	2
8	academy of green manufacturing engineering, Wuhan university of science and technology, Wuhan, 430081, China	1	22	2
9	Agh university of science and technology, department of computer science, al Mickiewicz 30, Cracow, 30?059, Poland	1	47	2
10	Algoritmi research centre/lasi, department of production and systems, school of engineering, university of minho, Guimaraes, 4804-533, Portugal	1	0	2

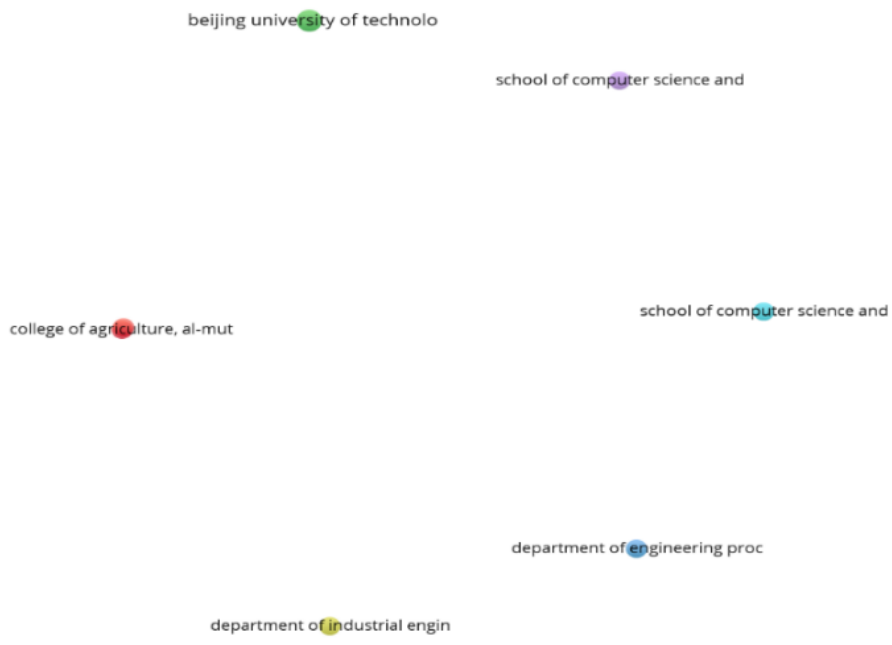

Fig. 6. Network Visualization of Organizations Co-Authorship

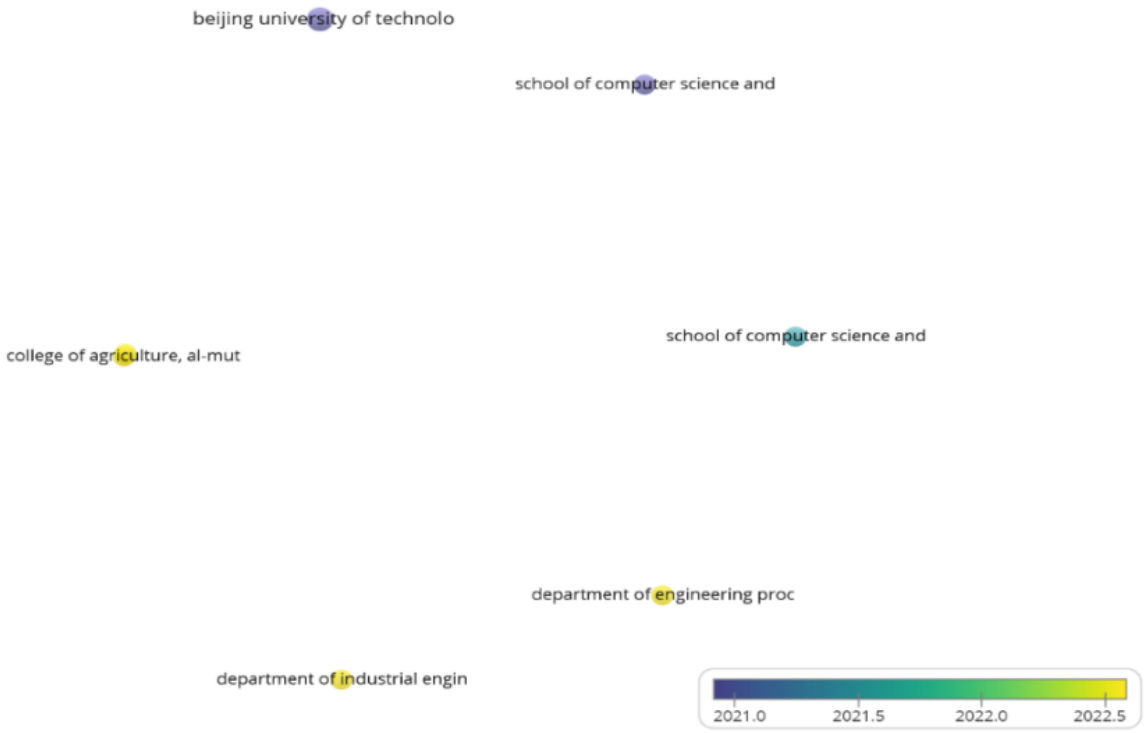

Fig. 7. Overlay Visualization of Organizations Co-Authorship

3.1.3 Co-Authorship maps for countries

The final analysis in the co-authorship approach involved an overview of the countries from which the papers originated, as it is crucial to understand which countries had the most influence with their published papers in the field under study. The analysis identified 46 countries, of which 30 met the threshold of at least 2 documents published. With approximately 65 documents, China was observed to have the most significant contribution to the database, followed by the United States and India with 14 and 11 documents, respectively. As seen in the network visualization map in Figure 8, countries like Japan, Indonesia, Iran, and Austria contributed the least to the combined data, indicated by the faded font of their circles on the map.

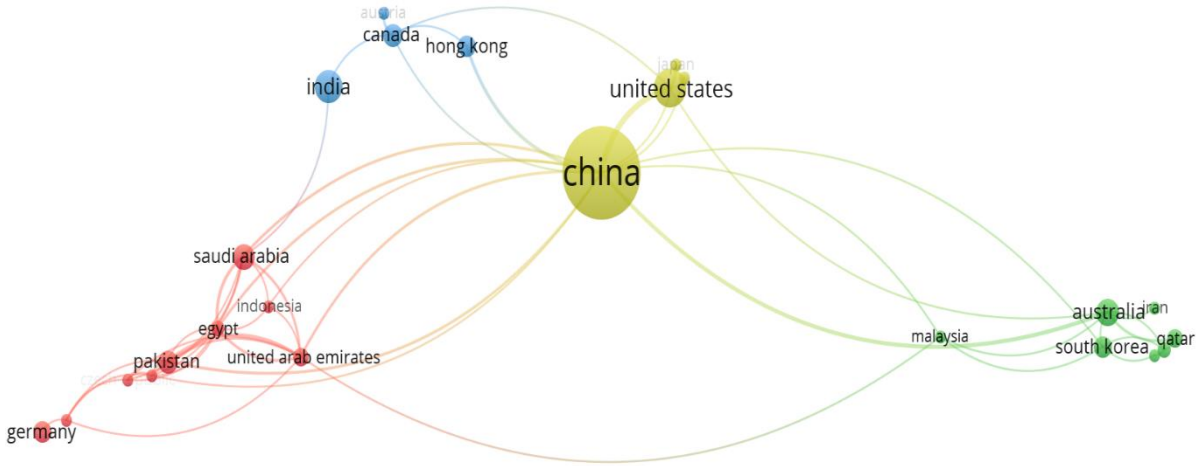

Fig. 8. Network Visualization of Countries Co-Authorship

To confirm the visual results observed from the visualization maps, a further step was taken to enhance the analysis by listing the top 10 countries appearing in our field of study. As indicated by the previous analysis, China had the highest number of occurrences and citations, as demonstrated in Table 3. Following China, the United States (US) contributed 14 out of 133 documents.

Table 3
Highest 10 Occurring Countries based on bibliographic data

Authors No.	Country	Occurrences	Citations	Total link strength
1	China	65	514	35
2	United States	14	65	13
3	India	11	47	4
4	Australia	8	69	11
5	Saudi Arabia	7	70	16
6	Canada	6	49	6
7	Pakistan	6	53	13
8	Germany	5	65	1
9	Hong Kong	5	108	4
10	South Korea	5	62	5

3.2 Co-Occurrence maps based on bibliographic data

Using co-occurrence visualization maps enables gaining valuable insights into the dynamics of the bibliometric analysis, and enhances the understanding of complex networks especially those that are based on the co-occurrence of keywords. In this section, both 'keywords' and 'author's keywords' will be analyzed based on their number of occurrences.

3.2.1 Co-occurrence maps for all keywords

For higher accuracy results, VOSviewer's thesaurus was integrated to enable the utilization of underlying semantic links between terms. It serves as a bridge between different concepts, allowing researchers to move beyond literal phrase matches. The thesaurus strengthens the analytical process, enabling a more sophisticated understanding of the data by leveraging synonyms, related terms, and hierarchical relationships.

As a result, the following Table 4 highlights keywords that have been replaced with a common related term:

Table 4
Thesaurus Replaced terms

Label	Replace by	Label	Replace by
block-chain	blockchain	optimisations	optimization
blockchain network operation	blockchain	optimization algorithms	optimization
blockchain technology	blockchain	optimization modeling	optimization
blockchains	blockchain	scheduling algorithms	scheduling
consortium blockchain	blockchain	scheduling models	scheduling
decentralisation	decentralization	scheduling optimization	scheduling
decentralised	decentralization	scheduling schemes	scheduling
decentralized system	decentralization	scheduling strategies	scheduling

decentralized systems	decentralization	scheduling systems	scheduling
health care	healthcare	task scheduling problem	scheduling
healthcare services	healthcare	task-scheduling	scheduling
healthcare systems	healthcare	tasks scheduling	scheduling
healthcare workflow	healthcare	work-flows	workflow
internet of thing	internet of things (IoT)	workflow management	workflow
internet of things	internet of things (IoT)	workflow managements	workflow
iot	internet of things (IoT)		

Upon integrating the thesaurus into VOSviewer, the first noticeable change was a reduction in the number of terms meeting the set threshold. Initially, out of 1301 terms, 263 had occurrences more than twice. However, after considering linkages and term synonyms, 1270 terms were identified, and only 232 of these met the criteria.

Using the bibliometric data from the compiled papers, the most frequently used keywords were identified, along with the relationships between them and their sub-keywords, as illustrated in Figure 9. By setting the threshold at a minimum of 2 occurrences per keyword, 232 out of a total of 1270 terms met this criterion. The network visualization map highlights the significant and broad focus on 'Scheduling' within the field of ‘Blockchain’.

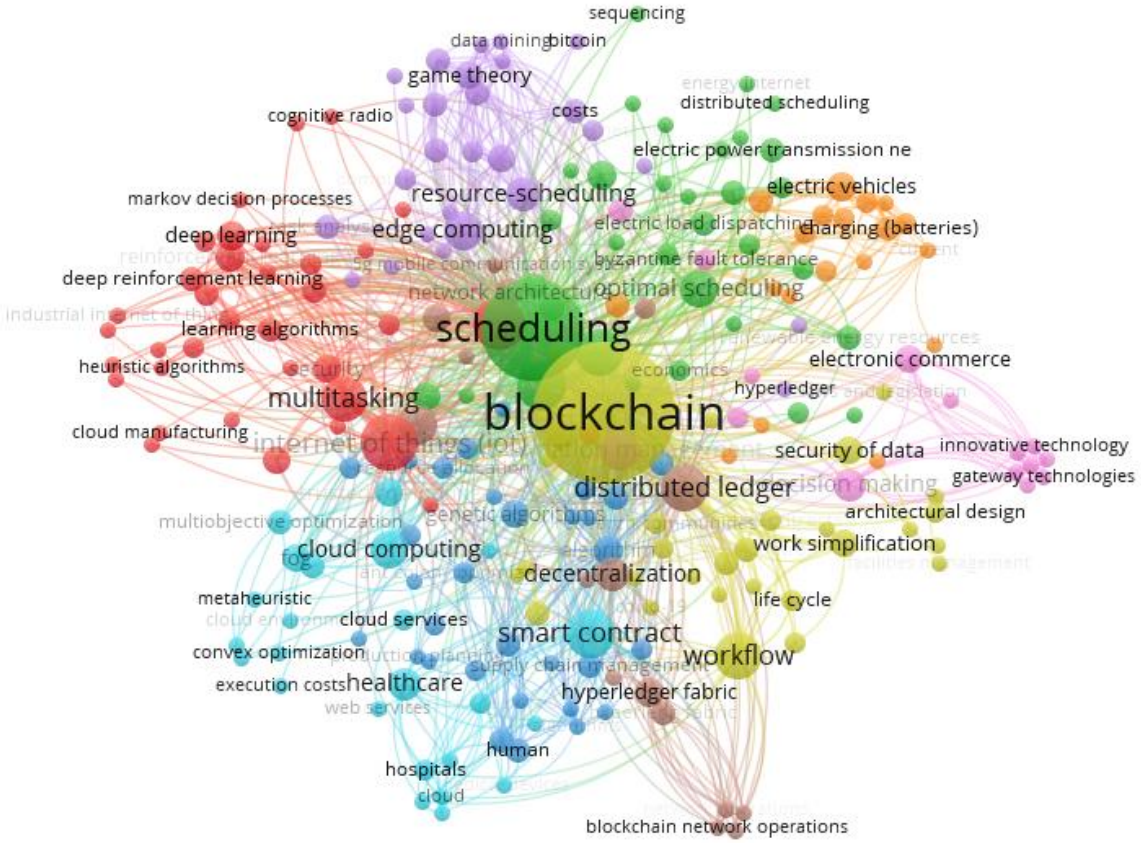

Fig. 9. Network Visualization Map of All Keywords

A table was extracted for a detailed analysis of the consolidated keywords, listing all the mentioned keywords along with their occurrences and total link strength. From this table, a list was generated that included the 10 keywords with the highest number of occurrences, as seen in Table

5. When analysing bibliometric data in VOSviewer, 'total link strength' for occurring terms is used to indicate the degree of association between different terms within the analyzed documents. Essentially, it quantifies the frequency with which terms co-occur across the analyzed literature.

Table 5
Highest 10 Occurring Terms based on bibliographic data

Keyword No.	Keyword	Occurrences	Total link strength
1	blockchain	130	198
2	scheduling	69	142
3	internet of things (iot)	22	53
4	optimization	18	45
5	network security	16	46
6	smart contract	16	33
7	digital storage	15	39
8	distributed ledger	15	36
9	workflow	15	28
10	multitasking	14	40

As indicated by the table above, ‘Blockchain’ is observed to have the highest number of occurrences, followed by ‘Scheduling’ and the ‘Internet of Things (IoT)’. Utilizing the same dataset of keywords, another visualization map was created to enhance our understanding of the development of these terms over time. This is depicted by the overlay network visualization in Figure 10, which shows that most terms have been developed since 2020.

3.2.2 Co-Occurrence maps based on text data

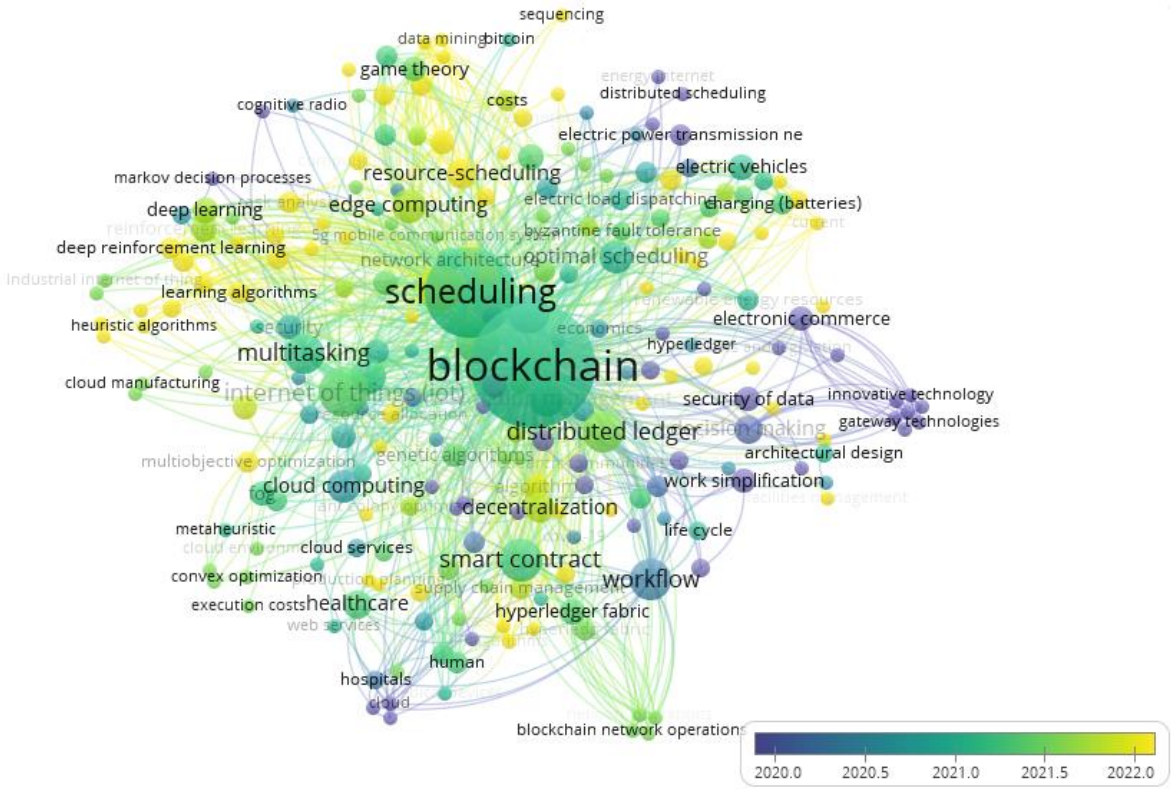

Fig. 10. Overlay Network Visualization of All Keywords

This section of the paper utilizes another function of VOSviewer, which involves analyzing the collected documents based on terms derived from raw text data, transforming them into visually comprehensible insights. The keywords and phrases used in this type of visualization map have undergone several filters to yield more accurate results. Initially, they were extracted from both the abstracts and titles of the papers in the dataset. Counting all terms resulted in a total of 3779 terms. To improve visibility, a threshold was set to only count terms with a minimum of 10 occurrences each, reducing the number to 81 terms eligible for analysis. Additionally, the software set a default restriction to enhance the visualization by including only 60% of the relevant terms, ultimately considering 49 terms for the final visualization.

Table 6
Highest 10 Occurring Terms Based on Text data

Term No.	term	occurrences	relevance score
1	scheduling	155	0.7495
2	process	78	0.7848
3	service	78	0.5896
4	task	78	0.6447
5	cost	73	0.4575
6	workflow	53	3.2163
7	time	52	0.3584
8	approach	50	0.6311
9	smart contract	44	2.2582
10	study	42	0.3099

Based on Table 6, the term 'Scheduling' occurred most frequently when analyzing the abstracts and titles of the papers, aligning with expectations as the search was conducted in the field of blockchain technology and its connections with terms relevant to scheduling. However, despite 'Scheduling' having the highest occurrence at 155 times, its relevance score is low at 0.7495, significantly less than that of other terms like 'Smart Contract' and 'Workflow,' which are close to or greater than 3.0. The relevance score is calculated based on the frequency of each term and its distribution across the documents. A term that appears frequently in the dataset and is evenly distributed across different documents tends to have a higher relevance score.

According to the density visualization map in Figure 11, and the network visualization map in Figure 12, the largest nodes, which correspond to specific high-impact terms extracted from the articles, are terms such as 'Scheduling,' 'Service,' 'Task,' and 'Process.' This is corroborated by the results in Table 6. Figure 12 illustrates the four clusters encompassing the filtered 49 terms from the analysis, highlighting the variety of recurring phrases that researchers have utilized in their abstracts and titles to direct their explorations.

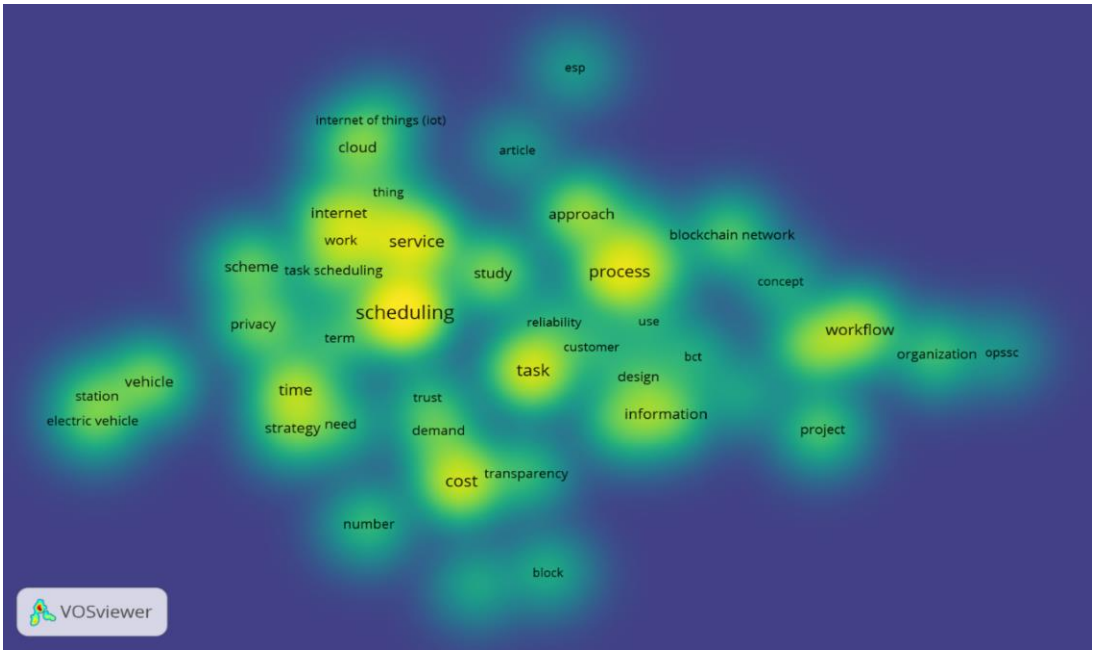

Fig. 11. Density Visualization Map of Terms Derived from Text Data

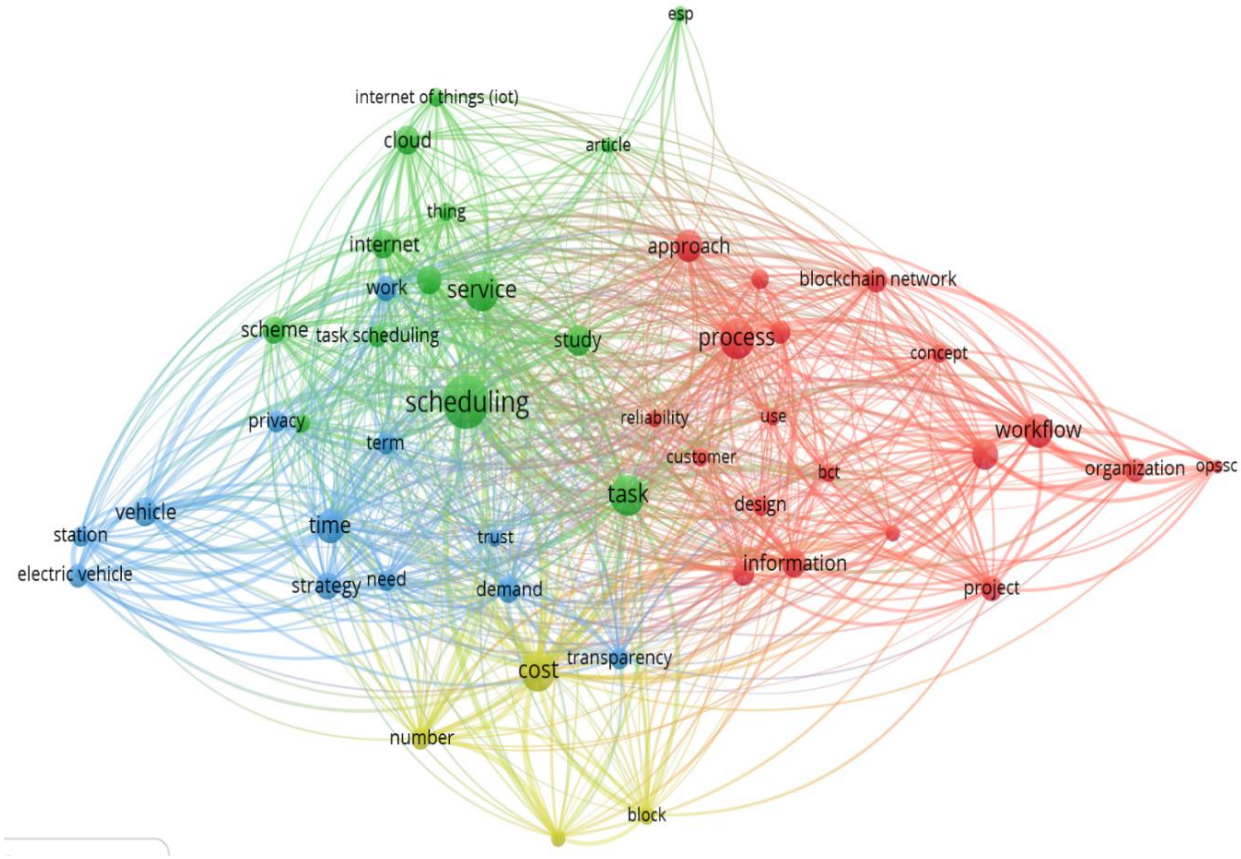

Fig. 12. Network Visualization Map of Terms Derived from Text Data

3.3 Classification of collected DATA

In the advancement of bibliometric analysis, a step forward was taken through the classification of the consolidated papers in our study. Six main categories were utilized for the classification of the

133 papers, including the subject area, fields, tools utilized in the papers, industry, purpose of the document, and the type of document.

While analyzing the documents, 11 subject areas were identified that described the branches of knowledge where blockchain was utilized. As shown in Figure 13, a total of 31 papers, accounting for the majority, aimed at optimizing services within specific industries for both service recipients and providers. This highlights the pivotal role blockchain can play in enhancing scheduling in the service industry. Common subject areas included the application of scheduling and blockchain in management, resource, and system planning, with occurrences of 20, 18, and 18, respectively. This draws attention to blockchain's general ability to enhance connectivity and transparency within organizations for effective scheduling of resources and workflow.

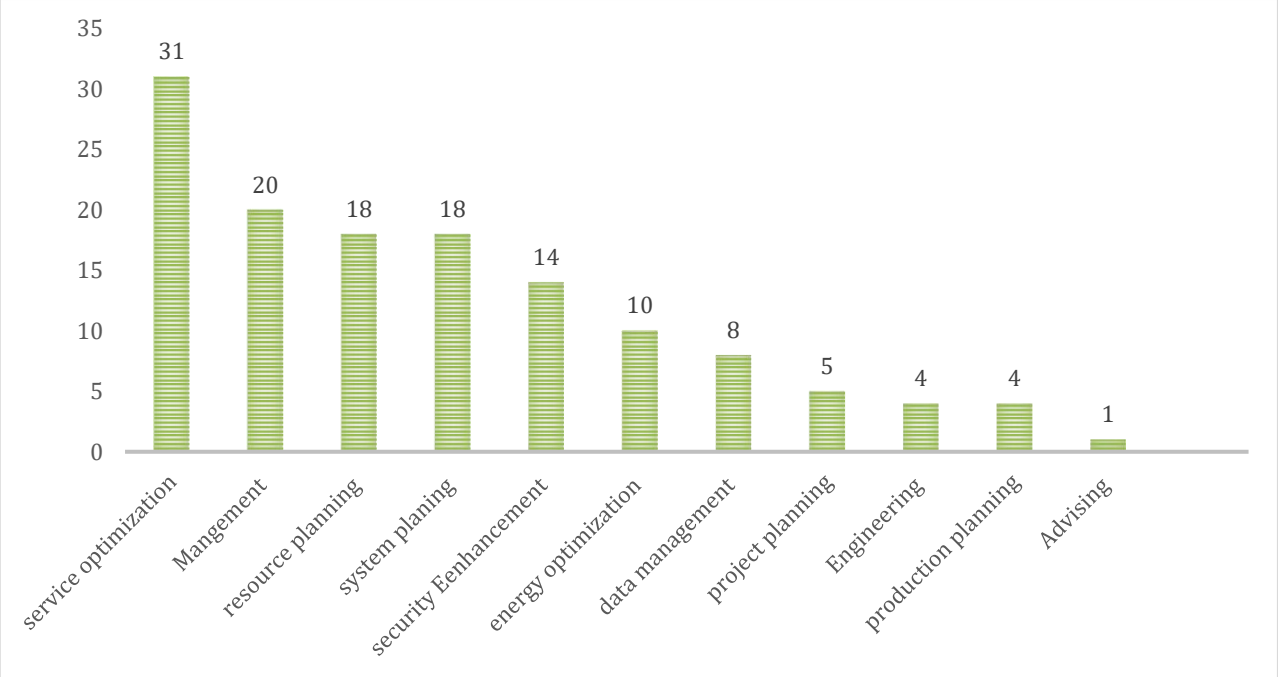

Fig. 13. Subject Area Diagram of the Consolidated Papers

Furthermore, the fields of the consolidated papers were influenced by the initial keywords used in collecting papers from Scopus, which include the previously mentioned fields: scheduling, workflow, planning, booking, workforce, personnel, and time management. The distribution of these fields can be visualized in Figure 14.

With 83 occurrences, scheduling was seen to be most closely associated with blockchain compared to other fields of study. This indicates blockchain's effectiveness and widespread use in offering superior scheduling operations by providing trust, transparency, and security through the integration of blockchain technologies. Additionally, workflow accounted for approximately 20% of the consolidated paper fields, with a total of 26 documents, highlighting the role of blockchain in enhancing system flows across different work contexts.

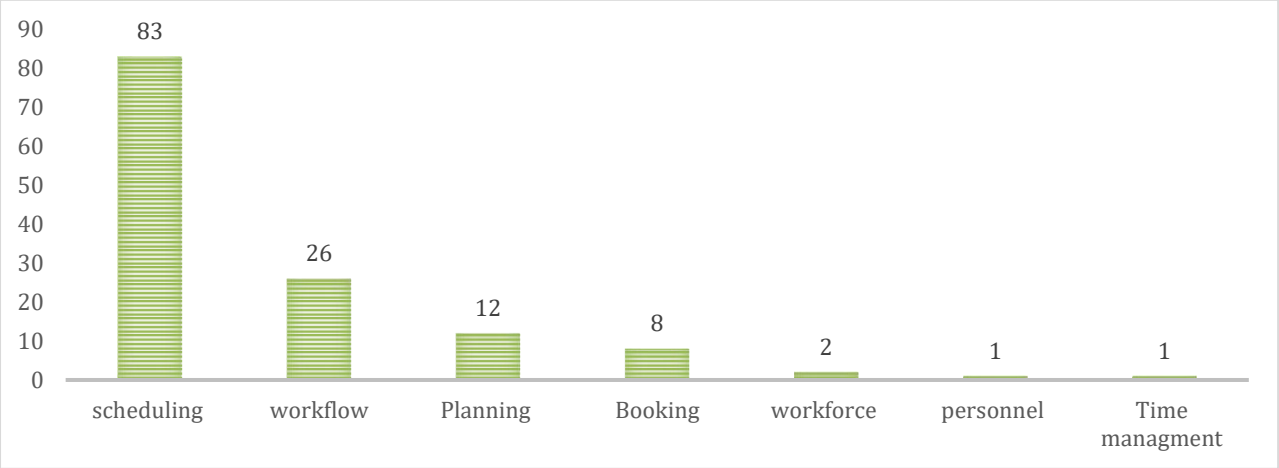

Fig. 14. Fields Diagram of the Consolidated Papers

Another classification examined during the document analysis was the tools used in the papers to leverage blockchain technology for scheduling and achieving the desired objectives. A total of 10 unique tools were identified, with smart contracts having the highest occurrence, being featured in 32 out of 133 papers. Twenty-seven papers focused on analyzing and using tools that could optimize the final outcomes, such as minimizing costs and losses, maximizing efficiency, and finding optimal scheduling sequences. The unique tools identified are displayed in Figure 15 along with their frequency of occurrence. The 'combined approaches' classification criterion, which was mentioned 19 times, was used to describe papers that conducted an in-depth analysis of existing blockchain tools and then integrated them into a superior blockchain algorithm or tool. This integration aimed to address one or more gaps in the currently employed tools.

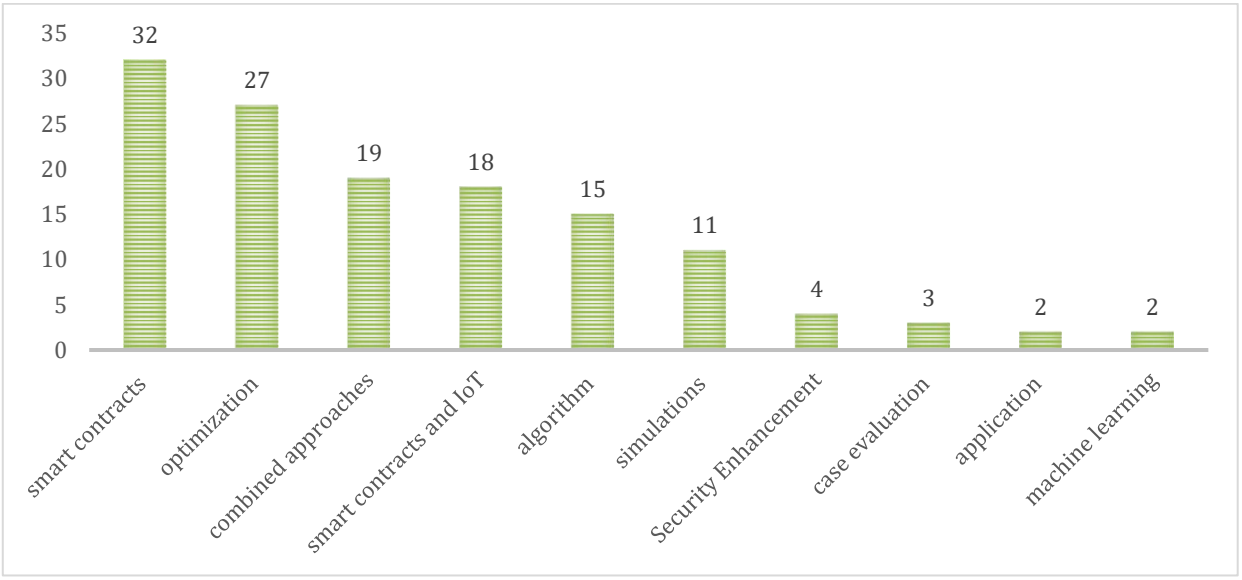

Fig. 15. Tools Used in the Consolidated Papers

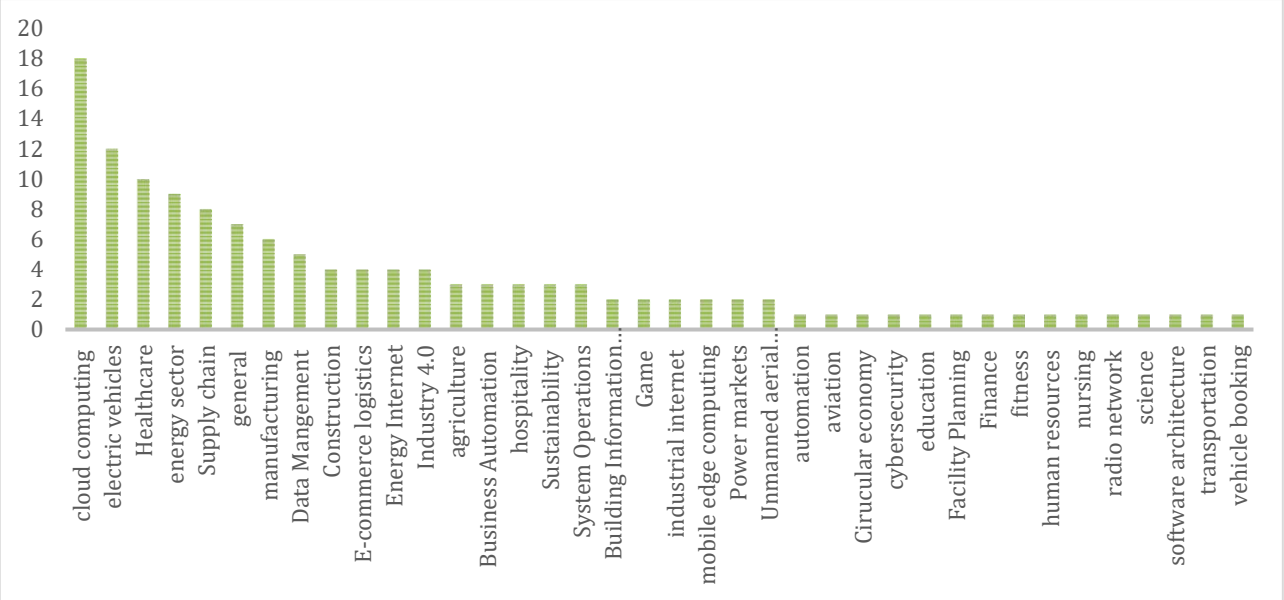

Fig. 16. Industries of The Consolidated Papers

The fourth category applied to the consolidated documents pertains to the industries where blockchain, combined with scheduling, was implemented. Upon analysis, 38 unique industries were identified, as seen in Figure 16.

For an in-depth analysis of the industries, another diagram was created featuring the 10 industries with the highest occurrences, as demonstrated in Figure 17. Among the papers, 18 implemented blockchain in combination with scheduling within the cloud computing industry, offering several benefits such as reduced wastage of computer resources, enhanced security, and resolution of threats. Following this, the electric vehicles industry utilized blockchain in the Internet of Vehicles (IoV) to manage data and address security concerns while considering energy consumption constraints. Moreover, healthcare emerged as another significant industry, with 10 occurrences, where blockchain improved resource utilization, such as medical records and staff scheduling, and addressed issues related to scheduling delays, thereby enhancing the efficiency and trustworthiness of the medical system.

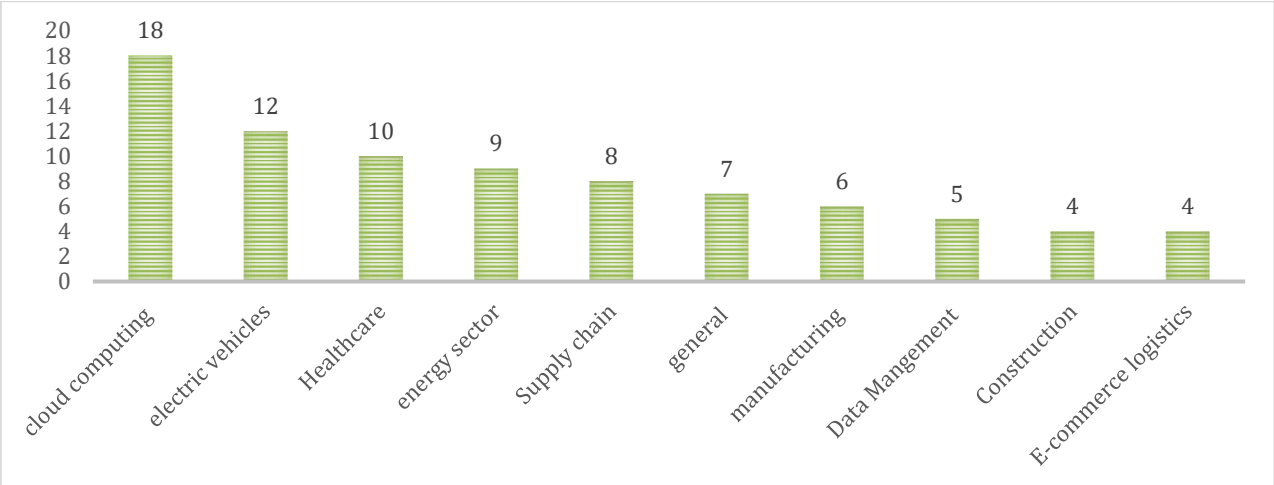

Fig. 17. Top 10 Industries of the Consolidated Papers

While examining the documents, it was necessary to understand the objectives and foundations of each paper. Consequently, a classification based on the documents' purposes was introduced, identifying 9 unique aims: instrument suggestion, analysis, framework, concept, research, case study, experimental analysis, educational, and literature review, as shown in Figure 18. According to Figure 18, 51% (67 out of 133) of the consolidated papers were published with the goal of suggesting a new instrument, approach, model, or tool to enhance organizational operations. This significant percentage highlights the diverse array of tools designed to address various market gaps. Among the detected purposes, two were most prevalent: papers aimed at analyzing and comparing existing tools, and those proposing a framework that considers all influencing factors based on research and simulation.

Moreover, a classification based on document type was established utilizing data derived from Scopus. Following the sorting process, the papers were categorized into four main document types: articles, conference papers, book chapters, and reviews. As illustrated in Figure 19, publications were predominantly in the form of articles, occurring 72 times. Conference papers were the second most common, making up 53 of the 133 papers, followed by book chapters and reviews with 5 and 2 instances, respectively.

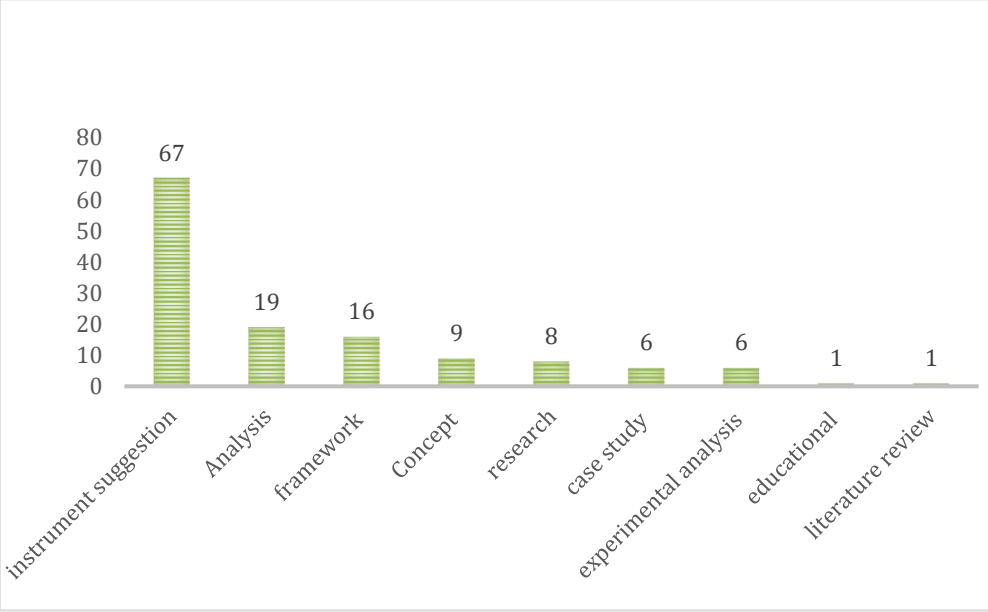

Fig. 18. Documents' purpose of the Consolidated Papers

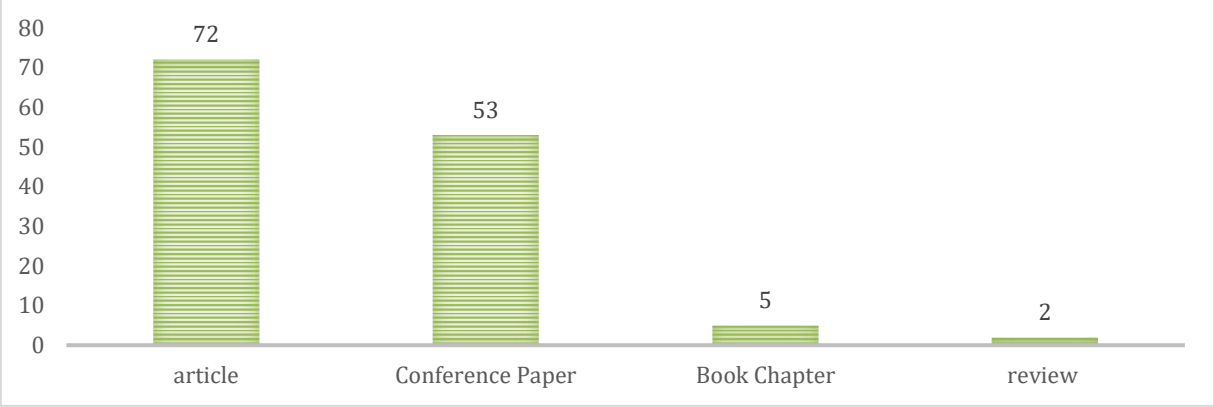

Fig. 19. Document Type of the Consolidated papers

Lastly, the dataset retrieved from Scopus was analyzed to gain insight into the main sources of the 133 papers. The top 10 unique sources were considered in these documents, as depicted in Figure 20. IEEE Access emerged as the source for 4 papers, followed by IEEE Internet of Things Journal and Proceedings of the Annual Hawaii International Conference on System Sciences, each with 3 occurrences, highlighting their significance in the field.

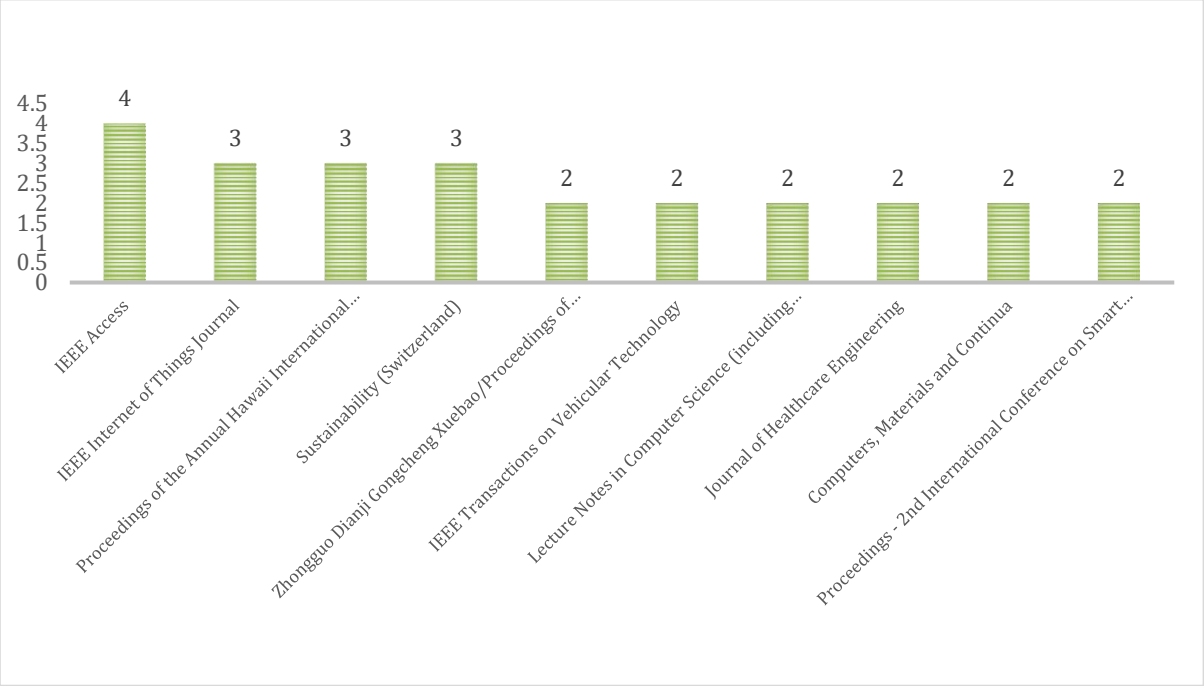

Fig. 20. Top 10 Sources of the Consolidated Papers

3.4 Discussion of the bibliometric analysis

After thoroughly analyzing the collected dataset, including the prevalence of research papers on the topic of applying blockchain in scheduling, the distribution of research across different educational and professional contexts, and the emerging trends in its applications, several key findings were drawn regarding the crucial roles blockchain can play in the work field.

The first key finding is the significant growth in the number of publications over time, as analyzed within the timeframe of the consolidated data that spanned from 2017 to 2023. This indicates promising opportunities for a more sustainable and effective future use of blockchain in scheduling.

Additionally, the data collection process revealed blockchain's widespread association with terms such as ‘Scheduling’, ‘Workflow’, ‘Workforce’, ‘Planning’, ‘Booking’, ‘Personnel’ and ‘Time Management’. This indicates its diverse applications in professional contexts, particularly in resource management, whether it concerns time or the workforce within an organization.

Moreover, implementing blockchain in such contexts raises concerns that must be addressed. The inherent transparency of blockchain could pose challenges in protecting sensitive organizational information, such as employee schedules and performance records. Furthermore, the adoption of blockchain introduces challenges related to its interoperability and integration with existing systems like human resources, as well as the costs associated with establishing a stable infrastructure to ensure a seamless and efficient data flow and prevent operational disruptions. Therefore, before shifting operations, it is essential to carefully weigh blockchain's inherent characteristics against an organization's dynamic scheduling and management needs.

Furthermore, the geographical distribution of the dataset's publications indicates China's dominance in the field of blockchain, followed by English-speaking countries such as the United States and Canada. Notable contributions also come from Middle Eastern countries like the United Arab Emirates and Saudi Arabia, as well as South Asian countries such as Pakistan and India. Therefore, cross-border collaborations can promote the advancement and efficient use of blockchain in professional settings, incorporating diverse cross-cultural perspectives.

4. Content Analysis

This content analysis delves into the multifaceted applications of blockchain technology across various sectors. It encompasses six key subsections: Service Optimization, System and Resource Planning, Management, Security Enhancement, project and production planning, and Energy Optimization. Each subsection critically examines the impact and advancements of blockchain technology in its respective domain. The objective of this analysis is to systematically explore how blockchain technology innovates and enhances processes, security, and efficiency, offering insights into its transformative role in various industries ranging from healthcare and manufacturing to energy and logistics. The analysis aims to provide a comprehensive overview of blockchain's diverse applications and potential future research directions in scheduling.

4.1 Blockchain in Service Optimization

Using blockchain technology to improve and streamline processes in services can result in increased efficiency, transparency, security, and trust in service delivery [31]. The decentralized nature of blockchain ensures secure and transparent recording of transactions [32]. Service optimization using blockchain has potential applications in numerous industries, including finance, healthcare, and supply chain management. Traditional scheduling often relies on central authorities or intermediaries to manage appointments, tasks, or services. In contrast, scheduling with blockchain is decentralized, enabling personnel to schedule, modify, and view schedules autonomously. Several researchers have discussed blockchain's impact on maximizing the quality of service metrics and improving scheduling and security schemes [33-35].

Traditionally, organizations stored data centrally, utilizing data servers and processors. This approach became increasingly costly and less secure as the volume of incoming data grew. The emergence of cloud environments offered a solution, providing services for data entry and maintenance on a platform that is safe, cost-effective, and secure [36-41]. When it comes to customer choice, the quality of service is crucial. Consequently, customers are more inclined to embrace blockchain-based solutions, attracted by their superior performance [42-44]. Blockchain technology's decentralization distributes workloads, enhancing performance by diminishing dependence on a single point of control or failure. Moreover, the security features of blockchain, such as cryptographic hashing and consensus mechanisms, safeguard the integrity and reliability of data. This reduces the necessity for extensive security audits and data validation, further improving performance. Research has confirmed the benefits of incorporating blockchain into IoT to achieve greater customer satisfaction [45,46]. Lei and Philip [47] have explored how blockchain influences the optimization of service quality, system cost, and security.

In the healthcare sector, blockchain technology can play a key role for overseeing the data workflow associated with complex medical conditions and treatment procedures. BlockIoT, an innovative system, merges blockchain with the IoT, seamlessly furnishing healthcare professionals with the crucial data required for complex healthcare operations [48]. Furthermore, a groundbreaking study has leveraged the synergy of blockchain and artificial intelligence to create a

digital workflow. This advanced system is adept at predicting breast cancer and orchestrating the healing journey [41].

Scheduling multiple tasks in large facilities has proven to be simpler and more effective when adopting data decentralization strategies [49]. Research suggests the integration of blockchain technology could significantly enhance the efficiency of worker deployment across facilities while reducing delays and costs [50]. The concept of data scheduling involves the meticulous organization and management of tasks, operations, and processes related to data within a centralized storage and management system [51]. Blockchain emerged as a viable solution to the challenges of data centralization in systems characterized by intensive data usage [45, 52]. A noteworthy application has been observed in planning long-term nursing programs for the elderly, demonstrating greater effectiveness and cost efficiency through the combined use of blockchain and IoT [53]. Amid the COVID-19 pandemic, the healthcare sector faced difficulties in processing and maintaining data related to the virus, highlighting the urgent need for blockchain-based systems capable of managing health records for a vast number of individuals [7,39].

Banerjee [40] has explored the transformative power of data decentralization in supply chain management, emphasizing the integration of blockchain systems with Enterprise Resource Planning (ERP) and Manufacturing Execution Systems (MES) to enhance efficiency. The mobility sector has recently recognized the potential of blockchain technology, applying it to online booking systems to streamline operations while improving traceability and security [54,55]. As electric vehicles gain popularity, there has been a surge in research focused on merging blockchain with the IoV. Manoj *et al.,* [39] developed a blockchain-based platform for various IoV scenarios, tackling security concerns and high energy consumption. Additionally, the management of charging stations has emerged as a significant challenge due to increased demand. To address this, several studies have proposed blockchain and IoT solutions to streamline charging demands, including scheduling, timing, and financial efficiency of stations [30,32,56]. This innovative approach has also been adapted for managing transactions related to scheduling and payments at unmanned aerial vehicle charging stations [56,38], showcasing blockchain's versatility across different applications. Furthermore, Khajeh *et al.*, [57] have adopted Blockchain technology as a platform for prosumers to trade energy with each other, to avoid using brokers. The study introduced a decentralized, price-based demand response model, enabling prosumers to manage their consumption.

In the hospitality industry, blockchain technology has been introduced to enhance booking applications and websites. This innovation allows booking services to become more user-friendly, offering a wide range of options, discounts, and access to a variety of hospitality brand names. Furthermore, security enhancements can make users feel more comfortable using online booking websites with their personal information [54,55].

Figure 21 showcases the widespread application of blockchain technology in enhancing services across a diverse array of fields. It highlights that the most common form of service optimization facilitated by blockchain is in scheduling activities, with particular prominence in sectors like cloud computing and electric vehicle management. Moreover, other scheduling aspects such as workflow coordination, booking systems, and strategic planning also benefit significantly from blockchain integration, demonstrating its versatility in service optimization. The spectrum of industries leveraging blockchain for scheduling purposes extends further, including healthcare, supply chain management, and the hospitality industry, indicating blockchain's transformative potential across various sectors.

While blockchain technology offers promising improvements across diverse service sectors, several challenges hinder its widespread adoption. Notably, networks, especially within public

organizations, may encounter scalability constraints. As the volume of transactions increases, the performance of these networks can diminish, leading to longer processing times. Furthermore, the majority of research has yet to apply blockchain solutions to large-scale networks and organizations, indicating a gap between theoretical potential and practical implementation. This discrepancy underscores the need for further investigation and development to overcome the obstacles to blockchain's broader application.

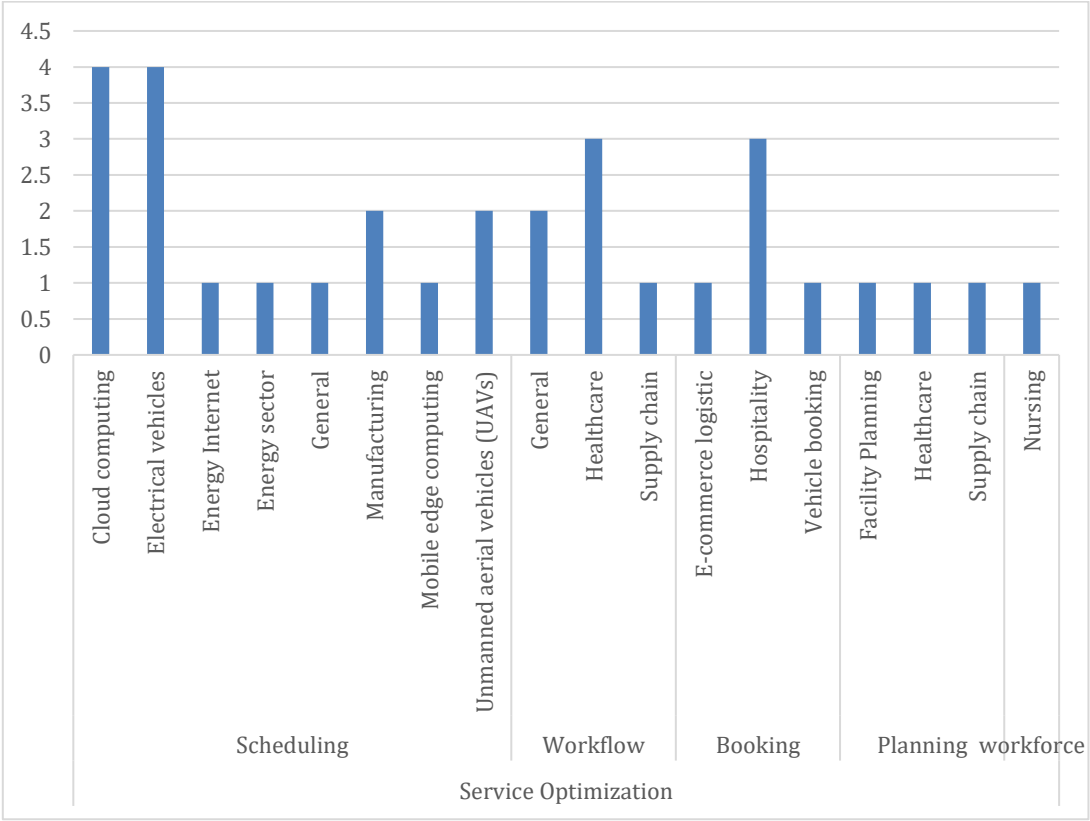

Fig. 21. Count of Publications on Blockchain in Service Optimization

4.2 Blockchain in System and Resource Planning

Blockchain technology is revolutionizing resource and system planning across diverse sectors. Originally conceived for decentralized cryptocurrencies, it has the potential to become an indispensable tool that enhances security, transparency, and efficiency. In the field of manufacturing, blockchain deploys an immutable ledger which streamlines processes and enables real-time tracking of materials, while simultaneously mitigating risks. This innovation optimizes resource use, minimizes waste, and revolutionizes strategies through the deployment of smart contracts. Beyond the manufacturing sphere, blockchain significantly impacts cloud computing, the Industrial Internet of Things (IIoT), and the IoV, offering efficient resource scheduling in unpredictable environments. In the electric vehicles sector, it introduces charging strategies that bolster data security and ensure system reliability. Moreover, blockchain's utility extends to healthcare, aviation, agriculture, energy management, and microgrids, affirming its potential as a foundational element for fostering trust, transparency, and enhanced coordination.

In the context of manufacturing, integrating blockchain creates an immutable and robust ledger, laying a solid foundation for transforming manufacturing processes. Blockchain technology efficiently manages the complexities of tracking raw materials and finished goods in real time, thereby

mitigating the risk of counterfeit products. For instance, Ramakurthi *et al.,* [9] presented a model to support blockchain-based distributed manufacturing, enabling job scheduling in traditional job shops with multiple machines, as well as in the settings of extended and virtual enterprises. Furthermore, the model introduced an innovative blockchain-based smart contract, enhancing the security and transparency of information exchange within distributed production systems.

The use of blockchain technology fundamentally enhances supply chain management by offering decentralized and tamper-proof safeguards for the detailed recording and verification of transactions. This approach to record-keeping becomes the cornerstone, elevating quality control processes to unparalleled levels of rigor, ensuring strict compliance with predefined standards. For example, Li *et al.,* [58] introduced a comprehensive blockchain-based smart manufacturing system that capitalizes on the decentralization, immutability, and auditability of blockchain to facilitate flexible manufacturing capable of swiftly adapting to on-demand services. They segmented manufacturing services into tasks, managed them through a unified scheduling system, and arranged tasks according to the logical flow within the transaction pool. To address the challenge of reconciling large-scale manufacturing with limited transactional throughput, they proposed a joint task scheduling mechanism using blockchain and a supply-demand configuration design aimed at maximizing customer net profit while maintaining a balance between timeliness, production efficiency, and the advantages of blockchain.

In the complex manufacturing field, blockchain can be a powerful tool for facilitating smoother communication and efficiently coordinating resources throughout the manufacturing processes, thereby fostering a philosophy of secure and transparent collaboration among manufacturers. In their study, Lohmer [59] investigated the challenges that arise in collaborative production networks, with a focus on IoT data storage and communication issues. They introduced a concept utilizing blockchain and smart contracts in distributed manufacturing and highlighted the potential benefits of decentralized approaches for trust and data security. Moreover, they examined both the benefits and risks associated with their proposed methodology, including a case analysis involving multiple companies engaged in distributed manufacturing.

Shifting the focus to cloud computing, researchers have adopted blockchain technology for managing and storing data, executing contracts, allocating resources, and enhancing trust in cloud-based services. For instance, Chen *et al.,* [60] proposed a method to balance computing resources in blockchain distributed systems by using a variance ratio, ensuring an adequate level of computational capability while minimizing resource wastage. In the study by Li *et al.,* [61], a blockchain-based IoT resource monitoring and scheduling framework was proposed to facilitate trusted edge computing. Meanwhile, Dai [62] suggested a hardware and software architecture that combines generalized IoT with quantum cloud computing and blockchain.

Numerous pioneering studies have been introduced in the dynamic environment of resource scheduling for emerging technologies. For instance, Lin *et al.,* [63] studied the domain of resource scheduling within the context of the IoT. Their approach encompassed the development of a collaborative terminal-edge IoT architecture, seamlessly integrating blockchain and artificial intelligence technologies. This architectural innovation helped dynamic resource scheduling in stochastic environments. They also adapted a smart contract-based multidimensional resource transaction model to increase efficiency and security by establishing a credit-based consensus process. Ahmad *et al.,* [64] highlight the growing interest in integrating blockchain and the IoT to create a secure communication platform. They investigated a message scheduling approach for a blockchain-based architecture, distinguishing between critical and non-critical messages. The study divided the fog layer into action clusters and blockchain fog clusters, managing critical message

requests between action clusters and the main cloud data center. Additionally, a fog broker is employed to schedule messages within the action and blockchain fog clusters.

In the emerging technology of IoV systems, blockchain provides a secure, transparent, and decentralized platform for managing data and transactions. For example, Gao *et al.,* [65] embarked on an effort to redefine resource scheduling in blockchain-enabled IoV systems. Their scheme was meticulously designed to optimize system performance by allocating computational resources. It adeptly navigated through the complexities of dynamic network topology and resource constraints to ensure efficient resource allocation. Meanwhile, Chen *et al.,* [66] proposed a resource scheduling method for the IoV that utilizes both blockchain and game theory. The main objective is to offload computing tasks from vehicles with limited resources to those with surplus capacity, integrating blockchain technology into the system to ensure secure and transparent transactions. In addition, game theory provides a strategic framework for optimal decision-making among vehicles.

Within the scope of electric vehicles, Javed and Javaid [67] introduced an efficient charging strategy, known as mobile charging from vehicle-to-vehicle, using blockchain technology to address privacy concerns and promote transparency, trustworthiness, and security. Hu *et al.,* [68] proposed a collaborative optimization model for power system scheduling that utilizes blockchain consensus. This model classifies the power system into transmission, distribution, and battery-swap station levels, aiming to minimize generation costs and daily load variance while optimizing scheduling through multi-level collaboration. The role of blockchain in this context is to ensure the accuracy of transaction data and guarantee tamper resistance.

Beyond these groundbreaking efforts, a variety of studies have delved into numerous aspects of resource and system scheduling across different fields and domains. Within the aviation sector, Jing *et al.,* [69] explored the development and implementation of a system that leverages blockchain technology for the planning and scheduling oversight in aircraft tow tractor operations. The integration of blockchain technology has opened avenues for examining how decentralized and secure ledger systems can bolster efficiency, transparency, and the management of aircraft towing activities. Deng *et al.,* [70] introduced a groundbreaking approach to Blockchain-Assisted Federated Learning over Wireless Channels, aimed at dynamically allocating resources and scheduling clients. This approach integrates training and mining on the client side, with the objective of enhancing learning performance by maximizing the size of long-term training data while minimizing energy consumption. Additionally, Shi *et al.,* [71] offered an optimal solution for offline workload management by minimizing the number of workers needed, thereby reducing total computational resource demand. This study also proposed a high-performance orchestration platform scheduling scheme aimed at maximizing worker utilization.

Incorporating blockchain technology into the agricultural sector tackles unique operational challenges, especially in the scheduling of machinery resources. Blockchain can serve as a key element in streamlining and enhancing the efficiency and transparency of scheduling processes across extensive geographical regions [72]. In the field of energy scheduling, Chen *et al.,* [73] delved into visual analysis and optimal scheduling of user-side source and storage resources within blockchain-based energy storage systems. Cantillo-Luna *et al.,* [74] explored the application of blockchain in distributed energy scheduling for district-level integrated energy systems. Liu *et al.,* [75] introduced a distributed energy scheduling method that employs a two-layer structure for energy interactions, aiming to reduce operating costs for each operator through the use of smart contracts, distributed ledger technology, and digital signatures. This research further developed a decentralized energy scheduling model utilizing the Lagrange multiplier method alongside a blockchain-based information transmission framework, ensuring fairness, openness, safety, and reliability in the energy

dispatch process. Additionally, Yin *et al.,* [76] proposed a secure socio-economic framework based on the point estimate method and blockchain, providing insights into optimal scheduling for reconfigurable interconnected microgrids.

The intersection of edge computing, resource pricing, and scheduling within the blockchain framework has also garnered attention. For instance, Huang *et al.,* [77] employed a Stackelberg Game approach to tackle the issue of resource pricing and scheduling for blockchain in edge computing environments. Expanding on this approach, Huang *et al.,* [78] presented a Stackelberg Game-based methodology specifically designed for resource pricing and scheduling in edge-assisted blockchain networks, further enriching the discourse on blockchain's versatility and applicability across different domains.

Within the broad landscape of system and resource planning, blockchain technology can serve as a transformative force and can potentially bring significant implications to a range of scheduling practices. This includes workflow management and workforce allocation across diverse domains. Its impact can be significant in critical sectors such as system operations, supply chain and logistics, healthcare, and e-commerce logistics, showcasing its current capabilities. Furthermore, it holds the potential to further enhance efficiency and transparency across an even wider spectrum of planning and operational processes.

In the context of system operations spanning various organizations, blockchain plays a crucial role in orchestrating and managing a wide array of activities, processes, and systems, necessitating cooperation among diverse entities. At the heart of blockchain network operations are the management of distributed ledgers, the execution of smart contracts, and the employment of consensus mechanisms that regulate the interactions between participants. Sato *et al.,* [79,80] unveiled an innovative Operations Smart Contract, designed explicitly for the Hyperledger Fabric v2.x platform, which addresses issues related to the manual coordination of operational information. This approach enhances channel and chain code operations, leading to cost reductions. Feng *et al.,* [81] advocated fointegrating wireless blockchain technology into cellular systems to decrease transmission airtime, employing a strategic fusion of blockchain technology, joint user scheduling, and power control within a multi-cell network framework. Li *et al.,* [82] leveraged Hyperledger Fabric to implement stringent permission levels and access policies, effectively thwarting malicious activities. Additionally, it examines a variety of strategies for overseeing blockchain network processes, including blockchain-as-a-service solutions like Chains-tack, noted for their simplicity and scalability. The main goal of this research is to devise a method that securely stores and retrieves task-scheduling schemes utilizing a consortium blockchain and an inter-planetary file system, aiming to bolster security and efficiency in task management.

Blockchain technology has found significant applications in supply chain and logistics, where transparency and trust are paramount. Rondanini *et al.,* [83] introduced a blockchain-based solution for managing inter-organizational workflows. This approach ensures controlled information sharing, with smart contracts playing a crucial role in securing and overseeing off-chain data exchanges during workflow operations. Yu *et al.,* [84] delved into blockchain's effects on supply chain practices, specifically within the apparel industry. Their research highlighted the use of blockchain to implement "smart credit" systems and increase transparency of demand information. Findings indicate that the operational value of blockchain varies between retailers and suppliers, potentially leading to positive effects on the supply chain workforce, especially under conditions of negatively correlated demand. Akshita *et al.,* [85] explored blockchain's utility in immunization management, underlining its capability to track vaccine inventory, guarantee transparent distribution, enhance visibility into vaccine dissemination, streamline appointment scheduling, and uphold the integrity

and transparency of the entire immunization process. Tan and Sundarakani [86] focused on the adoption of blockchain in the freight booking industry, particularly by a global freight consolidation provider. This investigation revealed blockchain's capacity to boost the competitiveness and sustainability of operations, showcasing its broad applicability and potential benefits across different supply chain and logistics sectors.

Beyond its impact on supply chain management, blockchain plays a crucial role in enhancing the healthcare sector, particularly by facilitating the secure transfer of patient data among healthcare providers. Smart contracts further streamline the process by automating appointment scheduling and billing, leading to improved patient care and reduced administrative burdens. Additionally, these innovations support the efficient management of medical resources, including the allocation of equipment and personnel within hospitals. Ruggeri *et al.,* [87] explored blockchain's potential to develop a Software as a Service (SaaS) solution designed for hospital clouds. This platform acts as a catalyst for establishing federations among hospital clouds, promoting the collaborative creation of virtual healthcare teams composed of doctors from various hospitals. Lakhan *et al.,* [25] introduced a blockchain-enabled Internet of Medical Things system that addresses cost, deadline, and security constraints. Meanwhile, Parthiban and Kumar [88] employed blockchain technology in modern healthcare to mitigate the risks of cyber-attacks and address resource shortages.

In e-commerce logistics, blockchain technology can play a crucial role in optimizing resource allocation for order fulfillment. It can enhance transparency in tracking shipments, curtail fraudulent activities, and streamline inventory management. Two distinct proposals, detailed by Li *et al.,* [4] and Li and Huang [89], tackle the challenges posed by the diverse service requirements of this dynamic sector. Li *et al.,* [4] introduced an innovative solution for a blockchain-enabled workflow operating system, utilizing gateway technology to efficiently manage a range of logistics resources. This system employs a multi-dimensional workflow model for seamless coordination and integrates a resource blockchain to guarantee data reliability. On the other hand, Li and Huang [89] introduced a blockchain-enabled workflow management system aimed at centralizing heterogeneous logistics resources to cater to various customer needs. This system combines gateway technology for Universal Plug and Play resource management, a workflow operating platform for effective coordination, and a resource blockchain for reliable data management. The primary objective is to overcome the challenges of resource fragmentation and achieve centralized coordination to satisfy the diverse demands of customers. Figures 22 and 23 illustrate the volume of contributions in the areas of resource and system planning.

As shown in Figures 22 and 23, blockchain technology can significantly enhance and transform resource and system planning across various industries, promoting security, transparency, and efficiency. Its multifaceted role in manufacturing includes providing an immutable ledger for streamlined material tracking and risk mitigation. In supply chain management, blockchain's decentralized and tamper-proof nature greatly aids in the accurate recording of transactions. Furthermore, its influence extends to resource scheduling in stochastic environments, affecting dynamic sectors such as cloud computing, IIoT, IoV. Beyond this, blockchain actively fosters trust in industries such as aviation, agriculture, and energy scheduling, through edge computing, pricing mechanisms, and scheduling processes. Its transformative effects are widespread, enhancing trust and transparency across organizational boundaries in system operations. Moreover, blockchain brings enhanced transparency and trustworthiness to logistics, streamlining secure data exchanges and automating processes within healthcare systems. In e-commerce logistics specifically, blockchain ensures transparent shipment tracking, reduces fraudulent activities, and automates inventory management, showcasing its comprehensive impact and utility.

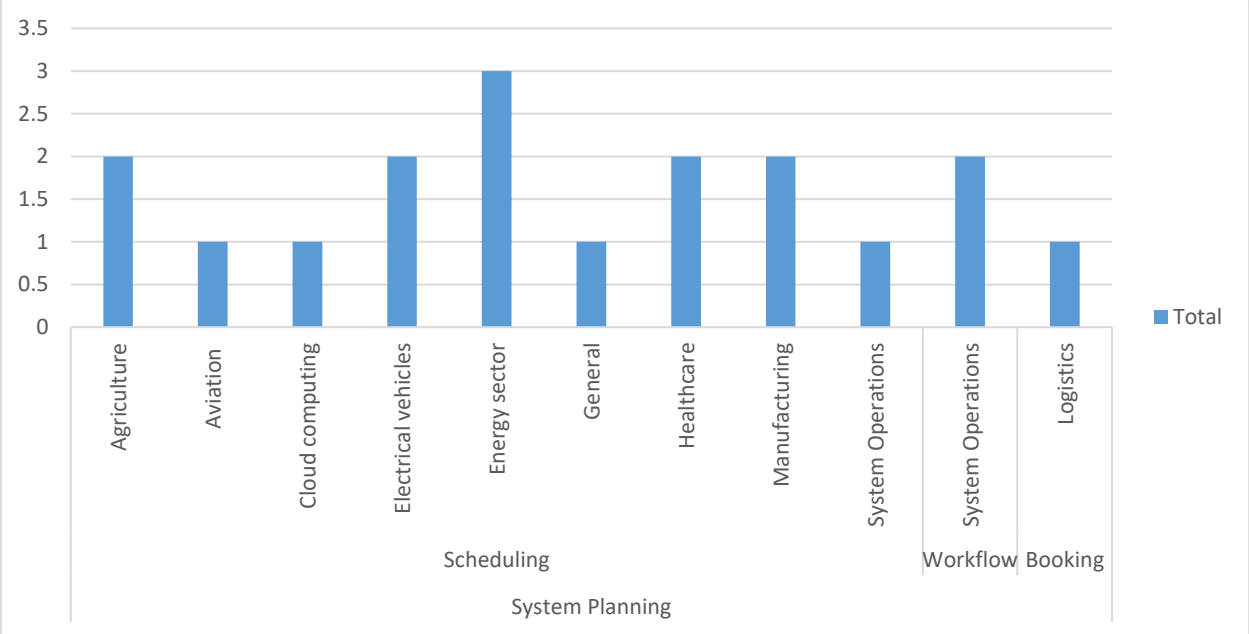

Fig. 22. Count of Publications on Blockchain in System Planning

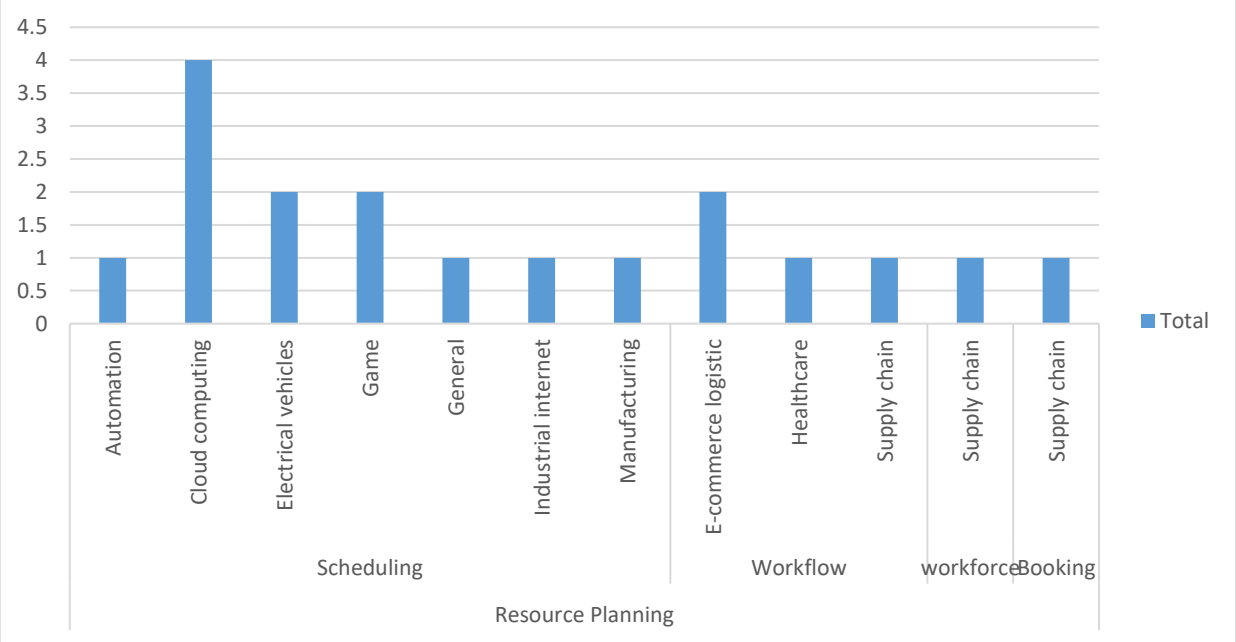

Fig. 23. Count of Publications on Blockchain in Resource Planning

While these findings provide valuable insights into the integration of blockchain technology across various industries for resource and system planning, they also highlight the need for a thorough examination of potential drawbacks and ethical considerations. The advantages of using blockchain for resource allocation are indisputable, but it is crucial to recognize and tackle potential challenges, including the risk of over-reliance on automated processes and their implications for the core principles of resource planning. Additionally, there is a pressing need to focus on developing advanced solution algorithms that consider decentralized task assignments while taking into account factors like resource needs, task interdependencies, and priority levels. Dynamic scheduling algorithms, to a significant degree, prove to be essential, offering real-time adaptability to changing

conditions. Furthermore, delving into consensus mechanisms is indispensable, requiring a careful assessment and selection of protocols that complement the features of scheduling algorithms, such as scalability, transaction speed, and energy efficiency. This underlines the complex nature of decision-making in this domain. Future research should aim to find a balance between the benefits and drawbacks of blockchain integration in resource planning, addressing crucial issues like data security, scalability, and innovative approaches for seamlessly incorporating blockchain technology into resource allocation strategies within diverse industrial contexts.

4.3 Blockchain in Management

As organizations increasingly undertake multitasking and branch out into diverse areas, the flow of data has become vast and increasingly challenging to manage [90,91]. Researchers in systems management have identified blockchain technology as highly effective for managing and scheduling a wide range of processes and data across various sectors, including supply chain, human resources, healthcare, manufacturing, sports and fitness, and the energy sector [27,92-95]. The adoption of blockchain in management introduces an immutable and auditable distributed architecture. This supports a distributed workflow, facilitating the rapid automation of business processes and enhancing workflow efficiency [96,97]. Furthermore, workflows enable the coordination among users from different organizations, allowing them to process and manage transactions, data, and documents in a secure, immutable, and transparent manner. This approach ensures trust and transparency for all parties involved [98,99].

In the human resources sector, blockchain technology has eliminated redundant channels in all production transactions. This streamlining has made resource selection for various production and service tasks much faster and easier [100]. In the medical sector, studies have demonstrated that utilizing blockchain technology in the management of operations can significantly reduce care plan completion times and increase transaction processing speeds [27]. Zhao [91] discovered that using blockchain technology in scheduling plans for medical device scheduling models significantly improved cycle times. The performance of medical emergency material scheduling programs, when integrated with supply chains, has been outstanding. Moreover, in the manufacturing industry, an example of using blockchain technology includes designing a work ticket system that enables employee identity authentication. These innovative systems allow users to fully control their private keys and store them locally, effectively preventing large-scale information leaks. Additionally, the use of blockchain ensures that work ticket data cannot be tampered with or forged, and the responsible individual can be accurately identified based on signature information in the ticket system [96]. Blockchain has also minimized large-scale data leaks by securely identifying users and granting them access to requested data [94].

Furthermore, Al- Refaie *et al.,* [10] proposed two models that integrate blockchain technology with maintenance planning and management. The results indicated a reduction in the number of failures, which decreased maintenance costs and increased resource utilization. The study utilized an Electronic Repair Records system for the blockchain of maintenance planning and management, sequencing failure repairs from different types over multiple periods. Each failure repair is considered a block, derived from failure repair parameters, resources availability information, and the optimal start and finish times of the assigned failure repairs.

In energy management programs, researchers have explored various models that primarily utilize blockchain technology [101]. Bian and Zhan [102] introduced a stochastic model based on fuzzy cloud theory to account for the uncertainties from renewable energy sources, market electricity prices, and hourly load demands. Each point within the fuzzy cloud denotes a deterministic framework, each

assigned a specific probability value. Additionally, other models focusing on renewable energy have employed blockchain technology to ensure secure implementation of the branch and bound algorithm. Blockchain enables efficient machine-to-machine interaction, with transactions recorded on a distributed shared ledger [95,103].

In database management, blockchain technology is viewed as a method for chronologically storing data in a database, while also securely and collectively distributing copies of it across a network of computers to maintain its authenticity [104]. Various studies have explored integrating blockchain with cloud computing to enhance interoperability, privacy, and trust in shared provenance data, and to combine blockchain technology with traditional cloud servers [105,106]. Multiple studies have demonstrated the effectiveness of using blockchain technology in workflow management processes over manual, paper-based systems for improved auditability, the automation of manual process steps, and the decentralized nature of the system, solving security issues and improving data flow [107-109]. Blockchain technology effectively addresses the challenges associated with the establishment of contracts and data exchange among untrusted parties. By utilizing smart contracts, it provides a robust framework for secure and controlled data sharing, ensuring comprehensive oversight and enhanced trust in these transactions [23,96,110]. In addition, within the fields of finance and supply chain management, numerous studies have put forward various smart contract models to evaluate and enhance desired operational efficiencies [8,75,111] . Moreover, Bai *et al.,* [112] proposed a multi-edge-chain structure to accommodate thousands of edge data and promote on-chain data efficiency.

The literature analysis suggests that blockchain technology can significantly automate processes and minimize the need for intermediaries, streamlining operations and reducing costs. This increased efficiency can enhance resource management and expedite task execution, propelling innovation in management practices. Blockchain technology opens the door to new business models and applications, promoting agility and adaptability in the face of a rapidly evolving business landscape. Blockchain technology holds the promise of transforming management practices by bolstering security and efficiency, diminishing expenses, and lessening the reliance on intermediaries across various sectors and industries. However, the applicability of blockchain to specific management tasks hinges on the particular use case and the selection of an appropriate blockchain platform and architecture. Challenges may arise as a blockchain network may not efficiently handle a high volume of transactions swiftly. With network expansion, processing times and costs can escalate significantly. Moreover, the complexity of blockchain interfaces and wallets for non-technical users can pose barriers to widespread adoption, underscoring the importance of user-friendly design to facilitate broader acceptance and utilization.

As illustrated in Figure 24, the deployment of blockchain technology in governmental and official contexts seems restricted, likely due to the complexities of regulatory and legal frameworks. The inherent decentralized and pseudonymous characteristics of blockchain introduce obstacles to achieving regulatory compliance, complicating the management of fraud, illegal activities, and disputes. In a decentralized setup, the lack of a centralized authority complicates dispute resolution and the implementation of essential protocol updates. Recognizing these limitations is critical when assessing blockchain's appropriateness for particular applications. Different blockchain platforms may tackle these challenges in various ways, and the choice of platform should be tailored to meet the specific requirements of the application in question.

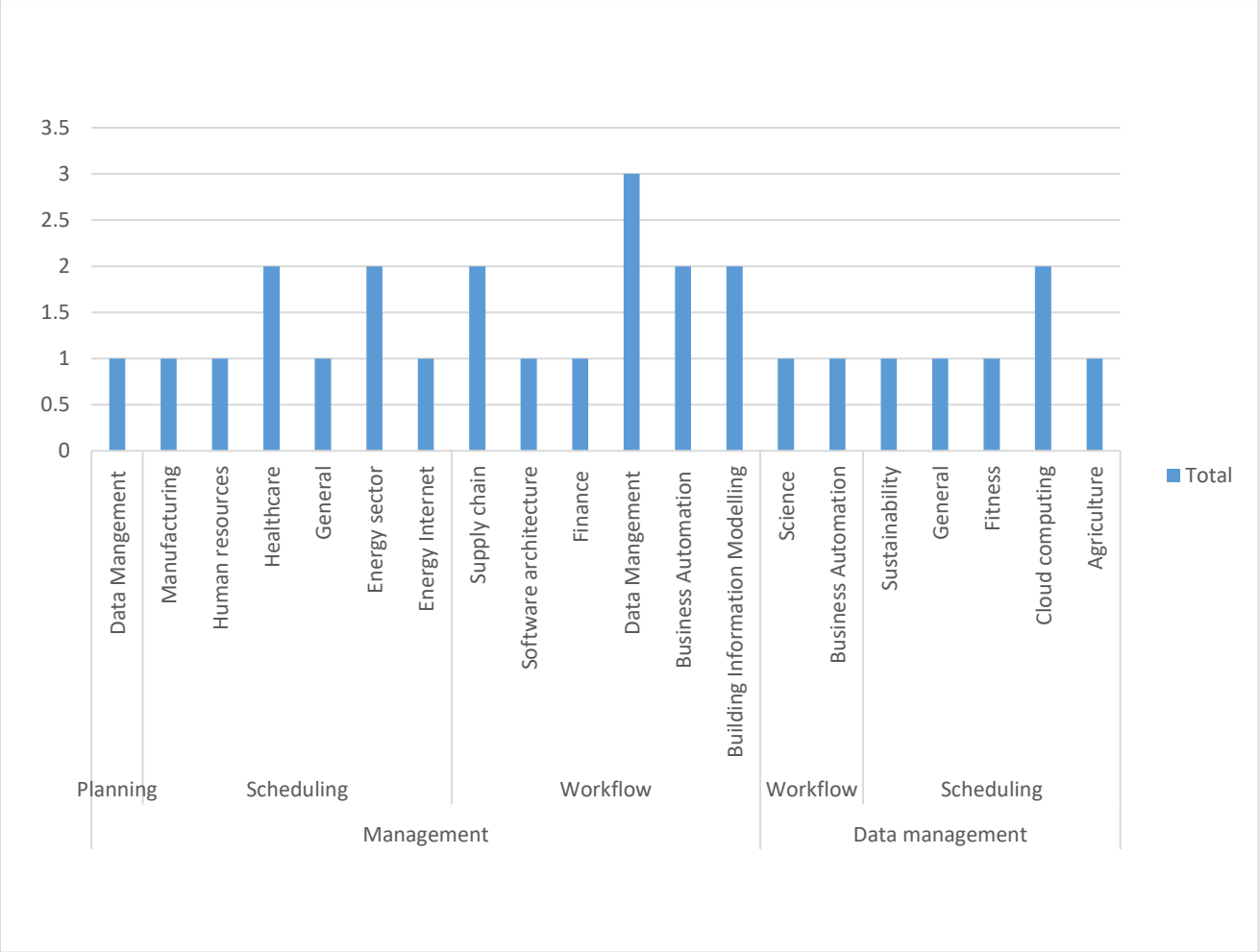

Fig. 24. Count of Publications on Blockchain in Management

4.4 Blockchain in Security Enhancement

In today's digital era, preserving the security and integrity of data and transactions is a paramount concern across various industries. Blockchain technology offers an innovative solution to tackle this challenge. Several studies have explored the integration of blockchain technology to address security challenges and optimize resource allocation in different computational environments. Wilczyński *et al.,* [113] proposed a model utilizing blockchain and Proof of Stake to enhance security-aware task scheduling in cloud computing, emphasizing efficiency through reduced computing power requirements. Vera-Rivera *et al.,* [114] introduced a task-sharing mechanism for Multi-access Edge Computing servers, using the Hyperledger Fabric blockchain to improve functionality, security, and privacy. Other studies, such as Nguyen *et al.,* [115], focused on designing a system that integrates a blockchain network into a fog-cloud environment, aiming to improve transparency and prevent attacks from suspicious entities. Baniata *et al.,* [116] introduced an Ant Colony Optimization algorithm within a Fog-enabled, Blockchain-assisted scheduling model to automate task assignment to virtual resources in cloud computing. This approach emphasizes the role of blockchain miners in generating optimal schedules and enhancing execution time, network load, and privacy awareness. Lastly, Wilczyński and Kołodziej [117] developed a new generic model of a secure cloud scheduler based on blockchain architecture, employing a proof-of-schedule consensus algorithm and Stackelberg games for improved task scheduling and resource allocation approval.

Some papers explore the intersection of security enhancement, blockchain roles, and resource allocation in the context of electric vehicles and charging stations. Shahidinejad and Abbasinezhad-Mood [118], for instance, introduced an ultra-lightweight framework based on blockchain for secure and anonymous communications during electric vehicles charging in vehicular edge computing networks. The proposed scheme ensures accountability for electric vehicles owners and addresses security metrics. Others, such as Sahu and Chandrakar [119], studied the integration of blockchain and electric vehicles to address problems related to the availability of charging stations and charging time. The proposed blockchain-based framework ensures trust, privacy, secure transactions, and unbiased charging port allocation. Liu *et al.,* [120] focused on Vehicle-to-Grid networks and proposed a charging station matching algorithm with an incentive mechanism for load balancing. They introduced a blockchain-based anonymous identity authentication scheme to secure mutual authentications, preventing identity privacy leaks.

In the context of energy systems, Wang *et al.* [94] proposed a privacy-preserving energy scheduling model based on blockchain technology. This model effectively addresses rising concerns about privacy and security in energy data management. They utilized the Lagrangian relaxation technique, consensus algorithms, and smart contracts within the energy blockchain network to optimize resource usage and ensure environmental protection and transparent scheduling for energy service companies. Similarly, Okoye and Kim [121] explored the application of blockchain in distributed energy trading, showcasing notable advancements in decentralized transactions and heightened security. This achievement was realized through the elimination of third-party intermediaries and the integration of the Practical Byzantine Fault Tolerance algorithm to optimize transaction latency and provide a flexible framework for regulating transaction times, catering to participant preferences. Furthermore, Wu *et al.,* [122] introduced blockchain technology into cybersecurity through the Sapiens Chain framework, emphasizing decentralized and trustworthy cybersecurity services while ensuring the privacy of anonymous users. They also tackled the challenge of selecting optimal service providers by proposing a pioneering scheduling algorithm that aligns user interests with factors such as bandwidth, computing resources, and activation degree. Addressing the technological and legal aspects of stock exchange transactions, Miraz and Donald [123] explored the application of blockchain technology, considering the complex operational nature of securities exchanges. They recommend creating a customized hybrid blockchain for each stock exchange, offering unique benefits beyond existing technologies. The proposed hybrid blockchain is crafted through a comprehensive analysis of various blockchain variants, aiming to enhance the efficiency of stock exchange transactions.

Figure 25 illustrates how collective research highlights the significant role of blockchain technology in enhancing security across various industries. The findings reveal blockchain's evolution in enhancing security in scheduling, time management, and data integrity. Notably, the highlighted instances of security enhancement in scheduling, particularly in cloud computing, cybersecurity, and energy sectors, underscore a significant convergence in advancing security measures. Research investigating the intersection of blockchain, electric vehicles, and charging stations illustrates the technology's versatility in addressing security metrics and surmounting challenges. Within the energy systems, novel models for privacy-preserving energy scheduling and decentralized energy trading are introduced. The incorporation of blockchain in cybersecurity emphasizes the establishment of decentralized and trustworthy services. Despite prevailing challenges associated with IoT protocols, researchers propose algorithms aimed at minimizing transaction latency in distributed energy trading.

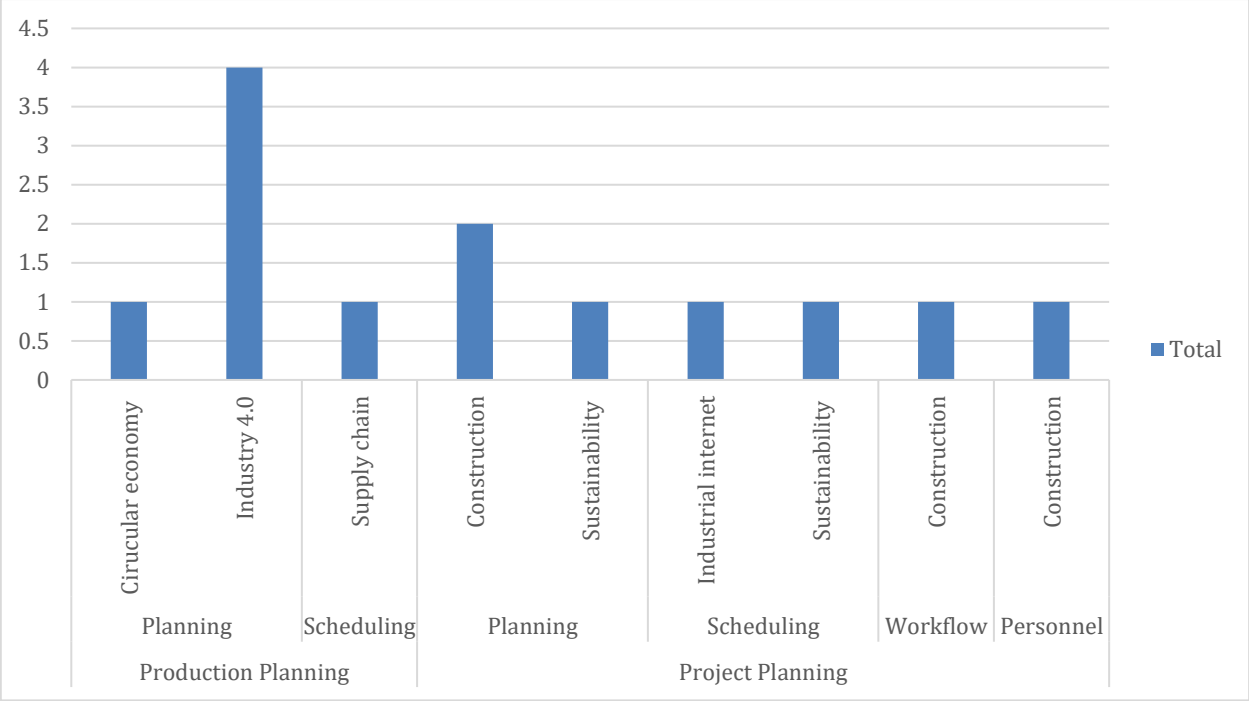

Fig. 25. Count of Publications on Blockchain in Security Enhancement.

Future research in blockchain technology must focus on several key directions to further enhance security and address evolving challenges. To propel the future of blockchain technology and elevate data security within the context of data scheduling, research must strategically explore key directions. Scalability and performance optimization emerge as critical focal points, demanding an in-depth investigation into methods that amplify the scalability of blockchain networks, particularly in dynamic environments like cloud computing and energy trading. Techniques should be innovated to optimize overall performance, factoring in transaction speed, network bandwidth, and computational efficiency. Interoperability and standardization constitute vital realms of inquiry, necessitating the exploration of approaches that seamlessly facilitate data and asset transfer across diverse blockchain networks and protocols, coupled with contributions to industry standards for enhanced compatibility and collaboration. Furthermore, privacy and confidentiality, perennial concerns, prompt researchers to delve into cutting-edge cryptographic techniques and zero-knowledge proofs, aiming to fortify privacy in blockchain transactions. The quest for energy-efficient consensus mechanisms drives exploration into alternative algorithms that strike an optimal balance between security, decentralization, and energy conservation. Effectively addressing security threats requires a dedicated focus on emerging risks unique to blockchain technology, such double-spending attacks. Additionally, a critical need arises to enhance interoperability among different blockchain platforms in scheduling applications, streamlining communication and data exchange through standardized protocols and frameworks.

4.5 Blockchain in project and production planning

BCT can significantly impact project planning and production management, offering valuable benefits such as increased transparency, enhanced data integrity, and improved collaboration. Additionally, it simplifies data sharing, leading to reduced errors and heightened data accuracy. Project planning benefits from the streamlined utilization of smart contracts and automated payments, significantly boosting project execution efficiency. Meanwhile, production management leverages blockchain's ability to trace the supply chain, offering real-time visibility into production

processes and ensuring product authenticity. Consequently, blockchain is revolutionizing these industries by offering innovative solutions for resource and data management. For instance, Huo and Pan [124] explored the path planning of intelligent robots and the application of blockchain technology with the goal of reducing development costs, improving real-time performance, and simplifying control software development. The use of the proof-of-work mechanism in blockchain systems guarantees the secure issuance and transfer of digital assets, especially in environments with untrusted nodes. They proposed algorithms to optimize failure detection by implementing a blockchain-enabled scheduling system, increasing security and transparency in the scheduling and sequencing of maintenance tasks. As a result, their research improved efficiency, reduced costs, and enhanced resource utilization in maintenance operations. Li *et al.,* [125] presented a method that enables the selection of the most economical, environmentally friendly, and socially responsible remanufacturing process. This approach integrates blockchain technology and leverages accumulated remanufacturing knowledge to support remanufacturing enterprises.

Within the field of the industrial internet, Chen *et al.*, [126] introduced a model for task scheduling that combines blockchain with task caching. The main goal is to mitigate task delays and costs, which stem from the expenses associated with blockchain mining rewards and the decisions made for optimal scheduling. This initiative prioritizes data security and the establishment of reliable communication. Additionally, Wang *et al.,* [127] incorporated carbon emission constraints into the economic dispatch of the low-carbon power industry, utilizing a combination of particle swarm optimization and blockchain theories. In this model, the blockchain serves as a sequential chain of blocks for information storage, with all servers or nodes in the system jointly owning it. Security is maintained by requiring a consensus from more than half of the nodes to alter information. Given the challenge of tampering with data across various sectors, this method promotes decentralization and trust in human interactions.

In production planning, Balon *et al.,* [24] introduced the integration of blockchain technology and IoT into production planning. The focus is on the creation of a distributed machine database based on blockchain technology. They presented a decentralized network for the exchange of production resources, acting as a link between the virtual and real environments. They also developed an algorithm for efficient production task allocation based on blockchain technology for smart contracts and secure transactions. Babaei *et al.,* [128] tackled the production and distribution planning challenge in two-stage supply chains, with a focus on limited information flow from manufacturer factories to distributors. They introduced a two-level multi-objective optimization model using Data Envelopment Analysis to minimize both cost and traffic congestion arising from distributor warehouses. Notably, the model incorporated transparency through blockchain technology and addressed uncertainties with stochastic and fuzzy programming in supply chain design. Zeng *et al.,* [6] addressed the complexity of supply chain scheduling in the blockchain context by presenting a three-echelon integrated scheduling model. It employed a Sequential Brainstorm Optimization algorithm to minimize overall production and transportation costs. Moreover, they introduced a system that optimized decentralized power and load resources through the integration of IoT and blockchain, highlighting the advantages of blockchain in data storage, security, and interoperability. Tohmé *et al.*, [129] discussed the impact of Industry 4.0 on production systems and the challenges associated with managing goods production while incorporating intangible factors like individual customer preferences. It proposed a novel approach in service operations management to autonomously generate production plans for mass customized environments using cyber-physical systems, leveraging blockchain technology to create a freely accessible database, ensuring plan

integrity through expert cyber-physical systems intervention, and employing big data methods and proof-of-stake tests for reliability.

In construction project management, Al-Refaie *et al.,* [130] developed two optimization models to enhance the scheduling and sequencing of multiple construction projects, accounting for probabilistic and stochastic task durations. They represented each project task as a block on the blockchain, designing an Electronic Project Recording system to securely provide task information to authorized users. This blockchain solution aims to optimize the scheduling and sequencing of multiple projects. Tedjo *et al.,* [131] merged blockchain technology with machine learning to create a system for efficient and cost-effective smart building construction planning. The blockchain component acts as a decentralized and secure ledger, enabling transparent and tamper-proof record-keeping throughout the construction process. This facilitates various aspects, including tracking construction task progress, verifying transaction authenticity, and ensuring data integrity. Curavić *et al.,* [132] introduced a system that integrates blockchain technology to improve asset management and maintenance in renewable energy projects, addressing legal inconsistencies and administrative complexities. This system supports the monitoring and management of business processes, offering bespoke solutions for developers, contractors, and project offices. Mohammed *et al.,* [133] explored the potential of blockchain technology in construction, highlighting its application in administrative tasks, smart contracts, and permanent transaction records to boost workflow efficiency and reduce disputes and delays. They advocate for the broad adoption of blockchain technologies and blockchain-based Building Information Models (BIMs) by both public and private stakeholders to improve construction workflows and processes. Zhang *et al.,* [134] described the increasing application of blockchain technology in the IoT, highlighting cost overruns as common in smart "IoT+ blockchain" projects. To ensure successful project delivery within budget constraints, the study proposed a reverse optimization approach using a 0-1 mixed-integer, bi-level programming model. This method aimed to infer duration and personnel re-assignment to meet budgetary targets.

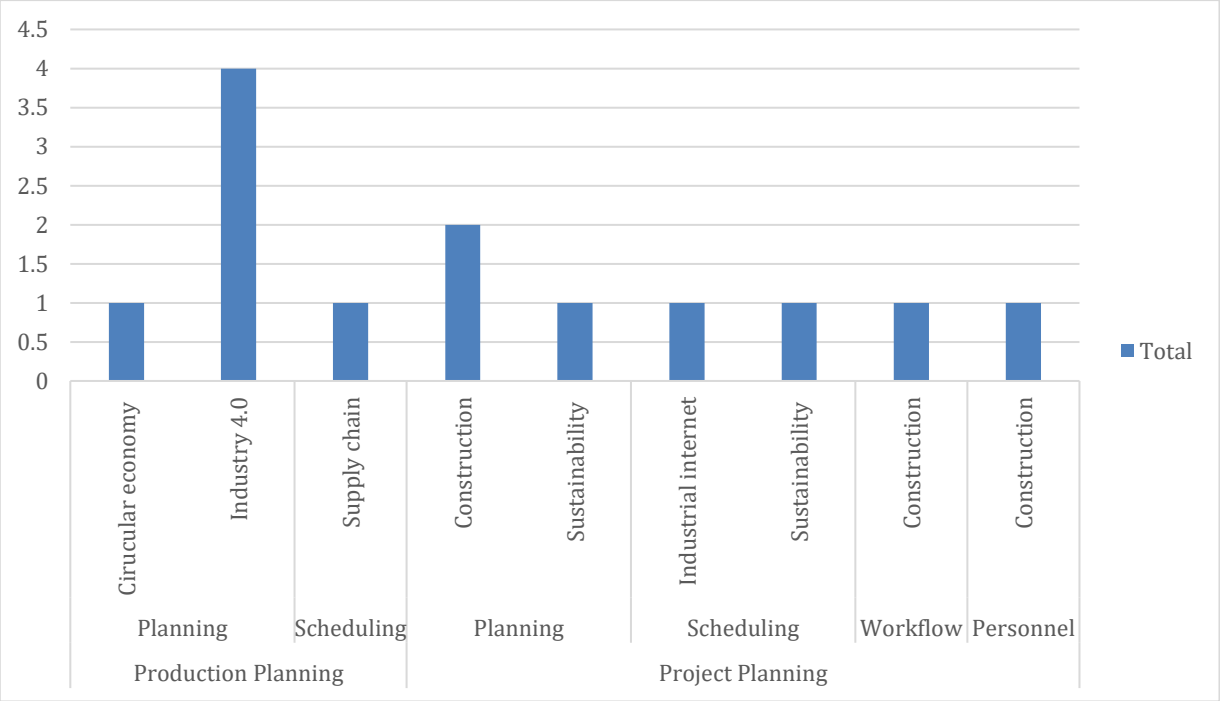

Fig. 26. Count of publications on Blockchain in Project and Production Planning.

The transformative influence of blockchain technology can be significant across diverse domains, such as project planning and production management. Its implementation can enhance transparency, improve data integrity, foster enhanced collaboration, simplify data sharing, and reduce errors. Notably, project planning can benefit from the streamlined utilization of smart contracts and automated payments, thereby enhancing overall execution efficiency. In production management, blockchain's ability to trace the supply chain provides real-time visibility and validates authenticity, revolutionizing resource and data management. As illustrated in Figure 26, numerous studies have demonstrated innovative applications ranging from robot path planning to the integration of carbon emission constraints, presenting decentralized solutions for improved security and efficiency. Moreover, Figure 26 highlights the volume of publications in the construction project management domain, underlining blockchain's pivotal role in optimizing scheduling, promoting transparency, and addressing asset management and dispute resolution challenges.

Despite ongoing efforts to utilize blockchain technology in project and production planning, there remains a high potential for future research avenues. One such avenue involves optimizing smart contracts, requiring a thorough exploration to refine current functionalities and discover new possibilities. This includes developing sophisticated contract templates tailored to various project requirements, enhancing automation for more streamlined execution processes, and integrating conditional agreements that are responsive to changing circumstances. Such a focused approach has the potential to lead to significant advancements in the efficiency and effectiveness of project and production management, resulting in reduced manual interventions and minimized risks of contractual disputes.

Exploring the role of blockchain in facilitating multi-party collaboration presents a promising avenue for future research. Efforts should be directed towards developing specialized blockchain networks designed to meet the unique requirements of production and project planning scenarios. This includes creating protocols that enable secure sharing and access to pertinent information among all stakeholders, such as contractors, suppliers, regulatory bodies, and clients. Furthermore, in the realms of risk management and smart contracts, there is an opportunity to develop dynamic contracts that can autonomously respond to predefined risk events. This would involve embedding risk management parameters within smart contract templates, allowing for self-executing actions based on real-time data. Directly incorporating risk management into smart contracts has the potential to significantly boost organizations' abilities to identify, assess, and mitigate risks in real-time, thus ensuring greater resilience and compliance with contractual obligations.

4.6 Blockchain in Energy Optimization

Various aspects of blockchain technology have been applied to energy optimization, with a primary focus on energy-efficient scheduling and saving (Figure 27). Mohammed *et al.,* [5] introduced the Energy-Efficient Distributed Federated Learning Offloading and Scheduling (EDFOS) system in blockchain-based networks for healthcare systems, addressing processing performance and data privacy issues. The EDFOS system employs energy-efficient offloading and scheduling to maintain application quality of service while operating within the system. Additionally, the application of blockchain technology for task scheduling in computing services (provided to end-users over the internet on a pay-per-use basis) has enhanced security and consistency [135]. The studied models leverage the capabilities of the fireworks algorithm to optimize schedules, aiming to minimize both the makespan and energy consumption. Yadav and Sharma [135] demonstrated a 14–25% improvement in performance, thereby achieving optimized scheduling with reduced energy consumption.

Blockchain-based solutions have been introduced for the scheduling of supply and demand in power energy. Blockchain technology facilitates the immediate recording and distribution of data across the network [136], enabling all stakeholders to access up-to-date information. This accessibility allows for more accurate and timely decisions in dispatch operations, which is crucial for aligning with regular operational requirements. Additionally, Tao *et al.,* [137] developed a model for dynamic electricity pricing aimed at optimizing microgrid loads, reducing power interactions, and enhancing economic and environmental performance.

The changing landscape of the power system, due to the increasing use of renewable energy sources, has lead to the integration of blockchain technology into the energy sector. The introduction of blockchain technology into the energy internet is seen as a solution to address information security and other related issues. Blockchain is applied to the scheduling and operation mechanisms of VPPs, aligning naturally with the energy internet due to its characteristics, such as intelligent contracts, distribution decisions, cooperative autonomy, and tamper resistance. This alignment is evident in running methods, topological structure, bilateral trade, and synergic dispatch [67].

Energy harvesting for IoT devices is another potential benefit of blockchain energy optimization. In this context, blockchain-and backscatter-aided IoT optimizes energy harvesting, backscatter time, and transmission time in IoT devices. In a simulation study, Anh *et al.*, [138] demonstrated that this approach outperforms traditional methods in network throughput and data storage efficiency within a blockchain network. Yufeng *et al.,* [139] discussed the integration of blockchain with mobile edge computing to enhance security and meet the demands of new applications. The scenario discussed involves data sharing, where the Base Station plays a central role in forwarding data packages and recording sharing events. These events are secured through blockchain transactions. The combination of Mobile Edge Computing and blockchain can enhance security and efficiency in data-sharing applications. The proposed algorithm demonstrates improved performance in scheduling data-sharing tasks, resulting in energy-efficient task scheduling.

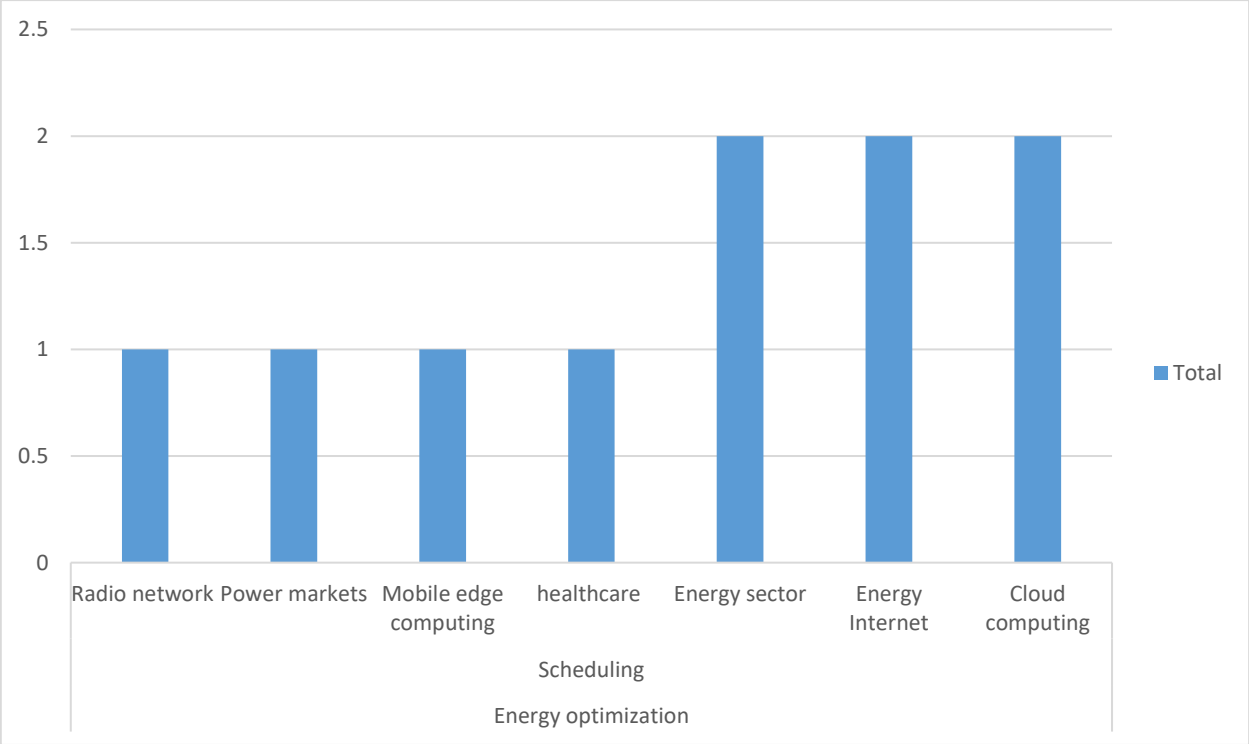

Fig. 27. Count of Publications on Blockchain in Energy Optimization

The literature highlights the adaptability of blockchain technology in tackling diverse energy optimization challenges across sectors such as healthcare, cloud computing, and the energy internet. Blockchain addresses security issues in these areas by leveraging its inherent features (security, transparency, and decentralized consensus) to improve the efficiency of processes and systems in healthcare, task scheduling, IoT, data centers, energy supply and demand, microgrids, and virtual power plants. However, an over-reliance on blockchain introduces potential security vulnerabilities. Furthermore, the majority of studies depend on simulations for validation, which may not adequately demonstrate the effectiveness of new blockchain models. While blockchain is noted for reducing energy consumption, networks utilizing Proof of Work consensus mechanisms consume considerable computational resources, leading to significant energy usage and environmental concerns. Additionally, given the relatively recent emergence of blockchain technology, there is a scarcity of long-term research on its impacts and applications.

5. Conclusion and future work

This review paper provides a comprehensive examination of the integration of blockchain technology in the field of scheduling. The study explores the expanding role of blockchain technology across multiple industries, focusing on its innovative contributions to enhancing and streamlining scheduling processes. By synthesizing literature from numerous sources, the paper highlights the transformative impact of blockchain on optimizing scheduling efficiency, transparency, and security. It discusses the application of blockchain in areas ranging from healthcare and supply chain management to energy and transportation, underscoring its potential to enhance decentralized operations and improve data integrity. The review identifies current trends, technological challenges, and potential solutions, offering insights into future research directions. The paper aims to bridge the gap in the literature by presenting a holistic view of blockchain's role in advancing scheduling methods, driving innovation, and fostering more robust, efficient, and transparent scheduling systems across industries.

The methodology of this research paper adopts a systematic four-step approach to collect and analyze literature on the integration of blockchain in scheduling. Initially, a comprehensive record of relevant papers is compiled through literature retrieval from the Scopus database, focusing on blockchain applications in scheduling. This step is followed by a meticulous literature screening process, which filters out irrelevant or duplicate papers, resulting in a refined dataset of 133 documents. The next phase involves bibliometric analysis, evaluating scholarly literature to identify impactful works, emerging trends, and key authors. Finally, content analysis is conducted, systematically examining and organizing the collected material to uncover dominant themes and patterns in blockchain's application in scheduling.

The bibliometric analysis of blockchain research revealed a significant increase in related publications from 2017 to 2023, highlighting its expanding role in scheduling activities. The research underscored blockchain's diverse applications in fields such as production scheduling, workflow management, workforce planning, and time management, emphasizing its potential to revolutionize resource management in organizations. However, this integration raises concerns about data transparency, system interoperability, and infrastructure costs. The study also observed a geographical concentration of blockchain research, with China leading the forefront, followed by English-speaking and Middle Eastern countries. This suggests an opportunity for global collaborations to harness blockchain's capabilities across various professional contexts.

The study classified 133 papers into six categories, unveiling key trends in blockchain's utilization across various industries. The predominant subject areas included service optimization and resource management. Smart contracts emerged as the most frequently utilized tool, underscoring their significance in blockchain applications. Industries such as cloud computing, electric vehicles, and healthcare notably leveraged blockchain, highlighting its broad impact. The objectives of the papers varied, with many proposing novel tools or frameworks. The majority of publications were articles, signaling a robust academic interest in the field.

Blockchain technology inherently provides a decentralized, secure, and transparent mechanism for recording transactions and managing data. This foundational characteristic of blockchain is utilized across different domains to improve scheduling processes. This paragraph highlights the key findings from the content analysis that demonstrate the relationship between blockchain and scheduling and details the impact of blockchain technology on resolving scheduling challenges. In service optimization, the decentralization offered by blockchain fundamentally transforms the approach to scheduling services, removing the dependence on central authorities or intermediaries. This shift leads to more efficient, transparent, and secure service scheduling, notably in finance, healthcare, and supply chain management. For example, in healthcare, blockchain enables the secure and efficient scheduling of medical services and appointments, thereby enhancing patient care by reducing waiting times and improving healthcare delivery. For systems and resource planning, blockchain permits real-time tracking and dynamic allocation of resources, which boosts operational efficiency and minimizes waste. The immutable ledger that blockchain provides ensures precise and secure record-keeping, bolstering trust and reliability in scheduling decisions and results. Additionally, blockchain technology facilitates decentralized management of data flows and scheduling in industries such as energy and manufacturing, guaranteeing data integrity and security. This factor is critical for accurately scheduling maintenance, production operations, and energy distribution, where reliable data is essential for effective scheduling and resource management. Moreover, blockchain's role in enhancing security directly affects scheduling by ensuring data integrity and trustworthiness across various sectors, including cloud computing and energy systems. This enhanced security lowers the risk of tampering and fraud in scheduling tasks, thus improving the overall dependability and efficiency of these processes. In the field of project and production planning, blockchain enables improved scheduling and planning through better data sharing and collaboration among stakeholders. Utilizing smart contracts, blockchain automates and enforces the execution of scheduling agreements, which decreases the likelihood of disputes and delays, ensuring timely project completion and optimal resource use. Finally, in energy optimization, blockchain technology introduces innovations in scheduling the distribution and consumption of energy, aiding in the pursuit of efficiency and sustainability. Smart contracts enabled by blockchain automate the regulation of energy flows, fine-tuning the balance between supply and demand and easing the integration of renewable energy into the grid. The integration of blockchain into scheduling systems addresses longstanding challenges such as data integrity, trust, and coordination among multiple stakeholders, offering a robust framework for more efficient and reliable scheduling solutions.

Future research, based on the content analysis, should encompass a diverse range of explorations of the application of blockchain technology in scheduling activities. For blockchain in service optimization, it is crucial to explore its application across various industries, assess its impact on customer satisfaction, and address scalability challenges in larger networks. In system and resource planning, research should delve into optimizing real-time data tracking and decision-making in sectors such as manufacturing, healthcare, and supply chain management through blockchain technology. In management applications of blockchain, the focus should be on developing user-

friendly interfaces for non-technical users and examining its utility in government settings while ensuring legal and regulatory compliance. Regarding security enhancement, emphasis should be placed on creating advanced security algorithms for cloud computing and IoT, mitigating potential security risks, and investigating blockchain's role in protecting critical infrastructure. Research in project and production planning should innovate in multi-party collaboration through blockchain, explore blockchain's potential in risk management, and enhance smart contract functionalities to cater to various project needs. Lastly, for blockchain in energy optimization, addressing the high energy consumption of blockchain networks, particularly those utilizing Proof of Work mechanisms, is crucial. It is imperative to explore sustainable, long-term solutions with minimal environmental impact.

Looking to the future, this research highlights several promising trends and areas for further exploration. The integration of blockchain with other emerging technologies, such as artificial intelligence and the Internet of Things (IoT), offers a vast field for investigation. These combinations have the potential to drive unprecedented levels of efficiency and innovation in scheduling activities. Furthermore, the study suggests that future research efforts should prioritize addressing challenges related to the scalability of blockchain solutions and their interoperability with existing systems. Additionally, there is a call to develop more user-centric blockchain designs aimed at enhancing usability and adoption.

Author Contributions

Conceptualization, Z.B., A.S., M.T., M.R. and H.A.; methodology, Z.B., A.S., M.T., M.R., H.A.; software, H.A.; validation, Z.B., A.S., M.T. and M.R..; formal analysis, Z.B., A.S., M.T., M.R. and H.A.; investigation, Z.B., A.S., M.T., M.R. and H.A.; resources, Z.B. and A.S.; data curation, H.A. and Z.B.; writing—original draft preparation Z.B., A.S., M.T., M.R. and H.A.; writing—review and editing, Z.B., A.S., M.T. and M.R.; visualization, X.X.; supervision, Z.B. and A.S.; project administration, Z.B. and A.S.; funding acquisition, Z.B. and A.S. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

Not applicable.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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