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REVIEW ARTICLE

Blockchain technology for sustainable supply chains: a network cluster analysis and future research propositions

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Abstract
Achieving the sustainable goals of the United Nations requires improving supply chain sustainability (SSC). Blockchain technology (BCT) has attracted attention on a global level with the ability to transform supply chain management and sustainability efforts. Recognizing this, this study investigates how BCT plays a role in SSC. The current study looks into the importance of BCT in order to move supply networks towards sustainability by performing bibliometric analysis, and network cluster analysis. Through the literature review, the current literature was analyzed and future research directions were concluded. We begin our study by selecting 297 papers on the relevant subjects by applying various filters to the Web of Science (WoS) database. Influential individuals, journals, and organizations in this field were identified using bibliometric analysis. A network analysis was performed to identify influential co-author, and keywords, and for page rank, and cluster analysis. The network analysis was revealed ten distinct study clusters, and ten propositions were suggested from the analysis of these clusters. Additionally, a conceptual framework for the research was proposed, which can advise managers, practitioners, and researcher communities on the key trends and topics in this emerging research domain. Furthermore, to guide research scholars in this field, 33 future research directions were suggested.

Keywords Blockchain technology (BCT) · Sustainable supply chain (SSC) · Research propositions · Network analysis · Future research directions · Cluster analysis

Introduction

There has recently been an increase in cooperate and academic interest in sustainability due to an increase in socio-ecological changes (Khan et al. 2021a, b, c), including global warming (Menon and Ravi 2021), growing environmental regulations (Mangla et al. 2020), rapidly exhausting resources (Luthra and Mangla 2018), increasing carbon emissions (Yousefi and Tosarkani, 2022), customer awareness about sustainability (Kouhizadeh et al. 2021; Paul et al. 2021; Kshetri 2021), carbon tax (Manupati et al. 2020), various disease caused by pollution (Khan et al. 2021a, b, c), climate change (Ahuja et al. 2019), corporate social responsibility (Ahi and Searcy 2013), United Nations sustainable development goals (Park and Li 2021; Yousefi and Tosarkani, 2022), and net zero-emission targets. United Nations Brundtland Commission's definition of sustainability "*making use of available resources to meet the need of the present population without compromising with the future generation's needs*" is the best way available in the literature to define sustainability.

Over the years, supply chains have played a prominent role in achieving a globally sustainable economy (Park and Li 2021). Supply chain management (SCM) is defined as managing a network of interconnected processes involved in providing the required product/service to the final customer (Wittstruck and Teuteberg 2012). By integrating ecological, economical, and social dimensions into this conventional definition of SCM, we get the notion of sustainable supply chain

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management (SSCM). SSCM is the capability to reduce continuing risks related to depleting resources, waste management, energy shortage, global warming, and pollution (Wittstruck and Teuteberg 2012). Supply chain sustainability adopts an integrated approach from an environmental, social, and economic perspective, to enable reliable management of inbound and outward operations as well as logistics within a supply chain (Njualem 2022). Companies that incorporate social and environmental concerns into their business strategy now prioritize sustainability as a key issue (Ghahremani-Nahr et al. 2022). Because of the market and ecological uncertainties, it is challenging to achieve SSC (Ghosh et al. 2020).

Blockchain technology (BCT) has been deployed by various firms recently to sustain their supply chains (Rejeb et al. 2021). BCT has been acknowledged as a digital technology that can give supply chains a sustainable component (Trollman et al. 2022). In the supply chain, various members are interacting with each other with their own pool of information, but proper communication between them is lacking. The reason mentioned for this lack of commination by Dujak and Sajter (2019) is a lack of trust in exchanging information. Clauson et al., (2018) suggested blockchain as a way to transfer information securely while maintaining data privacy. Scholars and professionals are intrigued by BCT as a potential remedy for social, environmental, and economic sustainability problems (Zhu et al. 2022).

Blockchain is a digital, decentralized network that operates in a shared and coordinated atmosphere where users validate the information (Wamba et al. 2020), which is contained inside the blocks (Tandon et al. 2021). Special software systems are used to manage these blocks, allowing data to be transmitted, processed, stored, and retrieved by humans (Niknejad et al. 2021). Every block is connected to the blocks that come before and after it through hash (Sharma et al. 2021). A hash can be compared to a digital signature that secures data within the blockchain (Wang et al. 2019). These blocks become immutable once they are linked together in a chain because only the majority of actors can add or remove them through a consensus mechanism. Blocks of the network continue to expand as more exchanges (records and data) are introduced (Kamble et al. 2020a). Accessibility, customer happiness, data management, safety, decentralization, and documentation are identified as essential success elements by (Sunmola 2021) for blockchain in SSC.

Since the inception of BCT, the promise of SSC has been raised; however, the promise has not yet been realized despite its successful and widespread adoption (Zhu et al. 2022). There are few papers in the literature on BCT from an SSCM perspective. For example, Esmaeilian et al., (2020) provided a series of recommendations on how technology may contribute to a sustainable future. Yadav and Singh (2020) justified the implementation of BCT in the supply chain over the conventional method by applying a fuzzy-analytic network process. Authors have proposed BCT as a solution to global price war and competition and as a way to reduce transaction cost and time. Saurabh and Dey (2021) identified drivers of BCT implementation in the grape wine supply chain and explored the relationship between them by employing conjoint analysis. Mangla et al., (2021) mapped the milk supply chain in Turkey to investigate information flow between diverse stakeholders for enhanced traceability and investigated the societal impact of BCT in the milk supply chain to shape social sustainability. Kouhizadeh et al., (2021) employed the technology-organization-environment model to find the obstacles to BCT adoption for SSC and then used the decision-making trial and evaluation laboratory (DEMATEL) to examine the results. Sahebi et al. (2022) recognized and implemented the relationship between BCT's enablers in renewable energy supply chains by using fuzzy interpretive structural modeling (FISM) and fuzzy decision-making trial and evaluation laboratory (FDEMATEL) methodology. Trollman et al., (2022) described how BCT could help the coffee supply chain's ecological embedding. Sahoo et al., (2022) conducted a comprehensive summary of the best blockchain research for the SSCM. It has been found that previous studies only examined a specific category of BCT-based applications domain in SSC. However, there are not many studies that map out BCT applications in SSC, which spurs researchers to conduct research outlining the uses and difficulties of BCT implementation in SSCM.

Previous study offers unique insights into this subject, but thorough bibliometric, citation, and co-citation analysis of this literature can reveal additional, previously unrecognized insights. Therefore, there is a clear need to close this gap. As a result, the following research goals are what motivate this study.

(1) To identify the most recent research trends on the relationships between SSC and BCT.
(2) To provide bibliometric and network analysis results of BCT applications in SSC.
(3) To make suggestions about the theoretical, managerial, and practical implications of using BCT technologies for SSC.
(4) What are the potential future directions for this field of study?

Following the introduction, the organization of the paper is as: research methodology and data statistics in "Research methodology", bibliometric analysis findings in "Bibliometric analysis findings," network analysis findings in "Discussions and recommendations," discussion on the results and recommendations in "Conceptual framework and implications of the study," and lastly entire work is concluded in Sect. 6 with the limitations of the present study.

Research methodology

The next subsections present data collection and the descriptive results derived based on the statistical analysis of the chosen literature. This study's research methodology entails screening, organizing, and ultimately drafting outcomes. The process flowchart for research is displayed in Fig. 1.

The first step in the bibliographic analysis is choosing appropriate keywords, then data is collected from the Web of Science with the help of chosen keywords. Then bibliometric analysis was done to identify influential individuals, journals, and organizations in this field and then a network analysis was performed to identify influential co-author, and keywords, and for page rank, and cluster analysis. In addition, it can be explained in the following three subsections.

Keywords selection and data collection

The data was gathered from the Web of Science, which enables the exportation of articles' metadata, including references, abstracts, and journal information, as well as the ability to locate articles using search keywords. Bibliometric studies frequently use the Web of Science as their data source (Ante et al. 2021). The selection of suitable keywords plays a significant role in the bibliometric analysis. Various keywords used for this analysis are "Blockchain Technology (BCT)," "Sustainable Supply Chain (SSC)," "Supply Chain Sustainability (SCS)," "Distributed Ledger Technique (DLT)," and "Supply Chain (SC)." Selected keywords link supply chain operations and strategic processes to BCT. Selected keywords were combined as (a) BCT AND SSC (b) BCT AND SCS (c) DLT AND SC and searched on the web of science database.

This collection includes publications published between 2018 and 2022. Articles obtained from the selected keywords are refined by using the following inclusion–exclusion criterion:

i. Articles published as books, meetings, and editorial materials are excluded because they do not generally have a rigorous review procedure.
ii. Only articles published in the research area of Business Economics, Environmental Sciences Ecology, Engineering, and Food Science Technology are included.
iii. Articles published only in the English language are included.
iv. Repeated publications, publications with missing information, and publications that off topic are eliminated.

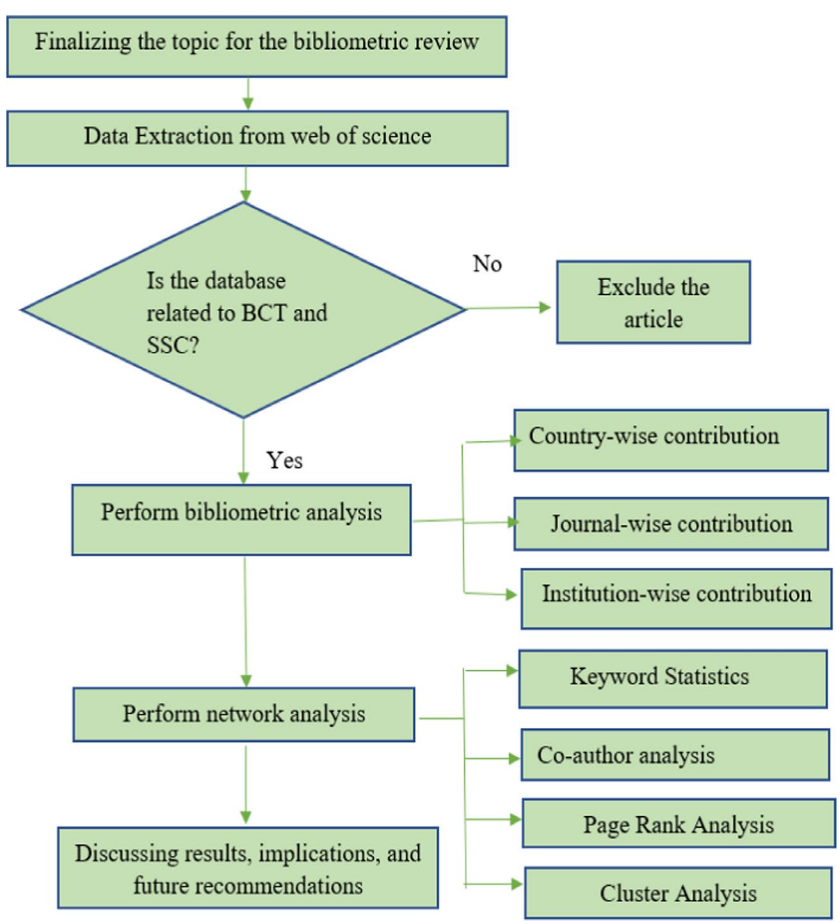

Fig. 1 Process flowchart for research

The number of initially searched articles and searched articles after refinement are listed in Table 1.

After reading the title and abstract 297 articles were shortlisted for bibliometric analysis.

Descriptive data evaluation

This study used two analytical techniques bibliometric and network analyses to look at the development and organization of the research field.

Bibliometric analysis

Bibliometric analysis is a statistical method for analyzing published articles (Moosavi et al. 2021) and gaining a complete grasp of a research area and identifying prominent scholars and fresh areas for future research. A bibliometric analysis aids in the analysis of statistics for publications published in a specific field (Agrawal et al. 2022a, b). A bibliometric technique, according to scholars, is a cross-disciplinary way for effectively mapping the directions and issues addressed during the growth of a field of study (Tandon et al. 2021). Bibliometric reviews, in contrast to conventional reviews, are a systematic analytical technique that aids scholars in identifying the most significant writers, their associations, the keywords they chose, and the connections among their works. This kind of analysis employs a systematic analysis technique that aids in the identification of the most well-known academics, the most popular keywords, affiliations, and related academic publications (Naz et al. 2022). The bibliometric analysis was carried out using the VOS viewer 1.6.16.0 software. In order to statistically chart the bibliometric data of research papers in BCT within the SSC context, the various bibliometric parameters, including country-wise contribution, journal-wise contribution, and institution-wise contribution, were presented in this study.

Table 1 Search results initially and after refinement

Keywords	Initially searched articles	Searched articles after refinement
BCT AND SSC	229	187
BCT AND SCS	238	197
DLT AND SC	32	29
TOTAL	**499**	**413**

Network analysis

The network analysis was carried out using the VOS viewer 1.6.16.0 software. VOS viewer can display a map in a variety of ways by emphasizing its unique qualities (Agrawal et al. 2022b). The network analysis was carried out to examine the network and research partnerships. In keeping with the studies by (Yadav et al. 2022), a network analysis was also conducted in this study as an additional qualitative layer to offer more in-depth explanations for the investigation's quantitative findings. Our network analysis is divided into three sections: cluster-based keyword statistics, cluster-based co-citation analysis of related writers, and cluster-based citation analysis in this area.

Bibliometric analysis findings

The main goal of this research work was accomplished by using a bibliometric analysis to evaluate the composition of the body of existing knowledge about BCT in SSC. Using bibliometric analysis, a researcher can conduct a systematic, comprehensive, and reliable literature review (Naz et al. 2022). In this section, the bibliometric analysis results are discussed.

Country-wise contribution

Countries worldwide have realized in recent years that their economic development and growth depend on research-based initiatives. Participation in research is one of the most important measures of development of any country on the planet. Research is believed as the cornerstone of a country's development. Furthermore, technology-based applications are becoming more prevalent, compelling countries to participate in this field.

Figure 2 depicts country contributions based on clusters, whereas the size of a node denotes the number of publications produced by a country. A minimum of 5 documents are considered for a nation. Only 26 of the 63 nations fit the criteria.

Table 2 shows the top ten countries with the greatest number of publications.

Table 2 and Table 3 show the top 10 countries in the world with respect to number of publications and the number of citations respectively. From Table 2, it can be depicted that China has topped in terms of the number of publications, with a total of 66 publications, followed by the US (49) publications. India is in third position with 48 publications, which shows that there has been an increase in research in the field of technology in India. Following India in the rankings are the following countries: England, Italy, Canada, France, Australia, Germany, and Pakistan. Figure 3 also displays the top 10 nations by contribution with respect to number of publications.

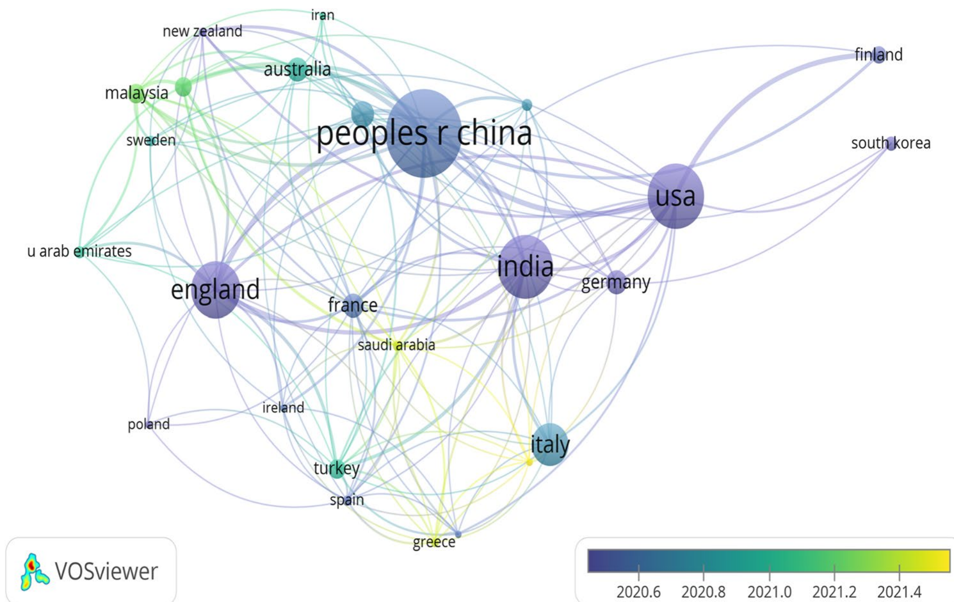

Fig. 2 Country contributions based on clusters

Table 2 Contribution of the top ten countries with respect to number of publications

S. no	Country	Number of publications	Total link strength
1	P.R. China	66	85
2	USA	49	56
3	India	48	48
4	England	43	51
5	Italy	32	17
6	Canada	20	25
7	France	18	33
8	Australia	18	24
9	Germany	18	10
10	Pakistan	15	33

Figure 4 displays a world map for country-wise contributions with respect to number of publications.

Table 3 shows the top ten countries with the greatest number of citations.

From Table 3, it can be depicted that the USA has topped in terms of numbers of citations, with a total of 2261 citations, followed by China (1398) citations, followed by England (1121) citations. India is ranked number 4 with a total of 1121 citations. Other countries following India in the ranking are Italy, Finland, France, Canada, South Korea, and Spain. The total link strength (TLS) measures a country's connection to other countries around the world. Figure 5 also displays the top 10 nations by contribution with respect to number of citations.

Figure 6 displays a world map for country-wise contributions with respect to number of citations.

Table 3 Contribution of the top ten countries with respect to number of citations

S. no	Country	Number of citations	Total link strength
1	USA	2261	56
2	P.R. China	1398	85
3	England	1121	51
4	India	1106	48
5	Italy	509	17
6	Finland	411	15
7	France	399	33
8	Canada	388	25
9	South Korea	237	4
10	Spain	232	18

Journal-wise contribution

Journal clusters in the domain as shown in Fig. 7.

Journal-wise contribution is given by the record of the top 20 journals, which has published the articles in the domain as shown in Table 4.

Figure 8 also graphically displays the journal-wise contribution.

Institution-wise contribution

Researchers and academicians are increasingly motivated by statistics that are based on affiliation or institutional acknowledgment of a certain topic. In Fig. 9, institution-based clusters are displayed.

Table 5, as shown below, represents the top ten institutions that have contributed most in the field of BCT-based SSC.

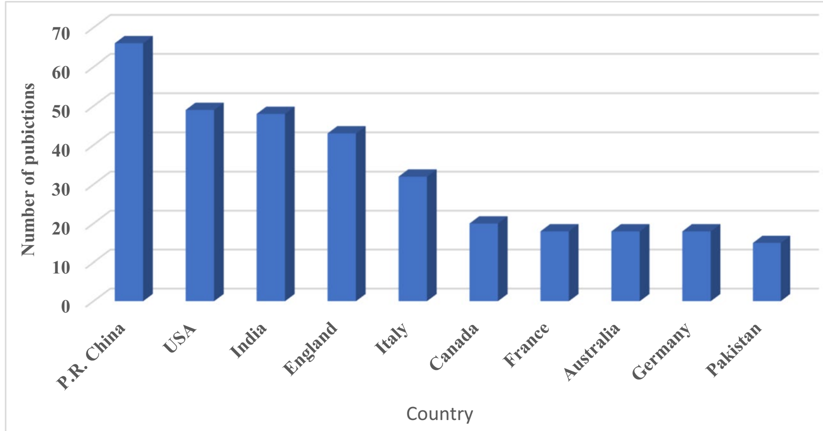

Fig. 3 Contribution of the top ten countries with respect to number of publications

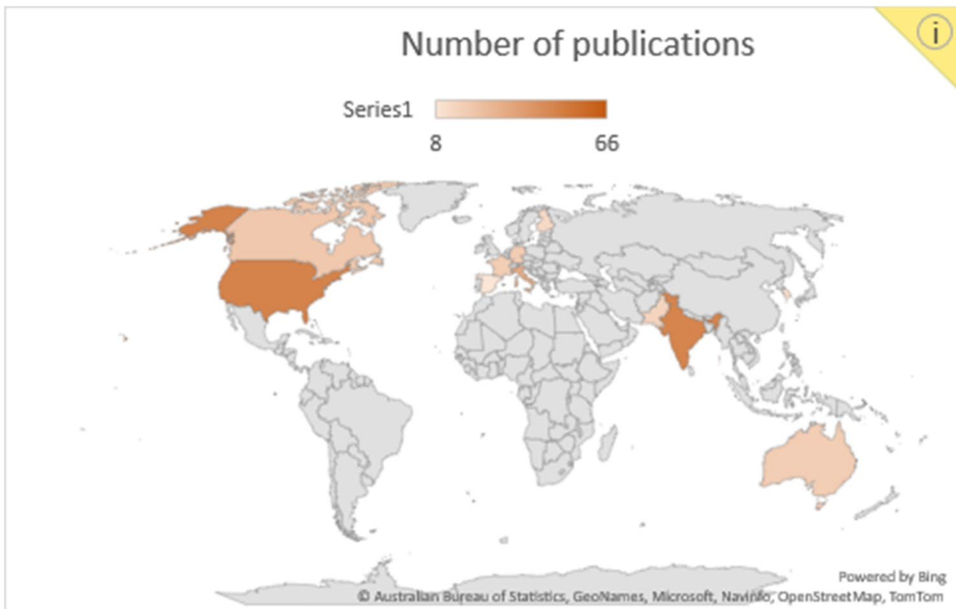

Fig. 4 World map for country-wise contributions with respect to number of publications

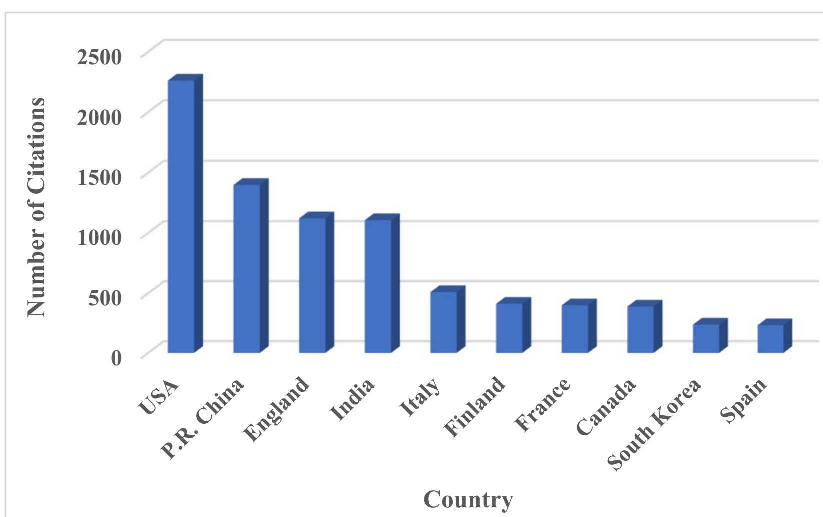

Fig. 5 Contribution of the top ten countries with respect to number of citations

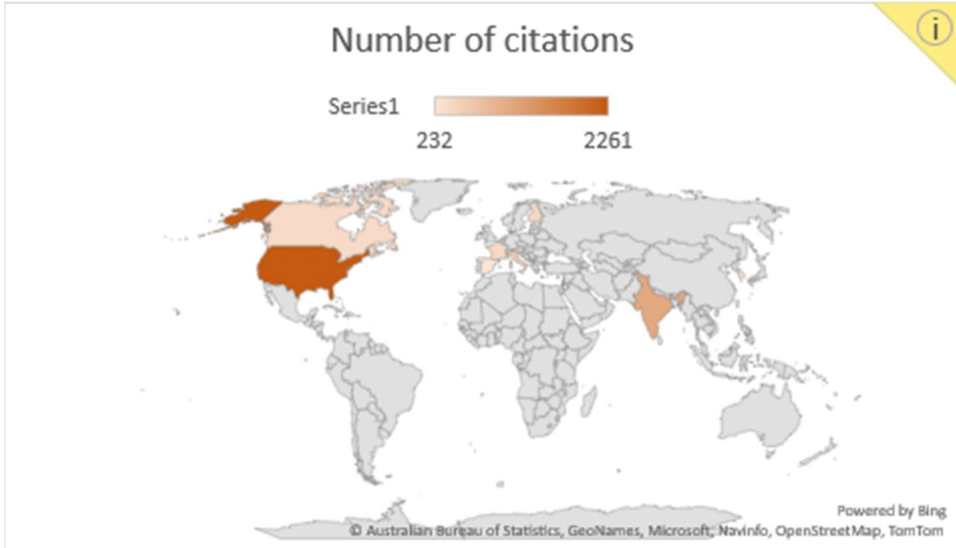

Fig. 6 World map for country-wise contributions with respect to number of citations

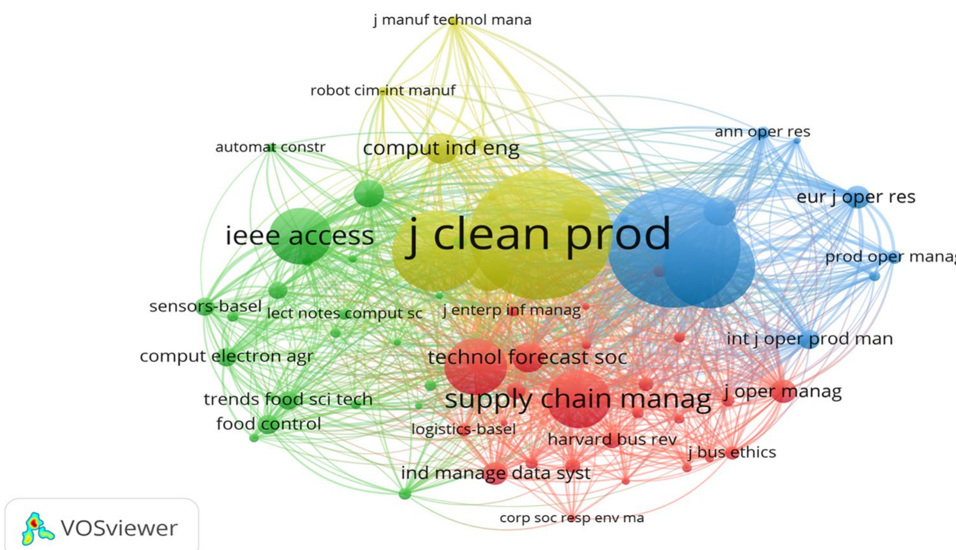

Fig. 7 Journal clusters

Based on the Table 5, it may be observed that Worcester Polytechnic Institute of USA has contributed most (14 documents and 1394 citations) which are followed by other reputed institutions like National Institute of Industrial Engineering, California State University, Bakersfield and Hong Kong Polytechnic University.

Network analysis

The network analysis was carried out using the VOS viewer 1.6.16.0 software. VOS viewer can display a map in a variety of ways by emphasizing its unique qualities (Agrawal et al. 2022a). The network analysis was carried out to examine the network and research partnerships.

Keyword statistics

The keyword statistics were developed to examine the most popular keywords in the headings of articles and the keyword section to comprehend the key conceptual trend established by current research (Agrawal et al. 2022a, b). The cluster-based network of keywords developed using VOS viewer is shown in Fig. 10.

Table 6 displays the cluster-based network of keywords based on the VOS viewer.

Based on the Table 6, it may be observed that cluster 1 has most occurrence keywords followed by other three clusters. Furthermore, the trending keywords are BCT, sustainability, supply chain, and technology.

Table 4 Journal-wise contribution

S. no	Country	Number of citations	Total link strength
1	Journal of Cleaner Production	944	43,979
2	International Journal of Production Research	876	48,843
3	International Journal of Production Economics	608	38,618
4	Sustainability Basel	591	27,237
5	Supply Chain Management	422	20,226
6	IEEE Access	416	16,772
7	International Journal of Information Management	412	18,407
8	Resources, Conservation & Recycling	293	13,783
9	Computers and Industrial Engineering	226	11,957
10	Transportation Research Part E: Logistics and Transportation Review	217	13,176

Fig. 8 Journal-wise contribution

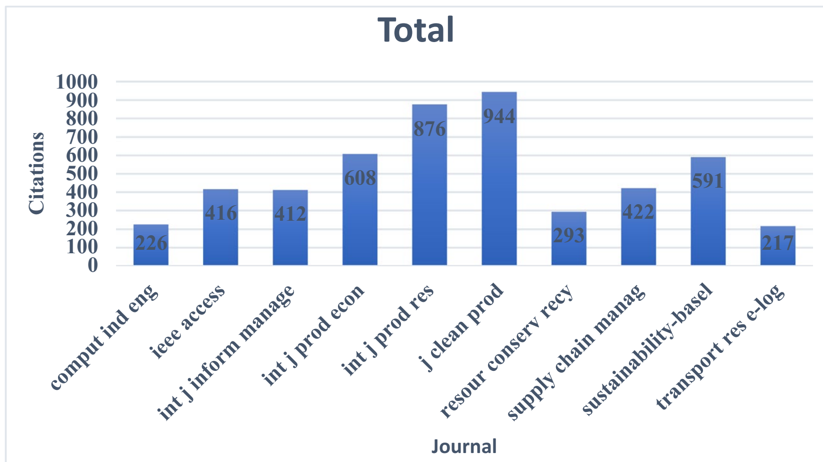

Fig. 9 Institution-based clusters

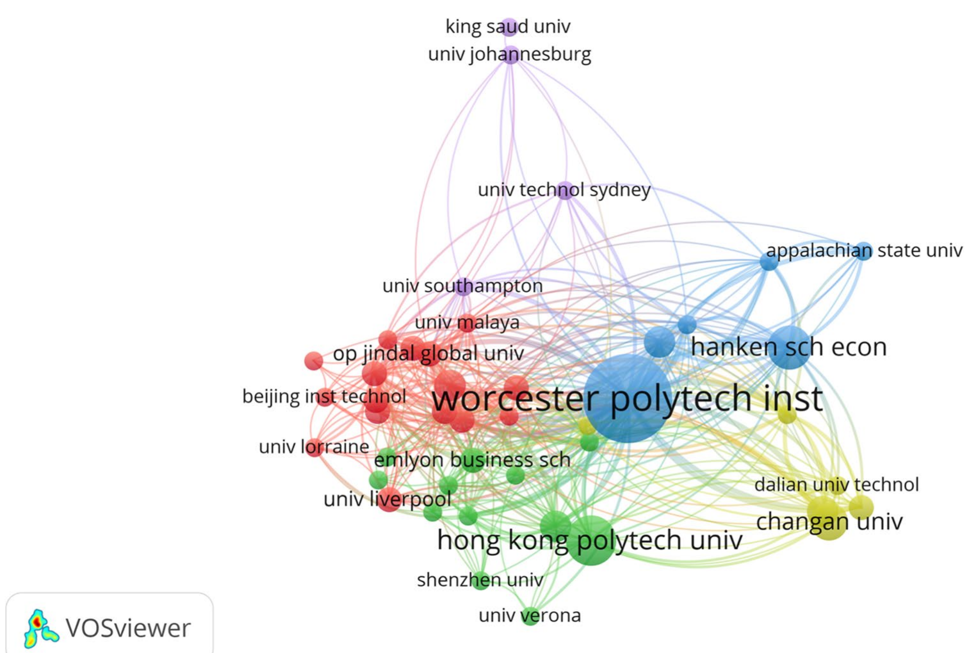

Table 5 Top ten institutions contribution

Institution	Country	Articles	Citation	Total link strength
Worcester Polytechnic Institute	USA	14	1394	309
National Institute of Industrial Engineering	India	4	453	71
California State University, Bakersfield	USA	3	295	37
Hong Kong Polytechnic University	China	8	242	48
University of Hong Kong	China	5	229	51
Guangdong University of Technology	China	5	185	50
Cardiff University	United Kingdom	3	178	21
Hanken School of Economics	Finland	7	169	95
Lancaster University	England	3	155	35
The University of Alabama	USA	3	150	83

Co-author analysis

Co-author cluster has been shown in Fig. 11.

The co-author analysis identifies six significant collaborative clusters and quantifies the number of collaborative publications between researchers, all of which contribute to the field's knowledge advancement. Total link strength assesses the strength of a researcher's or article's existing ties to other researchers and papers (Tandon et al. 2021). For co-author analysis, selected authors must have at least 3 documents. Out of 942 authors, 32 have met the requirement.

Page rank analysis

Prestige of an article is not indicated by its number of citations but by the number of citations by other highly cited articles. Page rank analysis reveals the level of prestige an article enjoys, whereas citations look at how closely related different articles (or network nodes) are to one another (Tandon et al. 2021). The higher a paper's page rank value, the more frequently it is cited by important papers. Page rank analysis is a method for determining how frequently someone visits a certain web page (Yadav et al. 2022). The initial aim of the page rank was to describe connections between webpages that

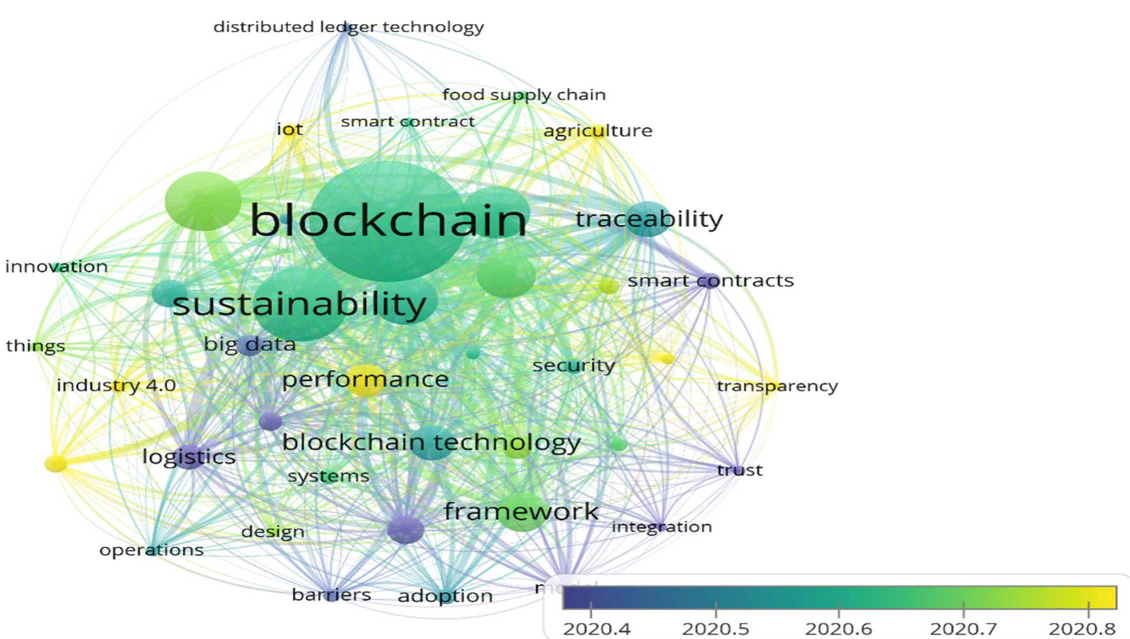

Fig. 10 Cluster-based network of keywords

Table 6 Cluster-based keywords

Clusters	Keywords	Occurrence	Total link strength
Cluster 1	Adoption	23	147
	Barriers	20	116
	BCT	53	281
	Design	15	93
	Framework	60	364
	Impact	35	187
	Industry	17	120
	Information	20	134
	Integration	13	85
	Model	21	128
	Performance	48	299
	Supply chain management	43	240
	Sustainability	110	585
	Systems	22	128
	Transparency	13	86
	Trust	15	94
Cluster 2	Agriculture	22	140
	Blockchain	182	835
	Challenges	69	415
	Distributed ledger technology	13	57
	Food supply chain	13	80
	IOT	20	121
	Management	79	462
	Smart contract	13	62
	Supply chain	89	451
	Technology	76	433
	Traceability	54	325
Cluster 3	Circular economy	27	140
	Future	28	194
	Industry 4.0	19	124
	Innovation	15	75
	Internet	41	275
	Logistics	38	207
	Operations	17	105
	Things	14	98
Cluster 4	Big data	33	193
	Internet of things	16	109
	Security	23	118
	Smart contracts	24	123
	Supply chains	16	96
	System	24	169

can be used to investigate interactions among networks, such as a network of publications in a citation study (Muessigmann et al. 2020). The page rank analysis of an article A, if article A is cited as T1, T2, …. Tn by other authors in their articles is calculated by using Eq. 1.

$$\mathrm{PR}(A) = \frac{1-d}{N} + d\left(\frac{\mathrm{PR}(T_1)}{C(T_1)} + \cdots + \frac{\mathrm{PR}(T_n)}{C(T_n)}\right) \quad (1)$$

where d = damping factor (generally ranging from 0 and 1)

$C(T_i)$ = number of times T_i has referenced other articles.

PR (T_i) = page rank of article T_i.

It is essential to mention that citations to other frequently cited publications have an impact on page rank. By their very nature, later publications cannot reference earlier ones. Page rank will probably deliver a better image of the prestige of articles in the future as the field expands in terms of publications and productivity. Note that the tools "GEPHI" and "VOS viewer" were used to compute PRA in this article. Table 7 lists the top 10 writers' page rankings after being calculated.

Analysis of clusters

In a bibliometric investigation, cluster analysis is crucial for examining the network of researchers, articles, and co-citations (Agrawal et al. 2022a). Data clustering seeks to group articles from the same academic field together into a single cluster while dividing articles from different fields into separate clusters (Yadav et al. 2022). The top ten clusters have been taken into consideration in the current analysis. Cluster of dominating articles is illustrated by Fig. 12.

The primary articles under each cluster are shown in Table 8, along with their link strengths and total citations.

Discussions and recommendations

Here, the study summarizes the preliminary conclusions from the done investigation into a number of broad and detailed research propositions. In the past 10 years, the subject of supply chain sustainability has gained tremendous significance, garnering the attention of industry, academics, and society (Kouhizadeh et al. 2021). A conventional supply chain system does not, however, offer the capability of real-time tracking of the product. Consequently, using BCT will enable digital supply chains. Major characteristics of BCT, which makes it a suitable tool for SSC are transparency (Kusi-Sarpong et al. 2022), traceability (Mangla et al. 2021), immutability (Ghode et al. 2020), audibility (Yadav and Singh 2020), disintermediation (Kamble et al. 2020a, b), and reliability (Sahebi et al. 2022). This paper's bibliometric mapping summarizes the pertinent data gathered from a thorough literature research in order to boost the acceptance of BCT in various supply chain operations. Cluster analysis has been done to propose the specific propositions (P_s) of various areas that various clusters have contributed to.

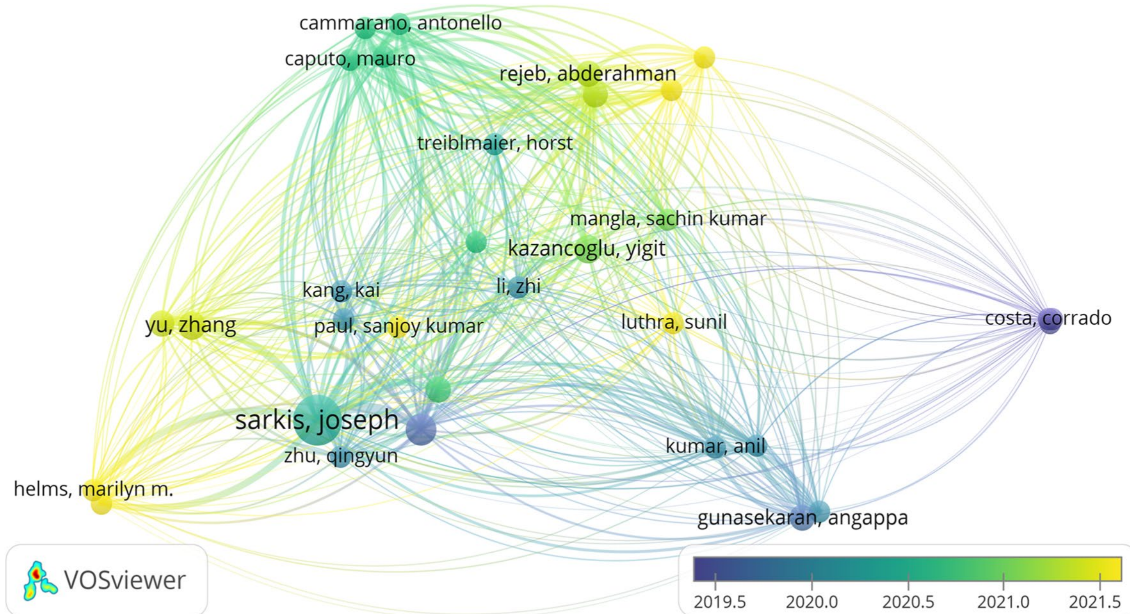

Fig. 11 Co-author cluster

Table 7 Top 10 authors' page rankings

Authors	Page rank analysis
Kouhizadeh and Sarkis 2018	0.068474
Saberi et al. 2019	0.033518
Boutkhoum et al. 2021	0.030896
Nayak and Dhaigude 2019	0.024779
Park 2020	0.023031
Ko et al. 2018	0.01604
Kamble et al. 2020b	0.014292
Cole et al. 2019	0.012545
Saurabh and Dey 2021	0.009049
Di Vaio and Varriale 2020	0.007884

Cluster 1: BCT and green supply chains

Cluster 1–based documents support the contribution of BCT to the green supply chains. BCT's features such as smart contracts with partners and transparent information sharing boost supply chain visibility dramatically (Khan et al. 2021c). In cluster 1, the top article was authored by Cole et al. (2019) with total citations of 151. The authors explain the use of BCT in supply chain management and operations. The authors also demonstrate the operation of a blockchain from the perspective of the supply chain. Kouhizadeh and Sarkis (2018) have a total citation of 141. They give information on how BCT might be used to support supply chains that use green approaches. Bai

Fig. 12 Cluster of dominating articles

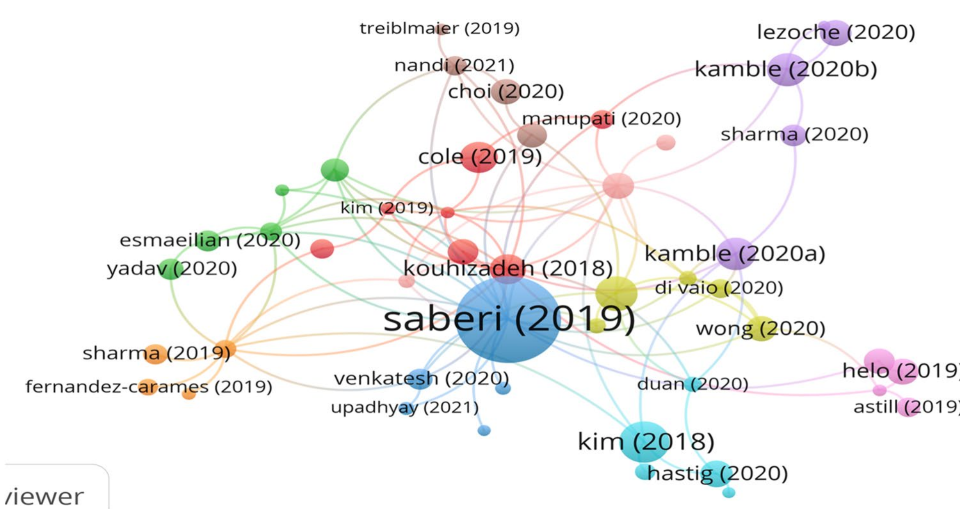

Table 8 Cluster-based article's citation and key findings

Clusters	Documents	Citations	Links	Findings of the clusters
Cluster 1	Bai and Sarkis 2020	113	3	This cluster covered the contribution of BCT to the green supply chain and circular economy with an emphasis on the environmental aspect of sustainability
	Cole et al. 2019	151	3	
	Khan et al. 2021a, b, c	38	9	
	Kim and Shin 2019	42	4	
	Kouhizadeh and Sarkis 2018	141	13	
	Manupati et al. 2020	75	4	
	Tijan et al. 2019	80	2	
Cluster 2	Esmaeilian et al. 2020	88	4	This cluster develops the conceptual framework of a BCT-based life cycle assessment method for controlling supply chains' environmental sustainability
	Farooque et al. 2020	39	3	
	Kouhizadeh et al. 2020	99	7	
	Yadav and Singh 2020	85	2	
	Zhang et al. 2020	71	6	
Cluster 3	Astarita et al. 2019	34	1	This cluster explores the potential of BCT to contribute to social sustainability in the supply chain by preventing child labor, and corruption through its traceability and transparency features
	Ivanov et al. 2019a, b	45	1	
	Saberi et al. 2019	648	19	
	Upadhyay et al. 2021	46	2	
	Venkatesh et al. 2020	86	5	
Cluster 4	Di Vaio and Varriale 2020	74	6	This cluster analyzed the relationship between operations management, sustainability concerns, and BCT within supply chain management and suggested BCT as a tool to increase supply chain visibility
	Rogerson and Parry 2020	54	2	
	Saurabh and Dey 2021	51	5	
	Wang et al. 2019	177	7	
	Wong et al. 2020	111	5	
Cluster 5	Kamble et al. 2020a	162	7	This cluster focuses on developing the model for the sustainable agriculture supply chain by implementing Industry 4.0 applications, BCT, and machine learning applications
	Kamble et al. 2020b	168	4	
	Kumar et al. 2021	35	2	
	Lezoche et al. 2020	116	1	
	Sharma et al. 2020	83	1	
Cluster 6	Antonucci et al. 2019	64	1	This cluster presents details on BCT capability for supply chain traceability
	Duan et al. 2020	54	4	
	Gao et al. 2018	35	1	
	Hastig and Sodhi 2020	122	2	
	Kim and Laskowski 2018	42	4	
Cluster 7	Fernández-Caramés et al. 2019	62	1	This cluster describes the function of BCT in the manufacturing firm's supply chain to track inventory, manufacturing parts, and quality of the products
	Ko et al. 2018	37	1	
	Leng et al. 2020	71	10	
	Sharma et al. 2018			
Cluster 8	Choi and Luo 2019	109	3	This cluster investigates the role of BCT in promoting triple bottom line sustainability. And also highlights BCT as a technique to aid post-pandemic supply chain resilience advancements
	Choi 2020	115	2	
	Nandi et al. 2021	80	6	
	Treiblmaier 2019	38	1	
Cluster 9	Astill et al. 2019	78	1	This cluster describes the transparency and traceability of BCT in the agriculture supply chain and suggests a strategy for its deployment in the agriculture supply chain
	Feng et al. 2020	111	2	
	Helo and Hao 2019	118	2	
	Köhler and Pizzol 2020	38	4	
Cluster 10	Biswas and Gupta 2019	51	1	This cluster support BCT as a tool to help circular economy initiatives through information sharing, smart contracts
	Kouhizadeh et al. 2019	49	5	
	Kouhizadeh et al. 2021	120	13	

and Sarkis (2020) have the total citation of 113 and authors designed a blockchain supply chain transparency evaluation methodology to reduce sustainability risks and boost global supply chain competitiveness. The study by Tijan et al. (2019) has total citation of 80 and investigates the use of BCT in logistics procedures, its effects on supply chain transparency, and the reasons it is crucial to integrate BCT into every step of the supply chain. The article by Manupati et al. (2020) has a total citation of 75 and create a blockchain-based distributed database solution for tracking supply chain performance and synchronizing the optimization of emission levels and operating costs. Kim and Shin (2019) have the total citation of 42 and examines how the application of BCT in supply chain activities may affect (raise or decrease) the effectiveness and expansion of supply chain partnerships, thus affecting supply chain performance outcomes. Khan et al. (2021a, b, c) has total citation of 38 and investigate how BCT is used in circular economy practices and how that affects sustainable and environment performance, which affects organizational effectiveness.

Based on the concise summaries of the articles that are offered in the preceding paragraphs, we suggest the following proposition (P1) for further investigation into this determined theme:

Proposition 1 (P1): BCT enables the precise tracking of a product's carbon footprint, aiding the government in determining the amount of carbon tax to be levied against each business and helps businesses to comply with environmental standards. Smart contracts initiate payments for returned goods automatically based on their condition.

Cluster 2: blockchain-based life cycle assessment

Cluster 2–based documents focuses on the development of the theoretical model of a blockchain-based life cycle assessment (LCA) method for controlling supply chains' environmental sustainability. LCA is the measure of a good's environmental effects throughout the course of its whole lifecycle, which includes the mining of raw materials, manufacturing, transportation, use and consumption of the goods, and eventually good's disposal (Farooque et al. (2020). Traditional LCA techniques, however, have a number of limitations (Farooque et al. (2020). Because of its unique technical property of data security, the newly emerging BCT presents a perfect alternative to address the data reliability challenges for conducting LCA (Zhang et al. 2020). Kouhizadeh et al. (2020) in cluster 2, with highest citations of 99, investigates how the adoption of the circular economy is going to change and advance thanks to BCT. Esmaeilian et al. (2020) with total citations of 88 give a brief review of Industry 4.0 and BCT to help supply chains move toward sustainability. Yadav and Singh (2020), with total citations of 85, determined factors that would justify BCT-based SSC vs. the conventional approach and created a cause–effect relationship between the major factors to find the causes. Zhang et al. (2020), with total citations of 71, suggest a blockchain-based LCA model in order to include BCT into several LCA phases and improve the operation's effectiveness and efficiency. Farooque et al. (2020), with total citations of 39, enumerate the main obstacles to using BCT for LCA.

As a result, in order to conduct further research on this subject, we suggest the following propositions (P2):

Proposition 2 (P2): BCT can reduce data uncertainty, enhance data authenticity, dependability, and transparency, and improve data inputs and outcomes for LCA tools.

Cluster 3: BCT and social sustainability

Cluster 3 explores the potential of BCT to reinforce social responsibility in the supply chain by preventing child labor, and corruption through its traceability and transparency features, protecting human rights. BCT offers enormous prospects for achieving responsible economic growth while protecting the environment and upholding social responsibility. Various contribution of BCT in promoting social sustainability found in literature are fraud prevention (Upadhyay et al. 2021; Kshetri 2021), assurance of labor and human rights (Venkatesh et al. 2020), ensuring the quality of the product (Saurabh and Dey 2021), to support sustainability certificates (Kouhizadeh et al. 2021; Paul et al. 2021;Kshetri 2021), to provide safe and good quality milk (Mangla et al. 2021), to fight against corruption (Kshetri 2021), (Khanfar et al. 2021), to monitor the origin of raw materials (Park and Li 2021), to trace the product waste (Park and Li 2021), to certify the authenticity of the product (Yousefi and Tosarkani, 2022). In cluster 3, Saberi et al. (2019), with highest citations of 648, critically reviewed the use of smart contracts and BCT in supply chain management. This study also summarizes the barriers to implementation of BCT for businesses. The study by Venkatesh et al. (2020), with total citations of 86, create a system architecture that incorporates Internet of Things, big data analytics, and BCT for supply chain traceability and social sustainability. Upadhyay et al. (2021), with total citations of 46, examine BCT's present and potential effects on the circular economy from a sustainability and social responsibility perspective. The article by Ivanov et al. (2019a, b) has a total citation of 45, outlines a framework for supply chain risk analytics and describes the idea of digital supply chain twins. A digital twin is created by the integration of modeling, optimization, and database management. Astarita et al. (2019) give a survey of the available research on the use of BCT-based solutions in the transportation sector through bibliometric review.

Fraud and counterfeiting might be overcome with a BCT-enabled system that makes traceability visible at the unit level (Rogerson and Parry 2020). Thus, we may attain sustainability and social responsibility goals through cooperation and data exchange in the BCT (Upadhyay et al. 2021).

Therefore, we suggest proposition (P3) for more study on the highlighted theme:

> **Proposition 3 (P3):** BCT possess significant potential to enhance the social sustainability of the supply chain like guaranteeing product quality, supports sustainability certificates, protects human rights, prevents frauds, child labor, and corruption.

Cluster 4: BCT and supply chain visibility

Cluster 4 analyses the relationship between operations management, sustainability concerns, and BCT within the supply chain management and suggested blockchain as a tool to increase supply chain visibility. Supply chain visibility enhances the long-term supply chain performance. The visibility offered by BCT systems facilitates decision-making by allowing stakeholders to view fast, precise, and trustworthy information while minimizing the amount of data sets that lead to decision-making (Rogerson and Parry 2020). In the past, trust was traditionally built through mutual supply chain investments or through the development of long-term relationships with partners. Because trust is already there in BCT systems, due to supply chain visibility, businesses do not need to "trust" their partners to the same extent when using blockchains (Wang et al. 2019). BCT eliminates intermediaries between organizations, and trust is generated via interconnected nodes (Wong et al. 2020). In cluster 4, the study by Wang et al. (2019) has highest citations of 177 and explores how upcoming BCT may change supply chains using the sense making theory by consulting with 14 supply chain professionals. Wong et al. (2020), with total citations of 111, examine into the effects of BCT adoption for supply chain and operations management among Malaysian small-medium enterprises. Di Vaio and Varriale (2020), with total citations of 74, analyze the relationship between operations management, sustainability concerns, and BCT within supply chain management. Rogerson and Parry (2020) has a total citation of 42 and explore the implementation of BCT to enhance supply chain transparency and trust. Saurabh and Dey (2021) have total citations of 51 and identify drivers of BCT implementation in grape wine supply chain and explored relationship between them by employing conjoint analysis.

For the supply chain to compete better while addressing the issues of product's damage, demand supply changes, safety, and sustainability, information collection and sharing are hugely beneficial and advantageous (Kamble et al. 2020b). Various benefits of BCT imply that blockchain can offer improved visibility through stronger links with digital supply chains (Rogerson and Parry 2020).

Therefore, we suggest the following proposition (P4) for more study on the highlighted theme:

Cluster 5: BCT and sustainable agriculture supply chain

Cluster 5 focuses on developing the model for the sustainable agriculture supply chain by implementing Industry 4.0, BCT, and machine learning applications. BCT may lower risks and enhance the effectiveness of the agriculture supply chain by removing mediators and ensuring transparency and accountability in the agriculture supply chain (Kamble et al. 2020a). In cluster 5, Kamble et al. (2020b), with highest citations of 168, and carried out a literature review to comprehend the extent to which supply chain objectives for sustainable agriculture, have been met and suggested a conceptual model for those working in the agri-food supply chain. Kamble et al. (2020a), with a total citation of 162, determine and linkages among the facilitators of BCT implementation in agriculture supply chain and their connections by using integrated interpretive structural modeling and decision-making trial and evaluation laboratory approach. The research by Lezoche et al. (2020), with citations of 116, reviews literature on Industry 4.0 techniques and agriculture supply chain to comprehend the future research implications in the agriculture domain. Sharma et al. (2020), with citations of 83, propose a framework on the use of machine learning for creating sustainable agriculture supply chain by reviewing the literature. Kumar et al. (2021), with citations of 35, highlight Industry 4.0 and circular economy adoption obstacles in agriculture supply chain and identified the contextual connections between them in order to rank them in relation to one another.

As a result, in order to conduct further research, we suggest propositions (P5):

> **Proposition 5 (P5):** Utilizing BCT allows smart agriculture to achieve crucial farming goals including water conservation, soil preservation, carbon emission reduction, cutting back on storage facilities, and productivity growth by using less resources.

Cluster 6: BCT and supply chain traceability

Cluster 6 presents details on BCT capability for supply chain traceability. BCT is found to increase the sustainability of the supply chain, which operates more efficiently and targets product recalls. The supply chain's significant effects, such as transparency and accountability, traceability and fraud prevention, security and authentication, and cybersecurity and protection, are recognized by BCT-based traceability. Product's traceability will be greatly improved because to BCT's expertise in product originality, traceability, and real-time transactions. This will have a favorable effect on product quality, safety, and sustainability (Kamble et al. 2020a). In cluster 6, Hastig and Sodhi (2020), with highest citations of 122, determine the business needs and the elements essential to an effective deployment to direct operations management study on the adoption of supply chain traceability operations. The study by Antonucci et al. (2019) have total citations of 64 and reviews literature on adoption of BCT in agriculture supply chain by using network analysis. Duan et al. (2020), with citations of 54, apply a literature evaluation based on content analysis to the implementation of BCT in the agriculture supply chain. Kim and Laskowski (2018), with citations of 54, create an ontology-based BCT for supply chain traceability Ethereum blockchain platform. Gao et al. (2018), with citations of 35, suggest a unique supply chain network based on BCT to create a uniform platform for the many parties and participants involved in the supply chain network to do business and share information.

As a result, in order to conduct further research on this subject, we suggest proposition (P6):

Proposition 6 (P6): Blockchain is a powerful tool for reducing food fraud and improving traceability effectiveness, which can save both time and money.

Cluster 7: BCT and inventory tracking

Cluster 7 describes the applications of BCT in the supply chain of manufacturing firms to track inventory, manufacturing parts, and quality of the products. This cluster explores how companies may use BCT to obtain real-time transparency and cost reductions by implementing distributed ledger technology. In cluster 7, the study by Leng et al. (2020) have highest citations of 71 and studies how BCT can be used to overcome possible obstacles to sustainability from the point of the production process and product lifecycle management. Fernández-Caramés et al. (2019), with citations of 62, develop and deploys unmanned aerial vehicles and BCT-based design for Industry 4.0 inventory and traceability purposes. Ko et al. (2018), with citations of 62, explore how companies may use BCT to obtain real-time transparency and cost reductions by implementing distributed ledger technology. Sharma et al. (2018) suggest a distributed architecture that uses BCT for the automotive sector in the smart city. Thus, we create Proposition (P7):

Proposition 7 (P7): BCT- integration in supply chain increase consumer confidence in product quality, increase the value of goods and services and reduce transaction and production cost.

Cluster 8: BCT and triple bottom line sustainability

Cluster 8 investigates the role of BCT in promoting triple bottom line sustainability. In cluster 8, the study by Choi (2020) have highest citations of 115 and creates empirical studies to examine how supply chains and technology might change "static service operations" into "bring-service-near-your-home" mobile service operations. Choi and Luo (2019), with citations of 109, develop theoretical frameworks to investigate how issues with data quality impact supply chain management for sustainable fashion and mentions an instance where BCT improved social welfare. Nandi et al. (2021), with total citations of 80, present lessons learned from the COVID-19 outbreak for robust, transparent, and sustainable supply chains. Treiblmaier (2019), with total citations of 38, introduces and explains the BCT and the physical internet, then incorporate them within a broad framework for logistics and supply chain management. We recommend the following proposition (P8) for additional research:

Proposition 8 (P8): Businesses are utilizing BCT to handle a range of concerns with the sustainable supply chain, including food contamination, carbon credits, identification of waste, and planned maintenance.

Cluster 9: BCT and supply chain transparency

Cluster 9 describes BCT's transparency in the agriculture supply chain and recommends a model for BCT implementation in the agriculture supply chain. BCT, one of the most rapidly developing and growing technologies, seeks to completely increase supply chain transparency by allowing simple and secure traceability, backtracking, and information tracing (Antonucci et al. 2019). In cluster 9, the study by Helo and Hao (2019) have highest citations of 118 and discusses immutable distributed ledger technology and its potential applications in operations and supply chains. Feng et al. (2020), with total citations of 111, study the features and functionalities of BCT, identify blockchain-based strategies for resolving issues with food traceability, and describe the advantages and difficulties of adopting BCT-based traceability solutions. The study by Astill et al. (2019) have total citations of 78 and outline enabling technologies offered by the Internet of Things, BCT, and big data analytics which could improve food production transparency. Köhler and Pizzol (2020), with total citations of 38, offer valuable information on how blockchain-based technologies may be deployed in the food supply chain and discuss about their social and environmental aspects.

As a result, in order to conduct further research on this subject, we suggest the following proposition (P9):

Proposition 9 (P9): The agriculture supply chain's significant effects, such as transparency and accountability, traceability and fraud prevention, security and authentication, and cybersecurity and protection, are recognized by blockchain-based traceability.

Cluster 10: BCT and circular economy

Cluster 10 support BCT as a tool to help circular economy initiatives through information sharing smart contracts. The adoption of circularity in supply chain management

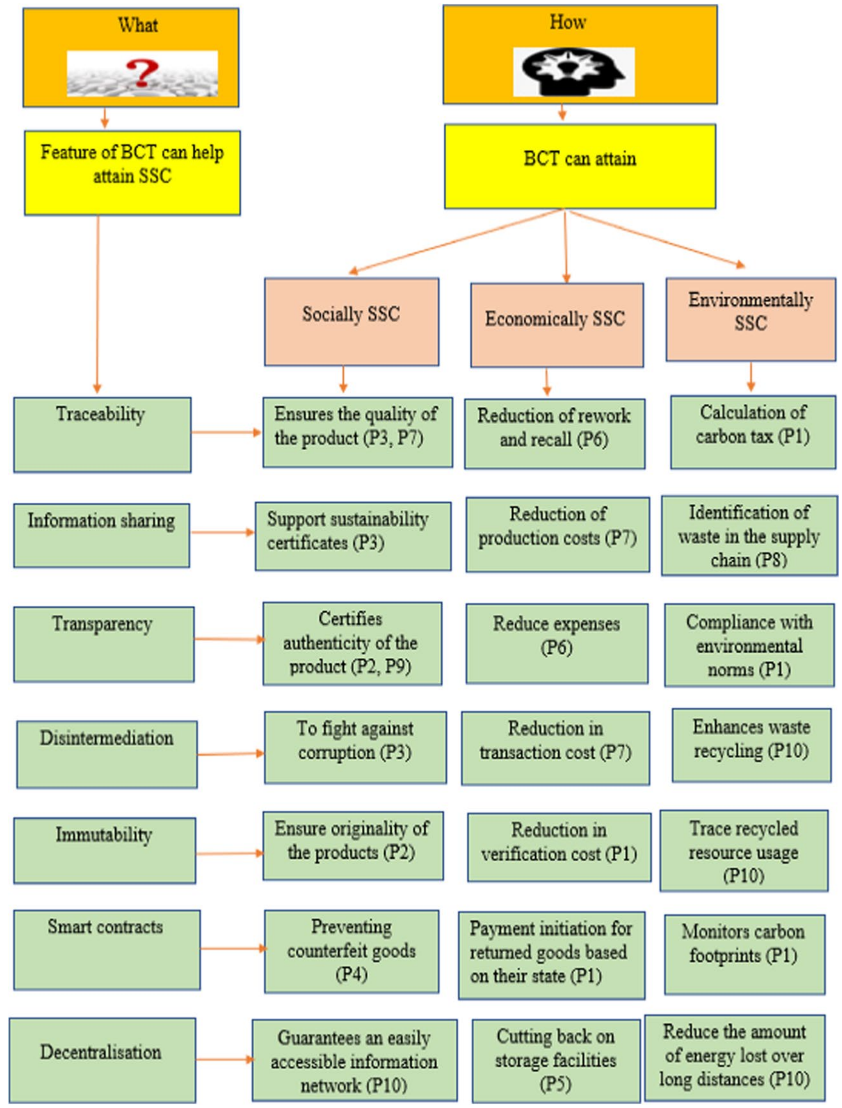

Fig. 13 Conceptual framework for the study

and logistics techniques can make it easier for customers to return products after using them and repurpose goods that have additional value (Agrawal et al. 2022a). In cluster 10, the study by Kouhizadeh et al. (2021) have highest citations of 120 and uses force field concepts and the technology-organization-environment model to examine BCT deployment obstacles, and Biswas and Gupta (2019) with total citations of 51 use the DEMATEL approach to provide a framework for examining obstacles to the implementation and effective use of blockchains across various businesses and services. Kouhizadeh et al. (2019), with total citations of 49, describe the connections between the circular economy, BCT, and product deletion. Through transparency and traceability, BCT may connect supply chains with circular economic sustainability (Upadhyay et al. 2021).

As a result, to conduct further research on this subject, we suggest the following proposition (P10):

Proposition 10 (P10): On a blockchain, precise data on recycling initiatives, material reuse, eco-friendly packaging, energy use, and carbon emissions can be made available.

Conceptual framework and implications of the study

By combining the findings of earlier studies, the present work has developed a conceptual framework to guide the operation of the SSC and BCT to aid policymakers and practitioners (Fig. 13).

This framework describes how various features of BCT can help in attaining sustainability in the supply chain. Various features of BCT found in the literature that support SSC are traceability, information sharing, transparency, disintermediation, immutability, smart contracts, and decentralization. These features support societal dimension of SSC by ensuring the quality of product (traceability), supporting sustainability certificate (information sharing), certifies authenticity of the product (transparency), fighting against corruption (disintermediation), ensuring originality of the product (immutability), preventing counterfeit goods (smart contracts), and guarantees an easily accessible information network (decentralization). Economic dimension of SSC is supported by BCT because of these various features by reduction of rework and recall (traceability), reduction of production costs (information sharing), reduce expenses (transparency), reduction in transaction costs (disintermediation), reduction in verification cost (immutability), payment initiation on return goods based on their state (smart contracts), and cutting back on storage facility (decentralization). BCT also support environmental dimension of SSC by calculation of carbon tax (traceability), identification of waste in the supply chain (information sharing), compliance with environmental norms (transparency), enhance waste recycling (disintermediation), trace recycled resource usage (immutability), monitors carbon footprint (smart contracts), and reduce the amount of energy lost over long distances (decentralization).

Theoretical implications

This study offers a series of recommendations on how BCT fits into a sustainable society, which adds to the literature on both sustainable development and BCT. Our study is a trailblazing investigation into the introduction and application of BCT to supply chains to enhance its sustainability. In light of the results, we provide five theoretical implications for improving future research on the use of BCT in SSC. First, our findings help scholars comprehend the extent and existing limitations of this field's study. As a result, this work gives academicians, supply chain practitioners, and policymakers a fundamental and unbiased framework for understanding the concept of BCT and sustainability as well as current research trends on this topic.

Second, our findings may be used by researchers to draw attention to the unique and less-studied topics to promote the deeper adoption of BCT applications in SSC management. Third, researchers may gain from identifying influential individuals, journals and organizations in this field as prospective partners and guides for promoting the study in this domain. Fourth, the results of the cluster analysis give scholars crucial knowledge about eminent and significant articles that might be viewed as the bedrock of this research topic. Fifth, research propositions suggest important study themes that potential future researchers should tackle.

Practical implications

As this paper has shown, BCT has the ability to change how organizations conduct business and serve as a catalyst for SSC models. These broad assumptions lead the researchers to various managerial and policy implications. Utilizing digitally linked supply chains offers a number of advantages in the midst of intense competition, uncertain markets, time-to-market needs, and difficulties with access to essential technology (Rejeb et al. 2021). A conceptual model for managers in the supply chains might be created by the various types of clusters described in this article. Managers may use this data in their policy decisions to support the deployment of BCT-based supply chains. This study advises managers to take BCT into account in order to increase supply chain social, economic, and environmental sustainability.

Unique contributions

This article's original contribution is the creation of a research framework for SSCs using BCT (see Fig. 13). This research is among the first to use bibliometric analysis and SSC views to examine the literature on BCT and SSC integration. This study has guided organizations for adopting BCT-based technologies in their supply chain sector. This study identified influential individuals, journals, and organizations in this field by using bibliometric analysis. Influential co-author, and keywords were identified, and page rank and cluster analysis were done using network analysis.

Also, this research classified the entire research of BCT-based supply chains into ten clusters and suggested ten specific propositions. Furthermore, to guide research scholars in this field, this study has suggested 33 future research directions. Overall, the study found that BCT has an enormous potential in the supply chain.

Conclusion and future research directions

The objective of this research was to present an exhaustive map of BCT research in the context of SSC by (i) identifying influential individuals, journals, and organizations in this field; (ii) identifying main keywords and research themes; (iii) presenting potential research propositions by conducting bibliometric and network analysis. The findings revealed ten major BCT research clusters in the SSC context, including BCT and green supply chain, BCT-based LCA, BCT and social sustainability, BCT and supply chain visibility, BCT and sustainable agriculture supply chain, BCT and supply chain traceability, BCT and inventory tracking, BCT and post-pandemic supply chain resilience, BCT and supply chain transparency, and BCT and circular economy. The major conclusions of the current study

Table 9 Future research directions

S no	Cluster	Future research directions (FRDs)
1	BCT and green supply chain	1. To compare the environmental and social benefits of implementing BCT with the financial investment required for its deployment 2. To assess how blockchain affects multi-tier networks' transparency and consider partnering with organizations as they adopt the technology 3. To examine into the deployment difficulties with BCT, how they might be resolved, and therefore relevant strategies for successful deployment of BCT across various supply chain tiers are also required 4. To understand the impact of BCT on SSC at organizational, managerial, and strategic levels
2	Blockchain-based life cycle assessment	5. To analyze implementation challenges for a blockchain-based life cycle assessment system and come up with efficient solutions 6. To create a blockchain-based life cycle assessment proof-of-concept system, then conduct a test to demonstrate its viability 7. To create of novel performance measures and life cycle assessment techniques
3	Blockchain and social sustainability	8. To investigate how social sustainability concerns are impacted by BCT 9. To understand how BCT-enabled supply chain can attain United Nations sustainable development goals 10. To investigate the potential benefits of BCT for the circular economy 11. To study the potential legislative and policy consequences for the advancement of BCT and the circular economy
4	Blockchain and supply chain visibility	12. To investigate whether BCT will revolutionize the idea of supply chain trust 13. To comprehend how privacy, data integrity, and confidentiality affect adoption decisions and the function of blockchain in safeguarding sensitive data 14. To find out if and how cultural and social factors can affect the advantages of BCT for sustainable performance in supply chain management 15. To perform a cost–benefit analysis or analyze the return on investment of BCT implementation in supply chain
5	Blockchain and sustainable agriculture supply chain	16. To investigate how the blockchain in agriculture supply chain can deal with the problems of ownership, distribution, and authority in the administration of community-sponsored agriculture 17. To investigate on how BCT may guarantee the records' permanency and ensure auditable knowledge transfer among the many agriculture supply chain stakeholders 18. To investigate on how blockchain will help the agriculture supply chain implement more automated processes and increase transparency
6	Blockchain and supply chain traceability	19. To develop a framework to prevent unapproved entry to supply chain–related data recorded in the distributed ledger 20. To modify and assess the implementation strategy, design architecture, and analytical roadmap for blockchain-based traceability in pilot applications from various angles 21. To find key advantages and difficulties of using BCT to maintain product traceability 22. To investigate how might a BCT-based IoT traceability system be used to manage product tracing
7	Blockchain and inventory tracking	23. To investigate commercial blockchain-based robots and robotics 24. To investigate ways to improve blockchain security by introducing specific features
8	Blockchain and post-pandemic supply chain resilience	25. To take into account how governments can assist BCT—circular economy—localization, agility, and digitization SSC models 26. To examine how COVID-19's experiences can be used to ensure the supply chain's sustainability in the future 27. Eco efficiency, or minimizing waste to save money, at the organization, supply chain, neighborhood, and municipal levels may also be included in a resilient model 28. To analyze the acceptability of collaborative private–public activities along supply chains after COVID-19

Table 9 (continued)

S no	Cluster	Future research directions (FRDs)
9	Blockchain and supply chain transparency	29. To examine long-term effects and determine whether BCT will result in the desired change in the supply chain 30. To conduct assessment of BCT's effectiveness in the supply chain 31. To find the ways in which BCT could be used to improve the sustainability of different agriculture supply chains
10	BCT and circular economy	32. To use qualitative investigations and interviews, to spot new obstacles of BCT 33. To resolve immaturity and security concerns associated with the BCT

provide insight into the BCT research agenda and significantly aid in situating BCT practices and activities that are in line with the SSC fundamentals in the future. A real-time guideline to direct future research areas and a tool to assist BCT policymakers and practitioners in supporting the SSC transition can be built on the presented comprehensive study environment of BCT systems and its salient highlight patterns. In order to promote SSC management, 33 specific directions for the future research agenda of BCT were suggested. A conceptual framework was developed to guide the operation of the SSC and BCT to aid policymakers and practitioners.

Some empirical limitations that this study had may be resolved in further studies. First, this study's investigation of a single database, Web of Science, constrained the articles' sectoral reach. Subsequent bibliometric research might take into account the other databases, including Scopus, IEEE, PsycINFO, and Google Scholar. Second, the dataset did not contain any working papers, reports, or books. Third, future study may use different software tools, such as Bib Excel and R-based biblioshiny, to perform a more thorough cluster analysis.

Further from the analysis of the clusters, a few problems that have not gotten much attention in the literature have been identified. Scholars should therefore concentrate on following the following research directions.

Future research directions identified from the cluster analysis have been summarized in Table 9.

Author contribution Nidhi Yadav: ideas, conceptualization, writing—original draft preparation, data collation and curation, methodology, formal analysis. Sunil Luthra: ideas, conceptualization, project administration, formal analysis, critical review and editing. Dixit Garg: ideas, conceptualization, formal analysis, review and editing.

Code availability Authors have used VOS Viewer, MS Excel, and R-based biblioshiny software.

Data availability Data will be provided on the request.

Declarations

Ethics approval Not applicable.

Consent to participate All authors give their consent to be co-author in the manuscript.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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