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ORIGINAL PAPER

DIGITALIZATION IN THE REVERSE SUPPLY CHAIN: A BIBLIOMETRIC ANALYSIS

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ABSTRACT. Background: This article analyzes scientific sources on the process of digitalization in the reverse supply chain. Its aim is to comprehensively investigate and analyze the transformative potential of digitalization in the context of the reverse supply chain. By exploring the utilization of digital technologies such as the Internet of Things (IoT), data analytics, artificial intelligence (AI), and blockchain, the study aims to uncover opportunities for enhancing the efficiency, sustainability, and environmental responsibility of reverse supply chain processes. A significant number of studies on this topic have been published in scientific journals such as *Sustainability*, *Business Strategy and the Environment* and the *International Journal Of Production Economics*. The most cited authors were identified, including Gupta and Yu. Among the main countries where such research has been conducted are China, the United States, the United Kingdom, India and Pakistan.
Methods: The study included a literature review, evaluation, analysis and mapping, which allowed the authors to identify certain trends. The Scopus database was used for this purpose, and the selected articles were analyzed using MS Excel and VOSviewer. Initially, 297 documents were identified, and 82 articles remained after exclusions.
Results: The findings of the study emphasize the growing interest in this topic, the increasing number of related scientific publications, and the importance of the sustainable use of resources in the reverse supply chain.
Conclusions: The relevance of this study lies in the possibility of optimizing the processes of the reverse supply chain, ensuring the rational use of resources and achieving sustainable development. The application of the results obtained could be useful for a wide range of industries, including the activities of enterprises and the formation of policies for the management and development of economic sectors.

Keywords: digitalization, reverse supply chain, blockchain, digital transformation, Internet of Things, circular economy

INTRODUCTION

Blockchain technology's growing influence extends to the economy and various facets of human life [Kouhizadeh and Sarkis 2018], with the reverse supply chain emerging as a pivotal realm for digital integration [Rane and Thakker 2020]. Digital technologies' potential to optimize these processes carries significant implications for the economy, environment, and society [Bekrar et al. 2021].

Kouhizadeh and Sarkis [2018] delve into blockchain's supply chain role, underscoring its favorable impact on sustainability. Factors like trust, traceability, and transparency are key, as noted by Centobelli et al. [2022]. Rane and Thakker [2020] examine industry challenges that blockchain and the IoT can help address by enhancing supply chains and boosting competitiveness.

The Internet of Things (IoT) has a significant impact on the supply chain, particularly the reverse supply chain. Parry et al. [2016] discuss the IoT's role in gathering consumer product data, while proposing a management framework. IoT adoption also facilitates the transition to a circular economy

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[Ingemarsdotter et al. 2019, Charnley et al. 2019] by means of strategies such as tracking, monitoring, and design evolution [Ingemarsdotter et al. 2019]. Gu and Liu [2013] explore the IoT's potential in reverse logistics management, introducing a data-driven closed-loop system.

Tang et al. [2022] study the impact of blockchain and Industry 4.0 on the circular economy, describing how it enhances enterprise efficiency. Their research underscores blockchain's potential for ecological production and processing within the circular economy. Additionally, Khan et al. [2021b] illustrate how blockchain and Industry 4.0 facilitate circular economy adoption, emphasizing improved environmental and financial efficiency for enterprises following circular economy principles.

Hrouga et al. [2022] propose the use of blockchain and IoT integration to digitize the reverse supply chain, ensuring reliability. Shambayati et al. [2022] suggest virtual supply chains (VSC) to tackle enterprise challenges, finding IoT integration enhances VSC profitability.

Sarkis et al. [2021] explore digitalization's role in sustainable environmental supply chains, affirming its positive impact on the green supply chain. Eldrandaly et al. [2022] assert that blockchain and Big Data Analytics (BDA) promote cleaner production and social responsibility. Terrada et al. [2022] highlight the IoT's importance in supply chain management. Khan et al. [2021a] show blockchain's influence on environmental and operational enterprise performance.

Wu and Zhao [2022] introduce green reverse logistics as a method to enhance environmental protection and resource utilization in enterprises. They highlight blockchain's role in boosting profits and environmental impact. Fiorini et al. [2022] investigate information technology's contribution to green supply chains, emphasizing its impact on environmental and financial efficiency. Long et al. [2022] study blockchain's effect on green supply chain efficiency, noting its influence on supply chain trust.

Bekrar et al. [2021] explore blockchain's potential to enhance reverse logistics (RL) within the circular economy. Krstić et al. [2022c] highlight the inadequacy of traditional approaches for modern supply chain demands and propose Industry 4.0 technologies like the IoT and cloud computing to improve reverse logistics and circular economy development. De Giovanni [2022] underscores blockchain's advantages for circular economy advancement, including transparency, traceability, visibility, and security, resulting in enhanced enterprise efficiency.

Rane et al. [2021] emphasize environmental sustainability's importance in supply chain management for green supply chain development. The integration of blockchain and the IoT stands as a pivotal factor in fostering this development. Mubarik et al. [2021] investigate blockchain's influence on green supply chain practices, revealing its positive impact on environmental practices, demand and supply planning, reducing overproduction, and enhancing cost savings. Feng et al. [2022] identify green supply chain innovation (GSCI) as an innovative approach on the part of manufacturers that uses digital technologies to incorporate environmental concerns into their supply chain management. Implementing digital technologies enhances green supply chain management (GSCM) performance by improving internal environmental management, green procurement, customer collaboration, inventory recovery, and eco-design.

Scholars also highlight the positive influence of supply chain digitalization on social welfare. For instance, Wang et al. [2022] contend that incorporating blockchain technology into supply chains enhances waste recycling and elevates social welfare levels within enterprises. Economic improvements are also realized due to blockchain implementation. Krishna et al. [2022] emphasize enhanced productivity and customer satisfaction resulting from supply chain digitalization. Yang et al. [2022] illustrate how enterprises adopt advanced IT technologies, like AI and blockchain, to ensure robust supply chain operations, leading to IT development and positive impacts on supply chain and enterprise sustainability.

Tseng et al. [2022] assert that digitalization and reverse supply chain practices enhance sustainable efficiency and enterprise benefits. Munir et al. [2022] highlight blockchain's positive impact on economic, environmental, and social performance. Ma and Hu [2022] underline blockchain's role in optimizing supply chains, boosting economic, social, and environmental outcomes. Pratapa et al. [2022] explore digital solutions for enhancing environmental sustainability in enterprises. Digital technology integration catalyzes enterprise transformation.

Difrancesco et al. [2022] describe blockchain's influence on supply chain performance and transformation. Ijuin et al. [2021] affirm digitalization's positive effect on supply chain management and environmental concerns.

Papanagnou's [2022] article addresses the intricacies of closed supply chains, highlighting the IoT's potential to mitigate inventory-related costs and disruptions. Kazancoglu et al. [2022] establish blockchain's role in enhancing supply chain resilience. Pathak et al. [2022] explore supply chain digitalization for optimization and positive outcomes.

Sutawijaya and Nawangsari [2020] examine environmental management in supply chains, revealing the substantial influence of Industry 4.0 on green supply chain implementation. Gayialis et al. [2022] advocate for an Industry 4.0-based system to enhance service supply chain management. Krstić et al. [2022a] confirm that modern foreign technologies enhance logistics efficiency.

Potential barriers can impede the adoption of blockchain technology and other digital tools in supply chains. Bajar et al. [2022] classify obstacles into operational, strategic, technical, financial, infrastructure, and governmental categories for blockchain implementation. Yu et al. [2022] investigate blockchain's influence on environmental concerns and the global supply chain, highlighting its potential to offer security, transparency, and traceability solutions.

However, the study of the impact of digitalization on the reverse supply chain still requires a more detailed analysis and study of various aspects of this process. With this in mind, the purpose of this article is to study the role of digitalization in the reverse supply chain, as well as to analyze its impact on various aspects of the economy, including efficiency, sustainability, innovation, and competitiveness. The research aims to answer the following questions: (i) Which academic publications have the greatest impact on reverse supply chain digitalization? (ii) Which authors are leading in publishing research on this topic? (iii) In which countries is there a particular interest in research on reverse supply chain digitalization? (iv) What are the main topic categories covered by research in this area? (v) How often are papers related to the digitalization of the supply chain cited? (vi) What are the most commonly used terms when analyzing research on the relevant topic?

The contribution of this article, which distinguishes it from other studies, is as follows: (1) This study contributes to the literature on the digitalization of the reverse supply chain. (2) The study reflects the processes of digitalization of the reverse supply chain in various industries, showing their importance, and therefore increasing the level of efficiency of logistics processes.

The rest of the manuscript is organized as follows: Section 2 presents the methodology for searching and analyzing publications on the digitalization of the reverse supply chain. Section 3 presents the results of the analysis and scientific mapping. It lists the most representative journals, authors, countries, institutions and organizations, subject categories, citations, and key terms. Section 4 contains a discussion of the research results. Section 5 contains conclusions, a discussion of the study's limitations, and potential avenues for future research.

MATERIALS AND METHODS

The bibliometric analysis investigates publications related to the digitalization of the reverse supply chain. This approach includes productivity analysis and network analysis applied to a dataset retrieved from the Scopus database to identify collaborations between authors, organizations, and countries. This study

developed a search for documents related to digitalization in sustainable supply chains to identify studies relevant to the topic. The search terms were based on the digitalization of the reverse supply chain, as shown in Table 1. Use of the SCOPUS database was selected as the search strategy because SCOPUS is a prestigious and significant repository for research of high importance and global relevance.

Table 1. List of keywords used for the literature search

Groups	Search for items
Digitalization	"digitalization" OR "digital transformation" OR "digital technologies" OR "digital innovation" OR "digital supply chain" OR "digital strategy" OR "digital society" OR "Blockchain" OR "Blockchain technology" OR "Internet of Things"
Reverse supply chain	"reverse supply chain" OR "reverse logistics" OR "closed-loop supply chain" OR "CLSC" OR "closed loop supply chain" OR "closed-loop supply chain management" OR "remanufacturing" OR "green supply chain"
Searched Equation	TITLE-ABS-KEY ("digitalization" OR "digital transformation" OR "digital technologies" OR "digital innovation" OR "digital supply chain" OR "digital strategy" OR "digital society" OR "Blockchain" OR "Blockchain technology" OR "Internet of Things") AND TITLE-ABS-KEY ("reverse supply chain" OR "reverse logistics" OR "closed-loop supply chain" OR "CLSC" OR "closed loop supply chain" OR "closed-loop supply chain management" OR "remanufacturing" OR "green supply chain") AND (EXCLUDE (AFFILCOUNTRY,"Russian Federation")) AND (LIMIT-TO (DOCTYPE,"ar")) AND EXCLUDE (PUBYEAR,2023)) AND (LIMIT-TO (LANGUAGE,"English")) AND (LIMIT-TO (SUBJAREA,"BUSI") OR LIMIT-TO (SUBJAREA,"ECON") OR LIMIT-TO (SUBJAREA,"SOCI") OR LIMIT-TO (SUBJAREA,"DECI") OR LIMIT-TO (SUBJAREA,"ENVI"))

The search of the Scopus database yielded two hundred and ninety-seven (297) documents. Certain articles were selected for research and analysis using four filters. The main stages of the selection process are shown in Figure 1.

The first filter concerned the exclusion of articles published in or related to the Russian Federation. This decision was made in light of the war and aggression launched by Russia against Ukraine. As a result, 8 articles were excluded.

At the next stage (using the second filter), all publications other than articles were excluded: reviews, conference papers, book chapters, books, etc. As a result, 146 publications were excluded and 145 articles were obtained.

The third filter removed articles published in 2023 and not in English (25 such articles were found).

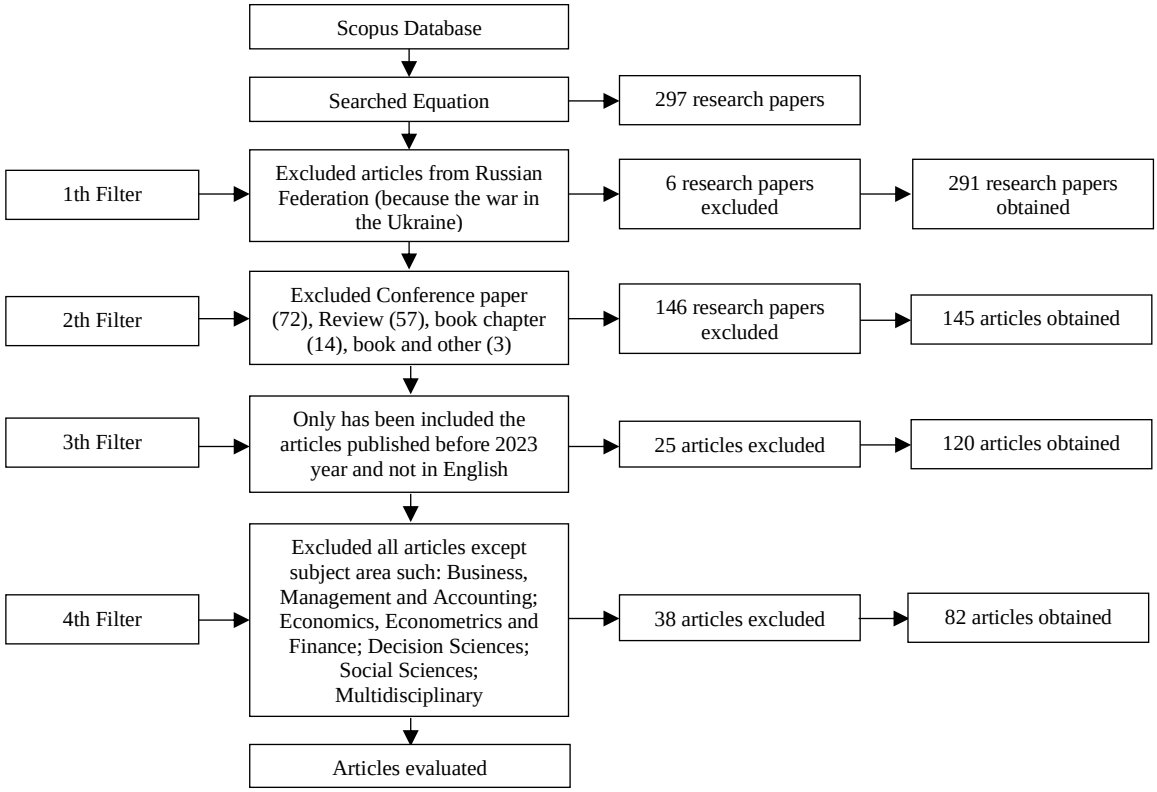

Fig. 1. Research methodology.

The fourth filter excluded subject areas that were not relevant to the research area. As a result of this filter, 38 articles were excluded. After applying this last filter, 82 articles were obtained, on the basis of which the main study was conducted.

The obtained articles were downloaded to MS Excel for analysis and visualization of information using VOSviewer software.

RESULTS

Publications by year

This study examines articles published over the past ten years, from 2013 to 2022. The number of documents per year is depicted in Figure 2. The number of publications began to increase in 2017, with the peak observed in 2022, with 37 articles. The ARIMA model was employed to forecast the volume of documents and analyze publication trends. The forecast for future publications (from 2023 to 2033) is as follows: 40, 43, 46, 49, 52, 55, 58, 61. Considering alternative forecasts (positive and negative), we can assert that the predicted rate of growth in the number of future publications in this field varies.

Journals

A total of 82 articles were published in 44 journals. In general, this shows that interest in research on the digitalization of the reverse supply chain is gradually growing in academia. In terms of quantitative indicators, 34 journals (77%) published 1 article, 6 journals (14%) published 2–3 articles, and 4 journals (9%) published more than 4 articles.

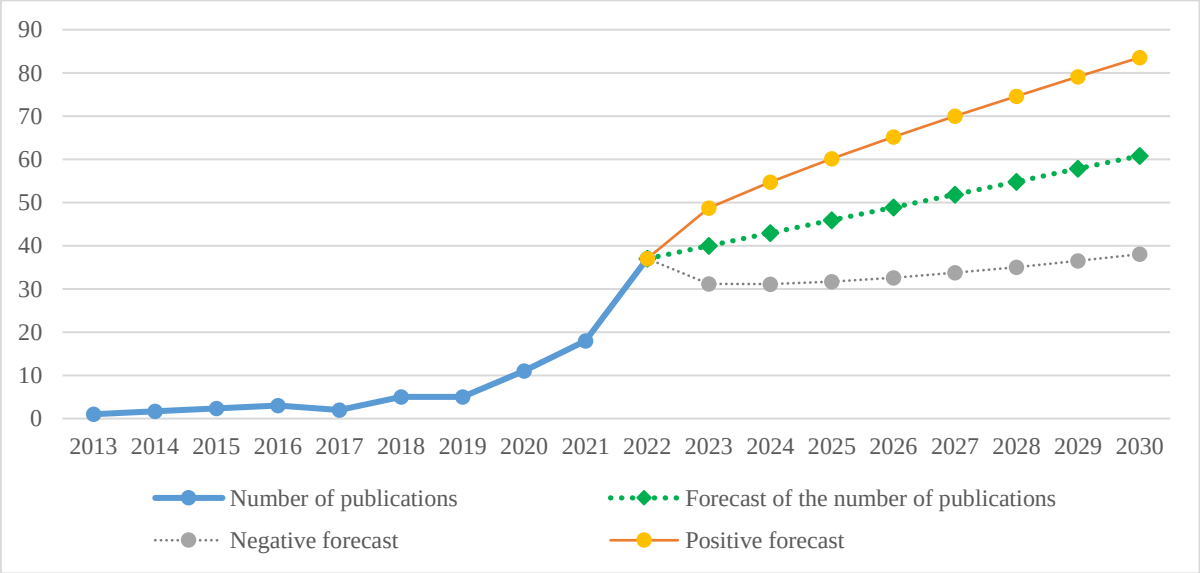

Fig. 2. Number of publications and cumulative total by year with a forecast until 2030.

In addition, the top 10 most productive journals in terms of the number of articles published on the digitalization of the reverse supply chain were identified. Table 2 shows the top 10 most productive journals, as well as information about the publisher, Scimago Journal Rank-SJR 2021 and H-index 2021, subject area and category.

The top 10 journals published 44 articles, which is 53.7% of the total number of articles in the study. Most articles were published in the journal Sustainability (16 articles), followed by Business Strategy And The Environment (5 articles), the International Journal Of Production Economics (5 articles), the Journal Of Cleaner Production (4 articles), Management Of Environmental Quality: An International Journal (3 articles) and Transportation Research Part E: Logistics And Transportation Review (3 articles).

Table 2. Top 10 most productive journals on the digitalization of the reverse supply chain

++++++++++	Journal	Publisher	№ of Publ	SJR-2021	H-Index 2021	Subject Area and Category
1	Sustainability Switzerland	Multidisciplinary Digital Publishing Institute	16	0.664	109	Energy Engineering and Power Technology (Q2), Renewable Energy, Sustainability and the Environment (Q2), Environmental Science (miscellaneous) (Q2), Management, Monitoring, Policy and Law (Q2), Geography, Planning and Development (Q1)
2	Business Strategy And The Environment	Wiley-Blackwell	5	2.241	115	Business and International Management (Q1), Strategy and Management (Q1), Management, Monitoring, Policy and Law (Q1), Geography, Planning and Development (Q1)
3	International Journal Of Production Economics	Elsevier	5	2.808	197	Business, Management and Accounting (miscellaneous) Management Science and Operations Research (Q1), Economics and Econometrics (Q1), Industrial and Manufacturing Engineering (Q1),
4	Journal Of Cleaner Production	Elsevier	4	1.921	232	Strategy and Management (Q1), Renewable Energy, Sustainability and the Environment (Q1), Industrial and Manufacturing Engineering (Q1), Environmental Science (miscellaneous) (Q1)
5	Management Of Environmental Quality: An International Journal	Emerald Publishing	3	0.816	42	Biochemistry, Genetics and Molecular Biology (miscellaneous) (Q2), Management, Monitoring, Policy and Law (Q1), Public Health, Environmental and Occupational Health (Q2)
6	Transportation Research Part E: Logistics And Transportation Review	Elsevier	3	2.835	122	Business and International Management (Q1), Management Science and Operations Research (Q1), Civil and Structural Engineering (Q1), Transportation (Q1)
7	Annals Of Operations Research	Springer Nature	2	1.165	111	Decision Sciences (miscellaneous) (Q1), Management Science and Operations Research (Q1)
8	IEEE Transactions On Engineering Management	IEEE	2	0.881	97	Strategy and Management (Q2), Electrical and Electronic Engineering (Q1)
9	International Journal Of Physical Distribution And Logistics Management	Emerald Publishing	2	1.950	117	Management of Technology and Innovation (Q1), Transportation (Q1)
10	International Journal Of Production Research	Taylor & Francis	2	2.780	153	Strategy and Management (Q1), Management Science and Operations Research (Q1), Industrial and Manufacturing Engineering (Q1)

If we analyze the publishers, the top 10 journals include Elsevier (3 journals with 12 articles) and Emerald Publishing (2 journals with 5 articles).

The subject categories of the journals in SJR were: Business and International Management (Q1), Strategy and Management (Q1), Management, Monitoring, Policy and Law (Q1), Management Science and Operations Research (Q1), Geography, Planning and Development (Q1), Civil and Structural Engineering (Q1), Transportation (Q1). These subject categories have a citation indicator that is higher than the average for cited documents, indicating that the articles published in these journals have a high impact and are frequently cited.

Authors

The top 10 most productive authors with the highest number of publications were identified, as were those who most frequently appeared as the first author (Table 3). First place was taken by Gupta, USA, with four publications on the digitalization of the reverse supply chain, but he

is not the first author of any of the publications. Yu, China, is in second place, also with 4 publications, but in one of them, he is the first author. Next are Khan and Krstić with 3 published articles, and in all 3 articles, they are the first authors. Sarkis has 3 publications but is the first author of only 1 article. Agnusdei, Miglietta and Tadić have 3 publications each but are not the first authors of any of them. Charnley has 2 published articles but is the first author of only 1 article. Hu has 2 published articles, but he is not the first author of either of them.

Table 3. Top 10 most productive authors on the digitalization of the reverse supply chain

No.	Name of Author	Country of Author	Number of Publications	Number of Publications as the First Author
1	Gupta, S.M.	USA	4	0
2	Yu, Z.	China	4	1
3	Agnusdei, G.P.	Italy	3	0
4	Khan, S.A.R.	China	3	3
5	Krstić, M.	Serbia	3	3
6	Miglietta, P.P.	Italy	3	0
7	Sarkis, J.	USA	3	1
8	Tadić, S.	Serbia	3	0
9	Charnley, F.	UK	2	1
10	Hu, J.	China	2	0

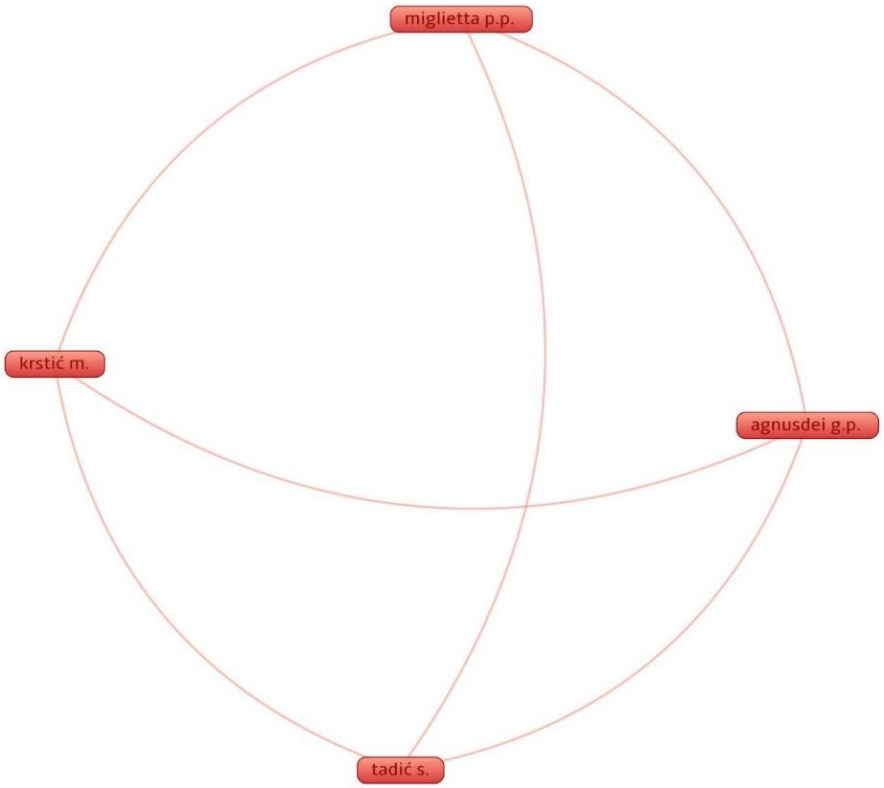

Fig. 3. Collaboration of authors in the study of the digitalization of the reverse supply chain (created with VOSviewer).

Countries, institutions, organizations

In terms of countries, the number of publications on the digitalization of the reverse supply chain was determined according to the Scopus database (see Figure 4). The study determined that the country with the largest number of publications is China, with 21 publications and 25.6% of the total analyzed articles. The United States is in second place with 16 articles (19.5%), followed by the United Kingdom, with 11 articles (13.4%), India, with 10 articles (12.2%), Pakistan, with 7 articles (8.5%), France and Italy, with 6 articles (7.3%),

Sweden, with 5 articles (6.1%), and Finland and Malaysia, with 4 articles (4.9%).

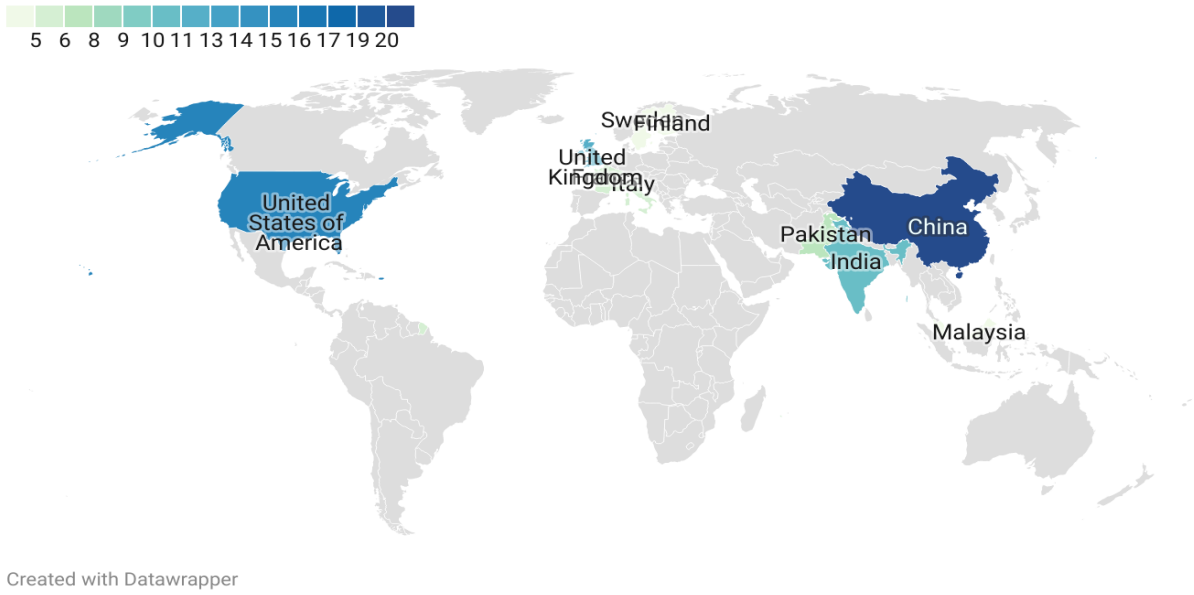

Fig. 4. Network of authors' cooperation in research on the digitalization of the reverse supply chain.

Figure 5 presents three correlation groups that show the extent of collaboration between authors from different countries on research articles. India, China, and Germany represent the clusters with the highest correlation due to the widespread collaboration of authors from these countries.

Figure 6 provides an analysis of cooperation between countries using density visualization.

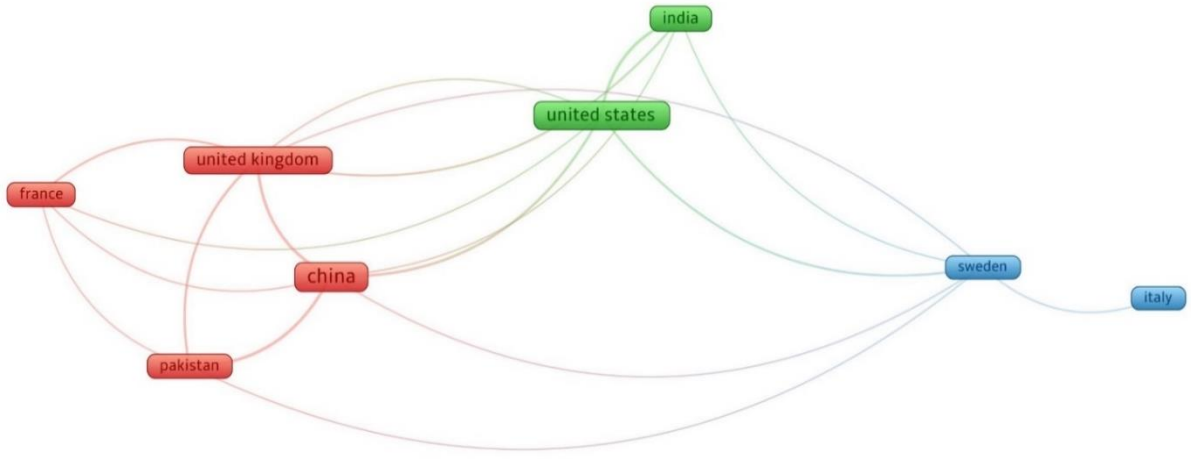

Fig. 5. Network of cooperation between countries in research on the digitalization of the reverse supply chain (created using VOSviewer).

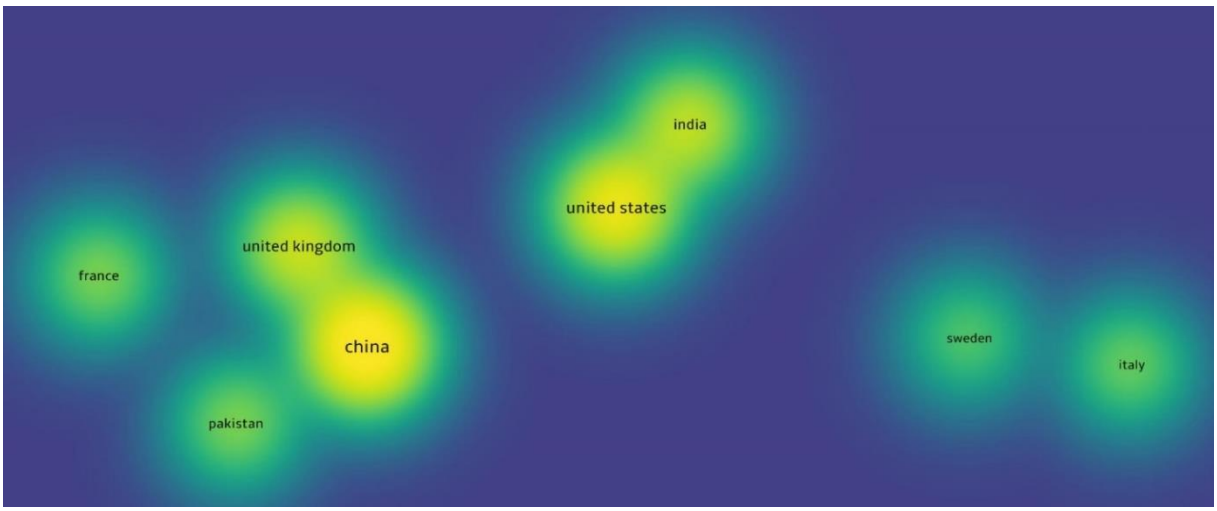

Fig. 6. Analysis of representative countries by topic over time with density visualization (created using VOSviewer)

The institutions and universities with the largest number of articles were also studied (see Table 4). Worcester Polytechnic Institute (USA), with 4 published articles, ranks first in the top 10. It is followed by Northeastern University (USA) and Chang'an University (China) with 4 publications each. The number of articles published by the universities and institutions in the top 10 (6% of the 160 institutions that published articles) accounts for 15.5% of the total number of articles published by all institutions worldwide. The remaining 84.5% were published by instutions that had only produced one (60.4%) or two articles.

Table 4. Top 10 most productive institutions in the digitalization of the reverse supply chain

No.	Funding	Country	Articles
1	Worcester Polytechnic Institute	USA	4
2	Northeastern University	USA	4
3	Chang'an University	China	4
4	Ministry of Education China	China	3
5	Universita del Salento	China	3
6	University of Belgrade	Serbia	3
7	Ilma University	Pakistan	3
8	Xuzhou University of Technology	China	3
9	The Business School	USA	3
10	Beijing Key Laboratory of Urban Spatial Information Engineering	China	2

Table 5 shows the 10 largest funding sources with the highest number of sponsored articles related to the digitalization of the reverse supply chain. The main funding sponsor is the National Natural Science Foundation of China, with 13 funded articles, which corresponds to 17% of all articles. The regions with the highest number of institutions sponsoring research related to the digitalization of the reverse supply chain are China, with 5 institutions, and the EU, with 2 institutions.

Table 5. Breakdown of items by financing entities

No.	Funding	Country	Articles
1	National Natural Science Foundation of China	China	13
2	Engineering and Physical Sciences Research Council	United Kingdom	4
3	Fundamental Research Funds for the Central Universities	China	4
4	European Commission	EU	3
5	Ministry of Education of the People's Republic of China	China	3
6	Basic and Applied Basic Research Foundation of Guangdong Province	China	2
7	Horizon 2020 Framework Programme	EU	2
8	Ministry of Higher Education, Malaysia	Malaysia	2
9	Ministry of Science and Technology, Taiwan	Taiwan	2
10	Research Grants Council, University Grants Committee	China	2

Analysis of subject categories

The analysis identified thematic categories in the research on the digitalization of the reverse supply chain (Figure 7). The results show that 44 articles (18.8%) were published on the topic of Business, Management and Accounting . The top 5 categories also include Engineering, with 38 articles (15.9% of publications), Environmental Science, with 37 articles (15.5% of publications), Social Sciences, with 34 articles (14.2% of publications), and Decision Sciences, with 24 articles (10% of publications).

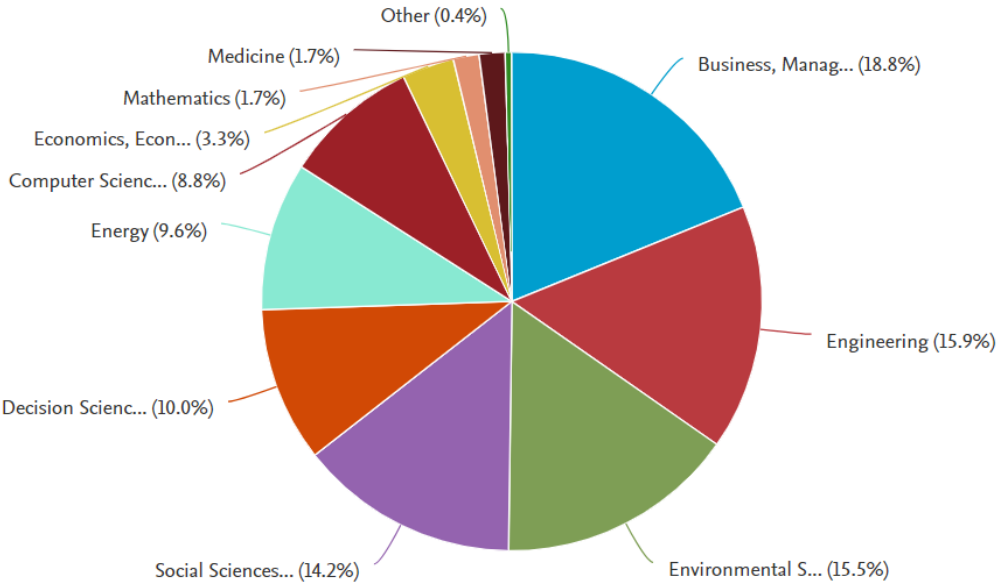

Fig. 7. Thematic categories in which articles on the digitalization of the reverse supply chain are most often published

Analysis of citations

The most cited articles are presented in Table 6. The table also shows the country, FWCI, Institution, SJR-2021, SDGs 2023, SciVal Topic, and main topic of each article. Kouhizadeh and Sarkis [2018] published the most cited article on the topic under study. Their paper discusses in detail the issues of green supply chains and blockchain technology. It has been cited 278 times, which corresponds to 12% of the total number of citations in the Top 10. Camacho-Otero et al. [2018] focused their research on the circular economy. This publication received 161 citations (7%). Khan et al. [2021] consider the role of blockchain technology in circular economy practices and its impact on the eco-environmental performance of an organization. The number of citations of this study is 127 (5%). Alcayaga et al. [2019] describe the relationship between the Internet of Things, business models, and the circular economy. This publication received 119 citations (5%). Centobelli et al. [2022] propose an integrated Triple Retry framework for the development of cyclic blockchain platforms. Their study has received 86 citations (4%).

Analyzing the SDGs, the main goals for research on the digitalization of the reverse supply chain are: 9 (Industry, innovation and infrastructure), 12 (Responsible consumption and production), 17 (Partnership for the goals), and 8 (Decent work and economic growth).

The analysis of citations by authors is shown in Figure 8.

Table 6. Top 10 publications with the highest number of citations on the digitalization of the reverse supply chain

No.	Authors Title	Times Cited (2014-2023)	FWCI	Institution	Country (1st Author)	Journal	SJR-2021	SDGs 2023 (Goal)	SciVal Topic
1	Kouhizadeh and Sarkis [2018] Blockchain practices, potentials, and perspectives in greening supply chains	278	11,55	Worcester Polytechnic Institute	USA	Sustainability	0.664	9,12	Bitcoin; Ethereum; Internet Of Things
2	Camacho-Otero et tl. [2018] Consumption in the circular economy: A literature review	161	8,14	NTNU Norwegian University of Science and Technology	Norway	Sustainability	0.664	9,12	Platforms; Collaborative Consumption; Peer to Peer
3	Khan et al. [2021b] Industry 4.0 and circular economy practices: A new era business strategies for environmental sustainability	127	20,59	Xuzhou University of Technology	China	Business Strategy and the Environment	2.241	9,12,17	Supply Chain; Environmentally Preferable Purchasing; Green Practices
4	Alcayaga et al. [2019] Towards a framework of smart-circular systems: An integrative literature review	119	6,36	Institute for Integrated Quality Design	Austria	Journal of Cleaner Production	1.921	9	Product-service Systems; Service Economy; Value Co-Creation
5	Centobelli et al. [2022] Blockchain technology for bridging trust, traceability and transparency in circular supply chain	86	38,56	University of Naples Federico II	Italy	*Information and Management*	2.558	9	Bitcoin; Ethereum; Internet Of Things
6	Parry et al. [2016] Operationalising IoT for reverse supply: the development of use-visibility measures	83	9,83	University of the West of England	United Kingdom	*Supply Chain Management*	2.385	9	Product-service Systems; Service Economy; Value Co-Creation
7	Zhang et al. [2018] The 'Internet of Things' enabled real-time scheduling for remanufacturing of automobile engines	82	3,93	Northwestern Polytechnical University	China	Journal of Cleaner Production	1.921	8,9, 12,17	Internet Of Things; Radio Frequency Identification Device; Shopfloor
8	Garrido-Hidalgo et al. [2020] The adoption of Internet of Things in a Circular Supply Chain framework for the recovery of WEEE: The case of Lithium-ion electric vehicle battery packs	81	4,43	Universidad de Castilla-La Mancha	Spain	*Waste Management*	1.741	7,12	E-Waste; Electronic Waste; Electronic Equipment
9	Khan et al. [2021a] Green data analytics, blockchain technology for sustainable development, and sustainable supply chain practices: evidence from small and medium enterprises	71	9,41	Xuzhou University of Technology	China	Annals of Operations Research	1.165	9,12,17	Supply Chain; Environmentally Preferable Purchasing; Green Practices
10	Alqahtani et al. [2019] Warranty and maintenance analysis of sensor embedded products using internet of things in industry 4.0	66	5,49	King Abdulaziz University	Saudi Arabia	International Journal of Production Economics	2.808	9	Warranty; Minimal Repair; Preventive Maintenance

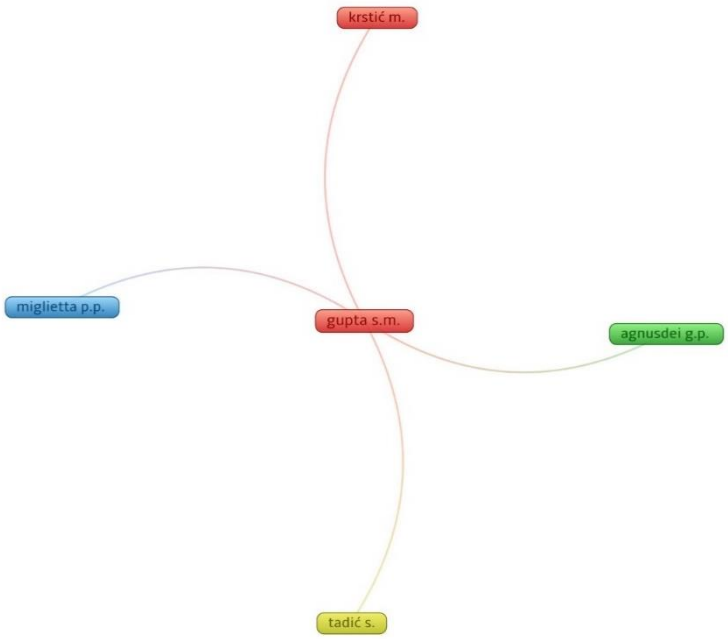

Fig. 8. Analysis of authors' citations in research on the digitalization of the reverse supply chain (created using VOSviewer).

The analysis of co-citations by cited authors makes it possible to identify four clusters. The results of the analysis are shown in Figure 9.

When looking at co-citations by cited sources, as shown in Figure 10, certain clusters can also be identified.

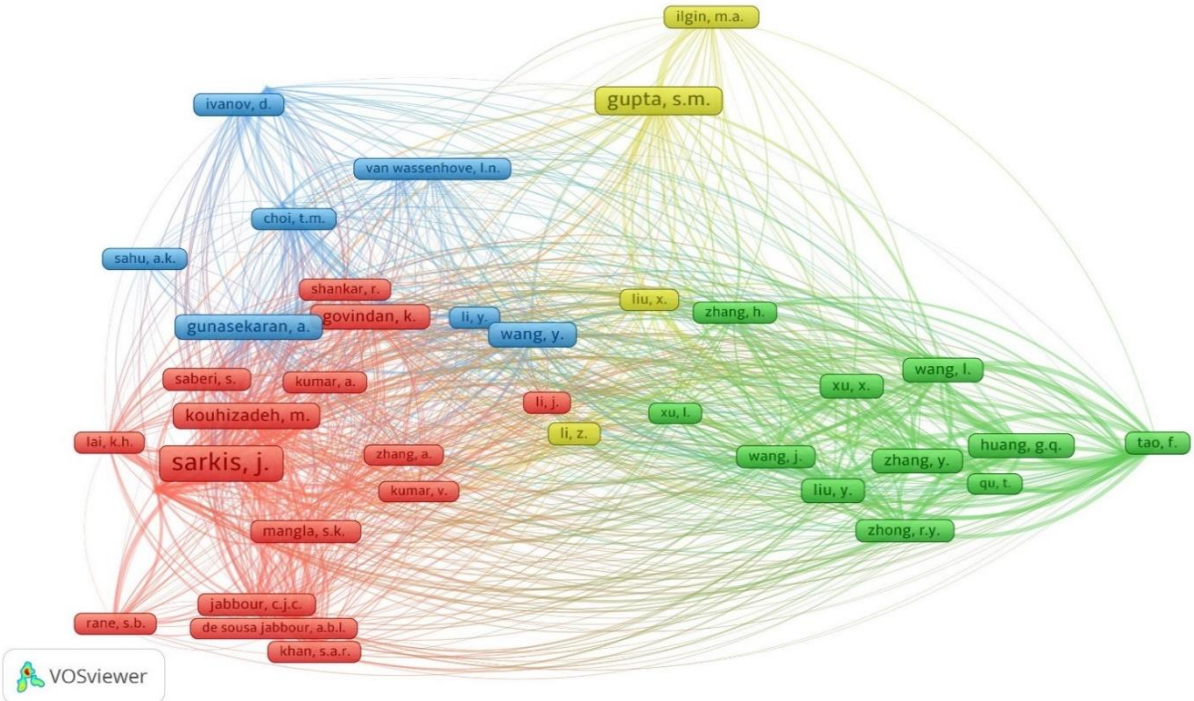

Fig. 9. Analysis of the most frequent co-citations in research on the digitalization of the reverse supply chain (created using VOSviewer).

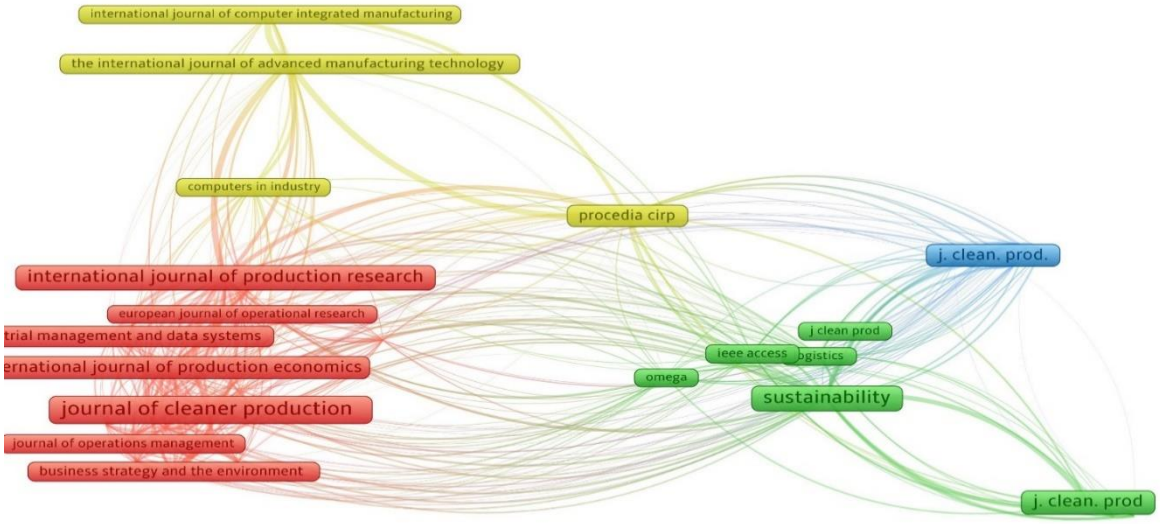

Fig. 10. Analysis of co-citation by cited sources in articles on the digitalization of the reverse supply chain (created using VOSviewer)

Analysis of terms

Analyzing the terms used in the titles and abstracts of manuscripts helps to identify areas of research on a given topic. Figure 11 shows the analysis of common usage for all words in the articles obtained using VOSviewer. The analysis identified three clusters. The first cluster is formed by such keywords as supply chain management and sustainable development. The second cluster contains the terms blockchain and closed-loop supply chain. The third cluster of words used in the selected articles is made up of circular economy, Industry 4.0, and Internet of Things.

Fig. 11. Visualization of keyword sharing (created with VOSviewer)

Figure 12 shows an analysis of the common use of words with overlay visualization. With this visualization, certain periods when keywords were used in research are more visible.

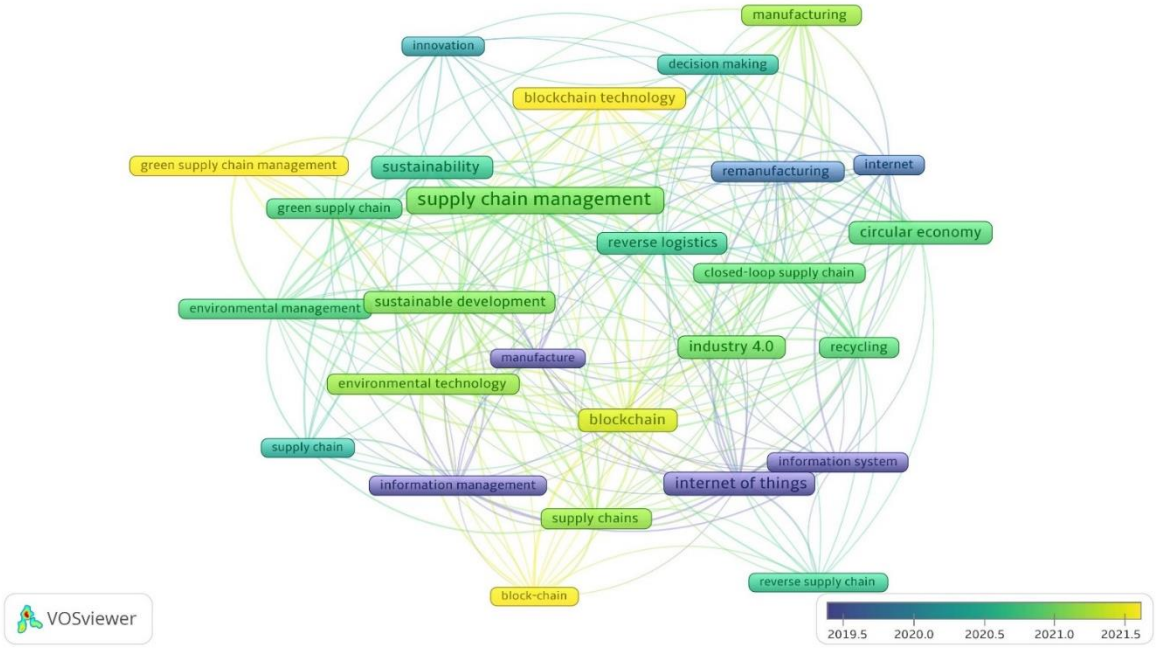

Fig. 12. Analysis of keywords by the density of their use (created using VOSviewer)

DISCUSSION

Beyond these concerns, various scholars delve into other dimensions of the digitalization of the reverse supply chain. Alcayaga et al. [2019] present a strategy employing IoT products for circular practices like reuse and recycling. Joshi and Gupta [2019] explore the IoT's potential in product recovery. Garrido-Hidalgo et al. [2020] suggest a Circular Supply Chain (CSC) framework incorporating digital technologies, including the IoT.

Camacho-Otero et al. [2018] focus on business models for waste reduction and resource reuse, exploring cultural barriers to circular economy adoption. They highlight a lack of awareness and understanding of resources and waste, which hinders acceptance. Zhang et al. [2018] address challenges in resource recovery management, suggesting the IoT as a solution to ensure timely and accurate information for real-time production planning on the shop floor.

Contemporary research addresses the impact of digitalization on remanufactured products. Alqahtani et al. [2019] highlight the IoT's role in providing accurate information about end-product components. Okorie et al. [2020] delve into the emerging field of digital recovery, focusing on recovery 4.0 or intelligent recovery. Niu et al. [2022] study consumer evaluation of remanufactured products with and without blockchain-quality information, investigating incentives for blockchain adoption by suppliers and manufacturers.

Tozanlı et al. [2020] suggest employing embedded IoT products and blockchain for efficient custom disassembly systems of high-tech industrial products, aiming at economic, environmental, and social sustainability. Trujillo-Gallego et al. [2022] employ a dynamic hierarchy of possibilities to analyze the influence of digital technologies and environmental management on environmental performance within the framework of sustainable development.

Fang et al. [2016] highlight the utilization of the Internet of Things for product life cycle data management. Subramoniam et al. [2021] delve into the digitalization of the product life cycle and its implications for product return or recovery.

Franchina et al. [2021] investigate digitalization's role in fostering environmentally friendly behavior across different economic

sectors. In a similar vein, Xia et al. [2020] emphasize the significance of enabling technological innovation through innovative resources within the supply chain and the strategic selection of innovation partners in integrated supply chains.

Krstić et al. [2022b] researched the optimal scenario for an intelligent reverse logistics system to foster a sustainable circular economy and closed supply chains, involving Industry 4.0 technologies like the IoT, autonomous vehicles, and AI. Similarly, Wei et al. [2021] suggest addressing e-commerce reverse logistics challenges using IoT-driven management strategies.

Bag et al. [2021] analyze resource involvement in digitalizing procurement for enhanced enterprise productivity. Lerman et al. [2022] reveal smart supply chains' positive contribution to environmental productivity. Cheshmberah and Beheshtikia [2020] affirm digitalization's positive influence on supply chain management. Dev et al. [2021] explore stimulus investments, additive manufacturing, and supply chain sustainability for green product diffusion in Industry 4.0.

In the context of the digitalization of the reverse supply chain, interesting opportunities arise for transforming traditional processes and introducing new innovative approaches. The use of digital technologies, such as the Internet of Things (IoT), data analytics, artificial intelligence (AI), and blockchain, can accelerate and improve the efficiency of the reverse supply chain. This opens up new opportunities for sustainability, optimizing return processes, reducing waste, and improving environmental responsibility.

In addition, digital technologies facilitate the collection, analysis and processing of large amounts of data, which facilitates forecasting, the identification of trends and the improvement of decision-making in the reverse supply chain. The use of digital tools also enables greater transparency, traceability, and automation of processes, which contributes to increased efficiency and reduced costs.

In general, the digitalization of the reverse supply chain opens up new horizons for process optimization, sustainability, and service quality improvement. This is an important area that requires further research and the implementation of innovative solutions to achieve a sustainable and efficient reverse supply chain.

CONCLUSIONS

This study analyzed the digitalization of the reverse supply chain and identified various opportunities to optimize processes, support sustainability, and reduce waste. Particular attention was paid to the use of digital technologies such as the IoT, AI, and blockchain, which open up new perspectives for inventory management and improved returns processes.

However, the study did have some limitations, such as using only the Scopus database and a limited time frame. Future research in this area could analyze the impact of digitalization on the sustainability, efficiency, and environmental performance of the reverse supply chain. It is also worth exploring the challenges and opportunities associated with the introduction of blockchain technologies and advanced data analysis in this area.

In essence, the article aims to contribute to the existing body of knowledge by shedding light on the transformative potential of digital technologies in reverse supply chain management and by advocating for the adoption of innovative solutions to achieve a more sustainable and efficient reverse supply chain system.

Digital technologies can help improve the efficiency, sustainability, and environmental responsibility of reverse supply chain management, creating new opportunities to support sustainable development in this area. The results obtained can be used as a basis for further research and implementation to optimize processes and increase the efficiency of supply chain management, taking into account sustainability and environmental impact.

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