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The role of blockchain technology in the transition toward the circular economy: Findings from a systematic literature review

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ABSTRACT

The circular economy (CE) has emerged as a paradigm to protect the environment and the well-being of future generations. In parallel, Blockchain technology (BC) has emerged as a critical enabler for accelerating the transition toward a CE. In order to understand and summarize prior research on the role of BC in the CE, we conducted a systematic literature review (SLR) of 70 seminal articles published before July 2022. Six main themes emerged: a) CE approaches and practices, b) BC and the integration of the Internet of Things (IoT), c) sustainable supply chain management, d) BC and the CE in the COVID-19 era, e) sector-specific BC applications, and f) barriers to BC adoption in the CE. Furthermore, we develop a comprehensive framework that integrates stakeholders, strategies and practices, industrial sectors and a BC-enabled CE.

1. Introduction

Global interest in the concept of a “circular economy” (CE) has grown in recent years (Amato, 2022; Chauhan *et al.*, 2021; Eraky *et al.*, 2022; Ghisellini *et al.*, 2016; Reichwald *et al.*, 2022). According to Kirchherr *et al.* (2017, p.229), the CE can be defined “as an economic system that replaces the ‘end-of-life’ concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond) to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations”. In light of dwindling resources, consumption must be balanced with economic growth and environmental protection (Murray *et al.*, 2017). With existing production approaches, a large amount of waste is generated. The transition toward a CE model, wherein materials, components, and products are kept for as long as possible in circulation (Bovea *et al.*, 2018), is a key step to addressing existing economic, environmental, and social issues, thereby establishing a resilient and sustainable economy (Chiaroni *et al.*, 2022; Heisel and Rau-Oberhuber, 2020). Furthermore, the realization of a CE offers growth prospects and reduces waste while optimizing resource consumption (Kirchherr *et al.*, 2017; Kristensen and Mosgaard, 2020). Reduce, Reuse, and Recycle, otherwise known as the 3Rs, were the initial guiding principles of the CE (Kristoffersen *et al.*, 2020). As a result, the first CE frameworks focused on these three pillars. Over time, these three principles evolved into the 6Rs and eventually the 9Rs, which stand for Reduce, Reuse, Recycle, Remanufacture, Redesign, Recover, Refuse, Refurbish, and Repurpose (Škrinjarić, 2020). There is still much confusion regarding the industrial applications of CE. As a paradigm shift in the relationship of human society with nature, the CE aims to close material and energy flows, mitigate resource depletion, and foster sustainable development at the micro (i.e., organization), meso (i.e., industrial network), and macro levels (i.e., city, region, state) (Prieto-Sandoval *et al.*, 2018). The CE concept has been hailed as a replacement for the traditional linear economic model and a vital agenda for implementing more ethical and sustainable business practices (Kirchherr *et al.*, 2017). By reducing resource waste and emissions, the CE constitutes a novel strategy that promotes sustainability

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(Geissdoerfer *et al.*, 2017). Therefore, cleaner manufacturing practices and implementing CE principles have led organizations to become more proactive in preserving the value of resources and products for the longest possible period while simultaneously minimizing waste (Kayikci *et al.*, 2022).

Implementing CE needs significant structural changes and the removal of several obstacles (Cohen and Gil, 2021). For instance, CE adoption may be accelerated by overcoming supply chain-related issues, including monitoring material flows, product traceability, and collaborative supply chain relationships. The recent emergence of Industry 4.0 offers substantial support for the CE transition (Abdul-Hamid *et al.*, 2021; Chauhan *et al.*, 2021; Cheah *et al.*, 2022; Suppipat and Hu, 2022). Conceptually, Industry 4.0 represents a paradigm shift in manufacturing activities, integrating CE principles with conventional business models through new technologies to maximize manufacturing efficiency and flexibility and foster cleaner production (Agrawal *et al.*, 2022; García-Muiña *et al.*, 2021). Several technological advancements linked with Industry 4.0, such as the Internet of Things (IoT), artificial intelligence, big data analytics, augmented reality, virtual reality, and additive manufacturing, accelerate the CE transition by enhancing the current manufacturing infrastructure and safeguarding economic and environmental sustainability (Khan et al., 2021; Rejeb et al., 2022). Besides these innovations, blockchain technology (BC) can play a critical role in achieving the CE vision (Böckel et al., 2021; Gong et al., 2022a, 2022b). Using BC, organizations can establish new circular business models by monitoring the movement of materials, components, and products throughout the supply chain, enhancing information immutability and transparency and promoting innovation (Böhmecke-Schwafert *et al.*, 2022; Kouhizadeh *et al.*, 2020). BC is defined as a "digital, decentralized and distributed ledger in which transactions are logged and added in chronological order with the goal of creating permanent and tamperproof records" (Treiblmaier, 2018, p. 547). Since BC is designed as a distributed ledger, a high-performance data center infrastructure is not needed to develop a secure and trustworthy network. Moreover, BC involves many parties, and cryptographic algorithms are used to verify the data-sharing procedures (Rejeb, Keogh, Simske, *et al.*, 2021). Currently, data stored and maintained on BC is very secure. In the BC system, once a block has been introduced and authenticated by all users, it is impossible to perform any modifications or adjustments (Treiblmaier, 2019). Thus, the technology is expected to disrupt current transactional processes, paving the way for various applications in several fields (Fosso Wamba *et al.*, 2020). Because of its distributed and decentralized nature, BC helps ensure the integrity and authenticity of transactions within its ecosystem (Rejeb, Keogh, Simske, *et al.*, 2021). Any data, including events, records, and transactions, can be stored in BC using well-defined mechanisms for information security and updates (Kouhizadeh *et al.*, 2020). In the CE context, BC can be used to relieve some of the constraints that prevent the CE from being properly implemented (Rejeb, Zailani, *et al.*, 2022). With the capability to provide consistent information to all supply chain partners, BC has the potential to improve trust among CE stakeholders (Alkhudary et al., 2022; Rejeb et al., 2022; Bhubalan *et al.*, 2022).

While the literature on the role of BC in the CE transition has recently witnessed a significant increase in studies focusing on the BC-CE nexus, there is a need for a detailed review and analysis of the current knowledge body. So far, only a few review studies have been conducted to report the potential of BC for the CE transition (see Table 1). For example, Böckel *et al.* (2021) conducted a systematic review and qualitative analysis of 57 publications to examine the intersection of BC and the CE. Alves *et al.* (2021) reviewed the literature on BC and IoT applications in the traceability of the textile and clothing value chain and their potential to advance the CE therein. In a broader context, Khan *et al.* (2022) reviewed 91 journal articles published between 2016 and 2021 to identify the present and emerging trends in the CE field. The findings indicated the importance of BC for improving productivity and reducing environmental impact. Gebhardt *et al.* (2021) reviewed the relationship between Industry 4.0, the CE, and supply chain collaboration. According to the authors, BC is among the most talked-about technologies facilitating information sharing, joint planning, and decision-making. Finally, Demestichas and Daskalakis (2020) performed a detailed review of leading information and communication technologies (ICT) solutions. They concluded with a great emphasis on BC's role in helping companies switch to the CE. Despite the important contributions of the previous reviews, there has not been any recent analysis of the state-of-the-art in the BC field, in which Scopus (Elsevier's abstract and citation database which covers more than 34,000 peer-reviewed journals) and Web of Science (an interdisciplinary database that includes records from numerous bibliographic databases) have been used. Furthermore, the main themes of BC application in the CE are unclear, and a comprehensive framework to guide further research is missing. To close these research gaps, an SLR must systematize the current literature and build a thorough conceptual framework for future research. Compared to previous review studies (Table 1), the novelty of this work resides in its exclusive thematic synthesis of BC-related studies in the CE context and its elucidation of many promising avenues for future research that need immediate attention in light of the increasing calls for mitigating the alarming threats of climate change, lessening the destructive effects of industrial activities on the environment, and preserving natural resources. As part of our investigation, we answer the following research questions:

- What is the current state of the literature at the intersection of BC and the CE (e.g., the evolution of scholarly production, most relevant journals, methods applied)?
- What are the main themes discussed in the literature regarding the role of BC in the CE transition?
- What are the current research gaps in the reviewed literature?

The structure of the paper is as follows. Section 2 presents the research method and the scope of the review. Section 3 discusses the descriptive results and the main themes scrutinized in the literature. Section 4 provides a framework and suggests several research directions for future studies based on the review's findings. Finally, Section 5 briefly concludes the paper.

2. Research method

The SLR approach was followed in this investigation. Future researchers will be able to replicate the study's findings thanks to this strategy. In the SLR approach, the first step is to plan and conduct a thorough search of pertinent publications (Martinez-Marquez *et al.*, 2022; Rejeb, Keogh, Leong, *et al.*, 2021). The research team then identifies the target journals, defines the eligibility criteria, and evaluates the selected studies. Finally, the findings of the review are reported. The current work consists of four major phases. The first phase defines the search keywords and the eligibility criteria. The research team then used popular academic databases to extract pertinent publications and performed a rigorous quality review of these publications using these criteria. The results of the SLR were reported in the final phase (Kushwah *et al.*, 2019; Tranfield *et al.*, 2003).

2.1. Planning the review

This work aims to examine and comprehend the current academic literature at the confluence of BC and the CE. Following the recommendations of Kushwah *et al.* (2019), we consulted two major academic databases to formulate the search query: Scopus and the Web of Science. Furthermore, we supplemented the findings from these databases by conducting an additional search in Google Scholar to ensure the accuracy and completeness of the search results. While the focus was mainly on the CE, we also included other related areas like sustainability, reverse logistics, and closed-loop supply chains if they addressed

Table 1
Main reviews related to BC applications in the general context of the CE.

Study	Scope	Research problem	Methodology	Sample and year coverage	Main results related to BC
(Böckel *et al.*, 2021)	BC and the CE	Identify the differences in research and practice concerning BC used for a CE	Systematic literature review	57 2016-2020	Three crucial outcomes: 1- The research lacks a clear terminology of BC types, technical characteristics, and benefits. 2- Trust and verification represent key benefits of BC but are difficult to implement. 3- A thorough evaluation of BC's benefits and challenges for the CE and its linkage to sustainable development is essential.
(Alves *et al.*, 2021)	BC and IoT in the textiles and clothing chain	To examine the current state of the art of using BC and IoT to facilitate a circular textiles and clothing value chain and to assess the sustainability of products and stakeholders	Systematic literature review	96 -	BC can be used in numerous approaches for the traceability of products in the textiles and clothing value chain. The integration of BC and IoT in the textiles and clothing value chain can maximize operational efficiency, prevent product damage, and increase transparency.
(Khan *et al.*, 2022)	CE practices	To understand the CE concept and its financial and environmental contributions to firms with conventional business models based on linear consumption	Systematic literature review	91 2016-2021	Digital technologies, including BC, can optimize organizational and environmental performance. CE scholars are required to apply empirical testing in various sectors to understand and encourage more new business models and practices.
(Gebhardt *et al.*, 2021)	Industry 4.0 technologies	To examine the nexus of the CE, supply chain collaboration, and Industry 4.0	Systematic literature review	96 2010-2020	IoT, BC, and cloud systems constitute the most discussed technologies to support information sharing, joint planning, and decision-making activities.
(Demestichas and Daskalakis, 2020)	ICTs in the CE	To review the key ICT solutions for the CE transition	Systematic literature review	63 -	BC enables increased traceability, improved waste management, and secure data management and storage.
(Upadhyay *et al.*, 2021)	BC and the CE	To explore BC's potential for the CE from the perspective of sustainability and social responsibility	Literature review	- -	BC supports the CE by reducing transaction costs, improving supply chain performance and coordination, protecting human rights, and reducing the carbon footprint. There is a need to establish appropriate legislation and policy development to promote trust, combat illicit activities, and prevent hacking.
(Chauhan *et al.*, 2022)	The CE and digital technologies	To summarize studies at the intersection of CE and digital technologies	Systematic literature review	123 2015-2021	BC can support manufacturers to increase control over products until their end-of-life phase. BC reinforces CE strategies and improves the decision-making process. BC and IoT are expected to improve ecosystem partnerships and drive profitable CE implementation.
(Pakseresht *et al.*, 2022)	BC and the CE in the food chain	To provide insights into BC implementations in the food chain and the implications for the CE	Systematic literature review	44 2017-2021	BC can accelerate the CE transition in the food chain by enhancing data utility, increasing supply chain management efficacy, improving eco-efficiency, and strengthening traceability.
(Rusch *et al.*, 2022)	Digital technologies for sustainable product management in the CE	To summarize the existing and potential cases of digital technology applications in sustainable product management	Systematic literature review	186 1989-2021	BC provides greater potential for fostering sustainability and the circularity of resources and products. BC optimizes business operations, facilitates tracking and control, increases circular supply chain transparency, and supports the monitoring of waste and energy flows.
(Jin and Chang, 2022)	BC and environmental management	To review BC applications in environmental management	Systematic literature review and bibliometric analysis	188 2017-2021	BC provides technical support for CE implementation, intelligent waste management, and efficient recycling and product disposals.
(Dantas *et al.*, 2021)	The CE and Industry 4.0	To explore the contribution of the CE and Industry 4.0 to sustainable development goals	Systematic literature review	50 2016-2020	The deployment of BC can help minimize the material and energy flow required for production by better controlling the resources used, thereby lowering the generation of carbon emissions.
(Hennemann Hilario da Silva and Sehnem, 2022)	The CE and Industry 4.0	To explore the paths and challenges associated with the CE and Industry 4.0	Systematic literature review	63 2017-2021	BC's features, such as transparency, traceability, reliability, and safety, can boost material reuse, support upcycling, promote recycling and circularity initiatives, and optimize circular supply chain performance management.

circularity issues. First, a preliminary search in the databases (i.e., Scopus and the Web of Science) was conducted using a few keywords to locate the relevant literature for current work. These keywords were also checked on Google Scholar, and the top 10 pages of results were taken into consideration when generating the updated list of keywords. Second, the research team conducted independent searches in the most prestigious business and management journals to ensure the list included all important keywords. The research team included the keyword "closed-loop" in the list of keywords after observing a correlation between CE studies and those from the closed-loop supply chain fields in the original Google Scholar search.

In order to ensure the integrity of the SLR procedures and avoid any potential biases, a panel of experts was formed. Three experts were on the panel (two professors and a researcher). After consulting with the panel of experts, the research team compiled a keyword list as follows:

(("circular economy" OR "closed-loop" OR "reverse supply chain" OR "durability" OR "eco-efficiency" OR sustainability OR disassembly OR repair OR "eco-design" OR sharing OR "product-service system") AND ("blockchain" OR "block-chain" OR "block chain"))

2.2. Review specification

The criteria for inclusion and exclusion must be established to specify the scope of the investigation (see Table 2). Applying these criteria narrows the search query results and retrieves the most relevant publications. Only papers published in peer-reviewed journals were included in this review since they contain more certified and high-quality knowledge (Rejeb, Suhaiza, *et al.*, 2022) than conference papers, books, chapters, and reports. The study did not include highly technical papers related to BC programming and algorithms, thereby keeping the publication sample manageable. Publications with an engineering and highly technical approach were also filtered out.

2.3. Data collection

The selected keywords were turned into two search strings combined by Boolean operators: AND and OR. The research team then consulted the Scopus and Web of Science databases applying the search query in the title, abstract, and keywords fields. In addition to this search, a search string was used in Google Scholar. The publications were examined up to July 2022, when the searches were conducted. The Scopus database returned 299 publications, whereas the Web of Science search yielded 200 publications. After removing the duplicate studies from the databases, we were left with 380 unique studies. The research team then applied the selection criteria to filter the pool further. As a result, the number of publications was reduced to 123.

Recommendations from the expert panel were then solicited to narrow down the remaining studies. The experts screened the tiles and abstracts against the selection criteria. This task was completed independently by each member of the screening panel to maintain the highest level of objectivity throughout the review process. Afterwards, the panelists shared the publications that made it to the next round. This yielded a total of 92 publications. Next, the panel of experts were tasked with resolving their disagreements and reaching an agreement on the publications that had been shortlisted. At this point, the experts advised the authors to discard publications that did not fit within the scope and focus of the SLR. After that, the research team reviewed the content of the remaining 92 publications to ensure they aligned with the objective of the current review. A total of 62 publications were retained. A large amount of material related to BC applications in supply chain management and logistics was rejected in this phase due to a lack of focus on CE-specific aspects. A backward and forward search was conducted to identify all pertinent cited references and citations to the chosen publications to ensure that no important work was missed. Using this snowballing technique, the research team could locate 12 publications for examination. Eight of these publications were added to the sample based on the expert panel's recommendations.

In the final round, 70 publications were assessed and approved for inclusion by the research team. The research team then collected the bibliographic details of all selected publications. Detailed information on all publications and their thematic classification are available as a supporting file Table S1. Fig. 1 shows the specifics of the SLR procedure.

Table 2
The selection criteria.

Inclusion criteria	Exclusion criteria
• Studies with a specific emphasis on the role of BC in the CE transition • English-speaking studies published until July 2022 • Peer-reviewed journals articles • Studies focusing on BC applications in one or more aspects of the CE (e.g., recycling)	• Studies that mention BC and/or the CE and its aspects without focusing on these concepts explicitly • Books, chapters, conference papers, reports, notes, and editorials • Studies focusing on the technical aspects of BC • Studies with an engineering and technical emphasis

3. Descriptive results

This section details the characteristics of the selected publications. The findings reported in this section evaluate the extant literature based on the annual evolution of scholarly research and the distribution of publications according to source titles and methods used. Researchers may obtain insights into the trend and momentum of the study area by organizing and summarizing the bibliometric profile of the publications. Fig. 2 shows the exponential growth in the literature at the nexus of BC and the CE over the recent years, reflecting the field's immaturity. In the past two years, academic interest in the subject has skyrocketed (2021-

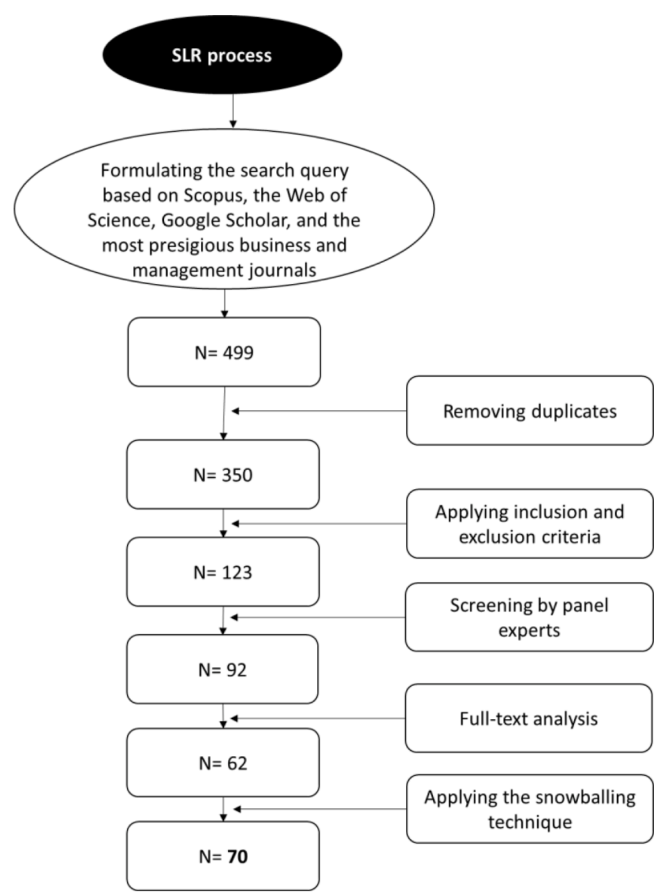

Fig. 1. Selection process.

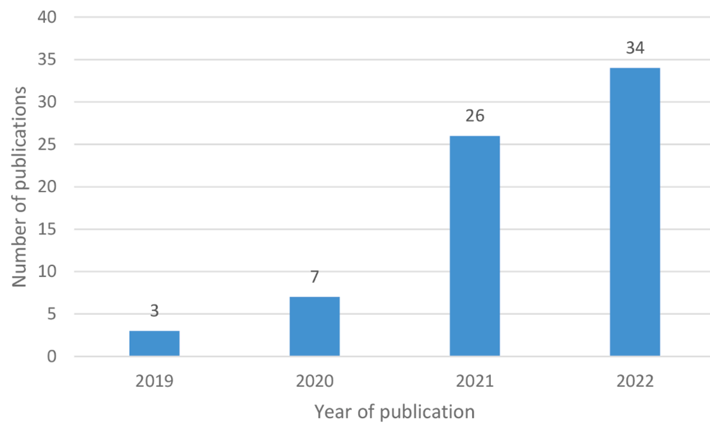

Fig. 2. Year-wise distribution of publications.

2022). The spectrum of journals in which BC-CE research has been published accentuates the observation of heightened academic interest in BC applications in the CE transition (see Table 3). For instance, only eleven journals have published at least two papers in this field. Five of these eleven outlets are associated with the sustainability knowledge field or sustainability-related topics. Fig. 3 classifies the sample of publications according to the research methods applied. The figure reveals that reviews, case studies, and conceptual studies are the prevailing approaches. This fact is evident in every area of rising interest (Holmström Lind *et al.*, 2022). It should be noted that the reviews included in the sample are limited in scope due to their focus on specific aspects of the CE (e.g., Alves *et al.*, 2021; Upadhyay *et al.*, 2021), thus making a sound justification for conducting an exclusive SLR on the role of BC in the CE transition.

4. Thematic analysis

This section provides an overview of the literature and discusses the most prominent themes and subjects. The research team conducted an in-depth review of the existing literature and analyzed each publication's content to provide a thematic summary of their results. Content analysis, which focuses on the systematic categorization, coding, and determination of themes, is commonly applied by researchers to ease the subjective interpretation of data (Hsieh and Shannon, 2005). The first author started by assigning open codes to each selected publication and then grouping related publications together. Subsequently, the research team discussed the open codes to get to an agreement on the classification of the literature. Next, the team combined the common open codes into axial codes and finalized the research themes. The primary themes and sub-themes are outlined in Fig. 4. The thematic categories identified in the review are not mutually exclusive, as there is an inherent overlap between the themes or sub-themes. For example, the theme "BC-IoT integration" covers the potential of leveraging BC and IoT to support CE approaches (e.g., sustainable business models, smart manufacturing, recycling) in various industrial sectors (e.g., plastics, construction, energy) and during crises and disruptions (e.g., the COVID-19 pandemic). As a result, the complementarity between BC and IoT in the CE can optimize supply chains' economic, environmental, and social performance. In contrast, the barriers to BC adoption in the CE emerge as an issue that can undermine the ability of BC to promote CE practices in the economy, alleviate supply chain disturbances, and achieve holistic sustainability. Overall, the delineation of the extant literature pertaining to BC and the CE in this way offers a valuable heuristic for organizing and structuring studies on the interplay between these two concepts. In addition, and keeping with the review's goal, structuring BC-CE-related works can enable scholars to identify possible knowledge gaps and prospective avenues for future research.

Table 3
Most relevant journals in the BC-CE literature

Journal	Number of articles
Journal of Cleaner Production	11
Business Strategy and the Environment	9
Industrial Marketing Management	3
Industrial Management and Data Systems	3
Sustainability (Switzerland)	3
International Journal of Production Research	3
Environmental Research	2
Journal of Business Research	2
Supply Chain Forum	2
International Journal of Logistics Research and Applications	2
Sustainable Production and Consumption	2
Others	28

4.1. BC-IoT integration

The first theme concerns the integration of BC and IoT in the CE transition, which is the main focus of six articles. Sustainable supply chain management and reverse logistics benefit greatly from BC and IoT, which represent a building block of Industry 4.0 (Dutta *et al.*, 2022). These technologies can optimize the performance of reverse supply chain systems, simplify the capture and analysis of data associated with end-of-life products, and enable more precise tracking (Hrouga *et al.*, 2022). Additionally, BC has the potential to have a beneficial impact on the regulations, processes, and resultant trust associated with information sharing. The combination of BC and IoT also improves product traceability throughout its life cycle, reducing its environmental effect (Hrouga *et al.*, 2022). As a result, these new technologies provide enhanced product safety and traceability.

Furthermore, IoT-powered by BC can handle the complexities and uncertainties of circular supply chains by providing more transparency and traceability (Paul *et al.*, 2022). According to Paul *et al.* (2022), organizations can profit from the capabilities of IoT and BC to accelerate resource deployment, minimize waste, and enhance the sustainability and durability of tea circular supply chains. Thus, with the help of these technologies, CE stakeholders can improve resource efficiency and increase the resilience of the material supply chain in organizational processes. In the context of product-service systems, Li *et al.* (2021) mentioned that the application of BC and IoT has several advantages, including sustainability improvement, efficient information sharing and synchronization throughout the lifecycle, and resilience against potential disruptions. Likewise, Alves *et al.* (2021) noted that BC, together with IoT, ensure traceability and enforcement of a CE, increases transactional transparency, supports diverse security and privacy policies, maximizes operational efficiencies, and prevents product damages throughout the supply chain.

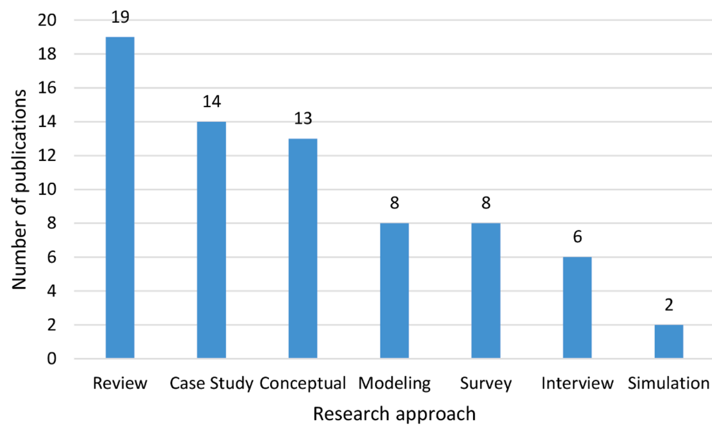

Fig. 3. Distribution of publications according to the research method used.

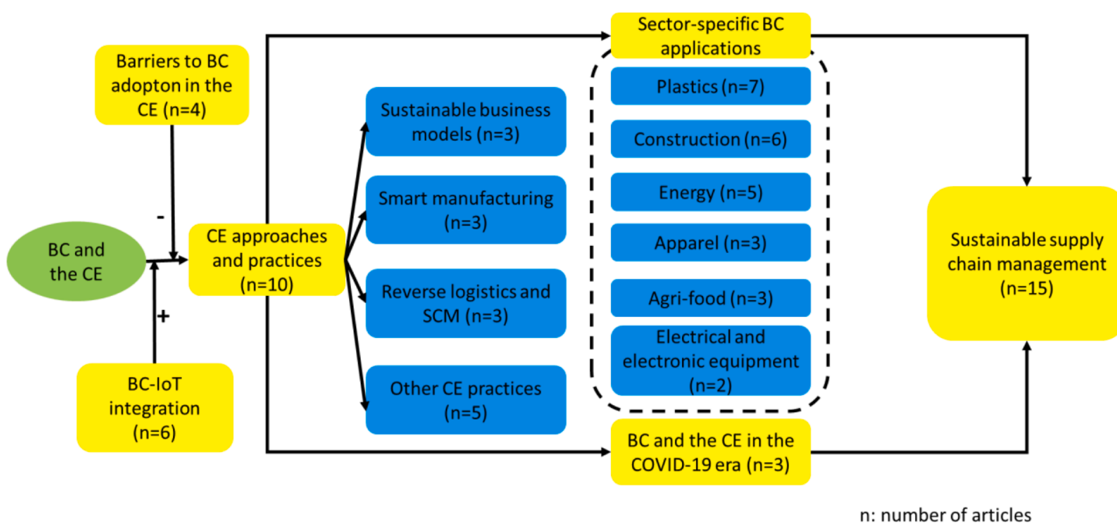

Fig. 4. Main themes and sub-themes in the BE-CE literature.

4.2. *CE approaches and practices*

This theme is the most discussed in the literature. In a generic sense, ten studies studied the potential of BC to support CE practices. Out of these, four literature reviews were conducted on the topic. These include Böckel *et al.* (2021). They reviewed 57 distinct documents and concluded the lack of a clear conceptualization of BC, the major benefits of the technology in terms of trust and verification, and the potential of BC for the CE and sustainable development. The literature review of Gebhardt *et al.* (2021) also demonstrated the utility of BC for supporting collaboration in circular supply chains. BC could streamline information sharing, empower joint planning, and support decision-making (Narayan and Tidström, 2020). Collaboration is essential to manage the complexity of corporate networks, enabling firms to shift to circular models. In this context, Narayan and Tidström (2020) highlighted how BC tokens could facilitate the shift to circular models of value generation and appropriation. Tokens on BC can bring together previously disjointed product ecosystems and stimulate innovation and creativity, which are necessary for CE business models. Furthermore, BC can enable large-scale collective decision-making processes, provide digital identification and verification of transactions between multiple players, and offer incentives for facilitating new trading and pricing systems for resources (Chauhan *et al.*, 2022).

Data from several CE stakeholders across different materials and product supply chains can be maintained in BC-based systems to offer the required visibility. By deploying BC, the CE monitoring parties can keep track of the movement of products and materials, as well as the efficacy of their policy instruments, and mitigate potential fraud. The technology enables CE stakeholders to be better equipped to influence the business community toward more sustainable and circular business practices and ultimately lead the CE transition. A stream of empirical studies focused on understanding how BC can alleviate the implementation of CE practices. For example, Erol *et al.* (2022) employed Multi-Criteria Decision-Making (MCDM) techniques to study the genuine potential of BC for removing CE adoption hurdles. Their findings indicated that the most important functionalities of BC to drive CE adoption are increased supply chain traceability, greater cooperation and coordination in business ecosystems, improved trust levels, and better business models. These findings are echoed in the study of Kayikci *et al.* (2022), who deduced that network collaboration represents the most important critical success factor for developing BC-based circular supply chains. With BC, organizations can benefit from a more decentralized, transparent, and secure business process and the potential for resource regeneration, cost savings, and increased responsiveness (Kouhizadeh *et al.*, 2020). Chaudhuri *et al.* (2022) conducted in-depth interviews with four small and medium enterprises engaged in the CE to determine the resources and capabilities necessary to offer customer value. The examination of CE initiatives that used digital technologies, including BC, showed that SMEs that participated in these initiatives could maximize recycled facilities, develop well-defined CE processes, select the appropriate raw materials, and optimize manufacturing processes. Finally, Kottmeyer (2021) noted that incorporating BC and new business models indicates the potential of digital technologies to bridge the gap between the theory and reality of the CE vision by boosting information sharing and communication amongst CE stakeholders. Nevertheless, the adoption of BC carries economic and social concerns, like regulatory arbitrage and power abuse, which must be addressed beforehand.

4.2.1. Sustainable business models

At a detailed level, four sub-themes were closely related to and were supportive of the first main theme. Three articles focused on the role of BC in developing sustainable business models. For instance, Calandra *et al.* (2022) recently examined the connection between BC and novel sustainable business models using a multiple case studies approach. According to the authors, BC promotes the development of sustainable business models that promote smart energy management, reduce climate change, improve waste management, and foster cleaner production. The primary use of BC for sustainable business models also involves lowering supply chain costs.

Moreover, Tiscini *et al.* (2020) point out that BC alters sustainable business models by supporting innovation and responding to consumers' concerns regarding transparency, authenticity, and data security. Wolf *et al.* (2022) also highlighted that consumer involvement in BC-based circular business models is determined by several factors, including transaction cost efficiencies, transparency, and simple access to trustworthy sustainability-related product information. Therefore, consumers appreciate the involvement in new sustainable business models in which BC can provide access to reliable information concerning product quality, environmental footprints, and tool conditions.

4.2.2. Smart manufacturing

In three studies, scholars have noted BC's capabilities in unlocking the potential of smart manufacturing. For example, Song and Zhu (2021) state that BC can be a viable solution to cover the shortfalls of smart manufacturing systems because the technology can be leveraged in the design stage to stimulate the involvement of individuals or companies and ensure the reliability of the associated design environments. A scenario that intrigues potential customers is the possibility of receiving rewards if their experiences with smart manufacturing systems are shared through BC networks. In the manufacturing phase, BC can be primarily used for scheduling resources, controlling devices, and tracking and tracing manufacturing activities to address issues related to inefficient resource allocation outside organizational boundaries, lack of transparency, and inflexible device control (Song and Zhu, 2021). By using specialized tokens to increase the visibility of product life cycles, BC supports CE practices and resilience, protects the integrity of upstream and downstream materials, minimizes mistakes, and shortens response times (Chari *et al.*, 2022). Tozanlı *et al.* (2020) further highlight that BC enables manufacturers to anticipate the total cost of the manufacturing system and helps companies conduct more reliable, well-informed, and profitable product acquisition strategies. Therefore, BC is envisioned to transform current manufacturing practices by increasing automation, reducing process complexities, and optimizing operational efficiencies.

4.2.3. Reverse logistics and supply chain management (SCM)

Logistics and SCM have evolved from conventional issues such as efficiency, cost, lead time, and flexibility to environmental effects and sustainable development due to increased environmental issues and stricter environmental legislation. In this regard, reverse logistics and SCM represent critical concepts in greening business processes and mitigating the negative environmental effects. As there is a greater degree of unpredictability involved in reverse logistics (e.g., quantity, quality, and uncertain timing of returned products and/or materials), production planning and control are more difficult to manage than in the scope of the forward logistics (Ferrer and Whybark, 2001). As a result, reverse logistics and SCM costs become more expensive than conventional logistics. To make these activities more cost-effective, efficient, and even lucrative, organizations can use BC to synchronize reverse logistics and SCM processes and reduce the uncertainties related to the condition and quality of used products. The role of BC in reinventing reverse logistics and SCM is thoroughly discussed in three studies. For example, Jraisat *et al.* (2022) investigate the potential of BC for reverse supply chain networks and assess the relationship between technology and sustainability performance. The findings indicated that reducing costs is the most important aim in deploying BC to boost revenues while increasing customer satisfaction by facilitating the return of damaged and undesired products.

Furthermore, BC empowers CE stakeholders to manage reverse logistics activities efficiently by supporting interaction, traceability, decentralization, and increased sustainability knowledge. De Giovanni (2022) finds that BC allows for a more efficient CE system by supporting an active return strategy, engaging stakeholders to join the closed-loop supply chain, and offering consumer incentives. Finally, Centobelli *et al.* (2021) conclude that BC can help reverse logistics waste transportation and product return management by providing better visibility and control over waste, trust, and traceability. Therefore, BC opens the space for more efficient and effective reverse logistics and SCM, representing a critical dimension of the CE that enables the management of economic, environmental, and social issues.

4.2.4. Other CE practices

The sub-theme "Other CE practices" focuses on four topics: the role of BC in ensuring sustainable product management, fostering collaboration in the CE ecosystem, facilitating auditing, and supporting recycling activities. According to the analysis of certain sustainable product management, Rusch *et al.* (2022) demonstrated the enabling role of BC to facilitate information sharing, the exchange of life cycle inventory data across the supply chain, the monitoring of product conditions, and the trading of carbon emissions. Related to the enablers of collaboration in circular supply chains, Gebhardt *et al.* (2021) stressed the importance of BC alongside the IoT and cloud systems to provide high levels of integration and information sharing and facilitate decision-making processes and joint planning. In addition, Imoniana *et al.* (2021) argue that BC ushers in innovative auditing towards the CE by authenticating and protecting potential communication systems due to its decentralized, transparent, and private nature. Finally, BC's role in recycling activities has been the major focus of two studies. Gong et al. (2022a) studied the applications of BC in recycling using a multiple-case approach. They found that BC is an effective solution to improve recycling performance, enable tokenization, facilitate waste flow monitoring, and increase the integration of recycling chains. In addition to environmental advantages, BC also contributes to stakeholder involvement, social inclusion, transparency, and accountability in recycling activities. Finally, Khadke *et al.* (2021) highlighted that the efficiency of recycling activities could be significantly enhanced by using BC since the technology can automate the segregation and collection of materials and facilitate the tracking of recycled products throughout the supply chain.

4.3. Sector-specific BC applications

Considerable research was observed regarding BC applications to accelerate the CE transition in different industrial contexts. Twenty-six studies were included in this theme and assigned to 6 sectors: plastics, construction, energy, apparel, agri-food, and electrical and electronic equipment. The following sections elaborate on the studies that addressed these sectors.

4.3.1. Plastics

Plastic waste is piling up throughout the world at an alarming pace. Most plastic waste generated in highly populated areas is disposed of on land or sent to the sea. The plastics generated are often non-biodegradable and have a complicated decomposition process. These pollutants linger in the natural environment for a long time and may cause harm to terrestrial and marine ecosystems. To reduce the negative impacts of plastics, seven studies explored the potential of BC in increasing the efficient management of these resources. For example, Chidepatil *et al.* (2020) note that with the use of BC smart contracts combined with multi-sensor data-fusion algorithms, it is possible to sort plastics by kind and increase the trustworthiness of information regarding recycled plastics. Using BC in the CE of plastics, manufacturers, recyclers, and segregators can securely share information, organize the plastics supply chain, manage purchase orders, and ultimately boost the utilization of recovered plastic materials. Khadke *et al.* (2021) posited that BC could be used to increase the effectiveness of plastic recycling, develop an internationally recognized instrument for sorting and collecting plastic waste, and facilitate the traceability of plastics across the supply chain. Furthermore, Bhubalan *et al.* (2022) highlighted that BC implementation in plastics management could help overcome several supply chain issues, such as traceability, information security and privacy, carbon footprint, and global warming. Finally, Gong et al. (2022a) showed that BC benefits plastics management and recycling in terms of the formalization of the plastics recycling practices, generation of economic benefits (e.g., job creation, poverty reduction), global collaboration, reward mechanisms, transaction security, and transparency and efficiency of the plastics supply chain.

4.3.2. Construction

The construction industry is a resource- and energy-intensive and is responsible for 35 per cent of the world's CO2 emissions, 40 per cent of the world's overall energy use, and 30 per cent of global water consumption (Çetin *et al.*, 2022; Widyasningrum, 2021). In total, six studies discussed BC's role in accelerating the CE transition in the construction sector. For instance, Shojaei *et al.* (2021) analyzed how BC can be a possible tool to facilitate the CE in the built environment and found that each material or component's present status can be recorded in a BC, allowing for a more proactive approach to reusability and full energy and material traceability. The technology also enables the system participants to forecast the reuse and recycling of goods and materials used in the construction environment. Moreover, Li *et al.* (2021) claimed that BC could ensure secure data transmission, facilitate traceability, and increase traceability in prefabricated housing construction. Figueiredo *et al.* (2022) stated that BC could resolve transparency issues across the lifecycle of a construction project, minimize human error, and boost the accuracy of decision-making procedures using smart contracts. Elghaish *et al.* (2022) mentioned that BC could create a collaborative construction design system to automatically trace the construction materials from origin to the end of useful life, foster sustainable construction design, track energy usage, and support the carbon credit market in the construction industry. Through its technical capabilities, Yu *et al.* (2022) contended that the possible applications of BC in construction engineering management were categorized into three areas, including notarization, transactions, and provenance. Finally, BC can be employed to ensure safe and reliable tracking of repurchased components and materials and offer novel financing structures and ownership models for construction products and services, providing clear information regarding the rights and constraints of utilizing IoT-enabled information for construction projects (Chen *et al.*, 2022).

4.3.3. Energy

BC plays an important role in improving the energy transition and supporting greener practices in the energy industry by delivering several advantages to energy companies. Five studies discussed BC's potential for the energy sector in detail. For example, Yildizbasi (2021) examined the integration of BC with renewable energy systems to eradicate the issues plaguing the energy grid management process. According to the authors, BC can benefit the energy sector by enhancing the governance of decentralized energy networks and microgrids, automating energy trading, and offering networking tools for exchanging services between different parties, such as sharing the charging facilities of electric vehicles. However, implementing the technology in the energy sector depends on effective government incentive programs and regulators (Erol *et al.*, 2021). In addition, BC's high level of security facilitates the integration of energy production, use, storage, and transmission, thereby helping monitor carbon footprint activity and trading transactions (Fernando *et al.*, 2021). Finally, BC can reduce the amount of resources necessary to produce biomass, enable more efficient energy distribution, and increase the sustainability level in the energy sector (Krajnakova *et al.*, 2019).

4.3.4. Apparel

Employment, trade, revenue, and investment are all tied to the apparel sector across the globe. Because of excess production and a "throw-away" mentality, the apparel sector is plagued by large losses. As a result, there is a need to incorporate BC to improve economic sustainability, reduce the negative environmental impact of the apparel sector, and accelerate the moves toward the CE. Overall, this topic was discussed in three main studies. For example, Alves *et al.* (2021) highlighted the benefits of BC and IoT integration in the textile value chain: increased operational efficiency, proper inventory management, end-to-end traceability, and product damage prevention. Jain *et al.* (2022) pointed out that a well-implemented BC in the garment business can be a powerful tool for monitoring and tracing the products. The authors also found that adopting BC-enabled e-commerce platforms could lower the risk of contamination in online secondhand clothing transactions, resulting in a stronger behavioral intention to utilize the technology. Finally, Huynh (2021) investigated digital circular business models in the fashion sector and argued that the BC-based supply chain model could support recycling and reuse approaches, thereby facilitating the CE transition.

4.3.5. Agri-food

Another major sector that can benefit from BC implementation is the agri-food industry. Overall, three studies mainly discussed the role of BC in the CE transition in the agri-food sector. For example, Sharma *et al.* (2021) suggested that BC could improve circularity in agri-food supply chain operations by ensuring traceability, real-time connectivity and information sharing, and sustainability. Anastasiadis *et al.* (2022) noted that traceability enabled by BC could enhance decision-making efficiency, decrease costs and time related to traditional food traceability methods, and foster sustainability and CE practices. Lastly, Paul *et al.* (2022) argued that circular tea supply chain management could be made more transparent and traceable with RFID technology, which BC powers. According to the authors, BC enables various parties involved in the tea supply chain to monitor the life cycle of reusable and recyclable materials.

4.3.6. Electrical and electronic equipment

Two studies mainly focused on BC application in promoting circularity in the electrical and electronic equipment sector. For instance, Magrini *et al.* (2021) studied the application of IoT and BC in the context of professional electrical and electronic equipment. They found that combining these technologies enables monitoring products until their end of life while supporting CE strategies and decision-making processes. Bressanelli *et al.* (2021) noted that BC could enable access to data that aids product management, supporting lifetime extension, a better understanding of customer behavior, and more appropriate CE strategies.

4.4. BC and the CE in the COVID-19 era

The recent COVID-19 crisis has exposed companies and society to regular production and consumption patterns and their long-term effects on the performance of supply chain networks (Igalavithana et al., 2022; Nandi et al., 2021). In this regard, three studies mainly focused on the applications of BC in the CE transition in the context of the COVID-19 pandemic. First, Nandi *et al.* (2021) offered insights from the COVID-19 pandemic and demonstrated the urgent need for supply chains to establish localization, agility, and digitalization (LAD) capabilities. Analyzing BC use cases, the authors demonstrated the role of BC-enabled CE practices in facilitating the LAD of supply chains by facilitating tracking, tracing, and responsiveness. Second, Nandi *et al.* (2020) investigated how organizations develop LAD capabilities by utilizing their CE and BC-related resources and capabilities. Significant correlations exist between the degree of the BC-enabled CE system and the establishment of LAD capabilities. The more the BC-enabled CE system capabilities, the higher the LAD capabilities. Finally, Nandi *et al.* (2021) argued that the success of the CE performance measurement depends on the use of multi-stakeholder new technologies that involve different technological innovations such as the IoT, BC technology, artificial intelligence, and tracking tools. The combination of these technologies accelerates the post-COVID-19 pandemic recovery and improves supply chain resilience and sustainability.

4.5. Sustainable supply chain management (SSCM)

SSCM represents a popular research theme in the selected publications for this review, and this theme constitutes the main focus of fifteen studies. Out of these, six studies comprehensively analyzed the impact of BC on overall organizational performance. For example, Rehman Khan *et al.* (2021) investigate the potential of BC for the CE to improve organizational performance using the China-Pakistan Corridor as an example. Based on cross-sectional data from 290 participants, it is found that BC has a positive impact on the CE because of its properties, such as transparency, visibility, smart contracting, and relationship management. According to the authors, companies that deploy BC can boost their economic performance, guarantee a secure and transparent process of transactions, enhance efficiencies, and achieve cost savings. Similarly, Khan *et al.* (2021) demonstrated that BC significantly enhances CE practices (e.g., circular design, circular procurement, remanufacturing, and recycling), leading to better organizational performance. Hayrutdinov *et al.* (2020) found that sharing product lifecycle-related information via a BC system can increase the profit of the whole supply chain.

The role of BC in fostering environmental sustainability has been intensively discussed in eight studies. For example, Khan *et al.* (2021) revealed that BC benefits CE practices because it facilitates smart contracts with suppliers, increases information-sharing transparency, and dramatically improves supply chain visibility. According to the findings, BC can also increase environmental sustainability by improving waste management, promoting green practices, reinforcing environmental regulations, and reducing carbonization. The findings of Tang *et al.* (2022) backed up the capability of BC to monitor environmental quality and provide real-time access to data on green product development. Data transparency can reduce uncertainties and promote cooperation, thereby supporting the development of efficient circular product designs. A crucial aspect of designing environmentally friendly products is using BC to ensure that all relevant information about the product can be traced back to its source (Tang *et al.*, 2022). Parmentola *et al.* (2022) argue that embracing BC can achieve sustainable development goals in several ways, such as offering the ability to map and share carbon emissions, creating a system of incentives to encourage low pollution and sustainable behaviors, and developing platforms to monitor waste and energy consumption. Fernando *et al.* (2021) also argue that BC can help companies reduce their carbon emissions by making more secure, transparent and efficient carbon trading processes. Consequently, information flows can be recorded using BC to prevent missing quotas and duplicate transactions in carbon emission trading. From the social sustainability perspective, Upadhyay *et al.* (2021) analyzed the existing and potential contribution of BC to the CE through the lens of social responsibility. Besides enhancing economic performance, BC can support human rights, increase stakeholder trust, and reduce power, information asymmetry, and centralization.

4.6. Barriers to BC adoption in the CE

The barriers to BC adoption in the CE have been an area of considerable interest in four studies. For instance, Böckel *et al.* (2021) revealed that the immaturity of BC and its incorporation in various domains is still continually growing, which poses several uncertainties. The authors noted that even when all precautions are taken, private information might still be compromised in a BC transaction. Although centralizing BCs is a workaround for this security vulnerability, this goes against the original idea of the BC system. Moreover, limited scalability, prohibitive development costs, the complexity of decentralized application use, the need for frequent and reliable internet connection, and a lack of digital literacy are all additional technical hurdles that hamper BC adoption in the CE. According to Böhmecke-Schwafert *et al.* (2022), these issues negatively impact the role of the technology in CE innovation and, thus, indirectly weaken the moderating role of BC in the CE transition. When implementing BC in circular supply chains, risks associated with inaccurate data entry can be difficult to overcome since it is challenging to guarantee that no harmful or inaccurate information from the physical world is transmitted to the BC system. In a recent review, Khan *et al.* (2022) indicated that financial barriers, unclear responsibility distribution, political environment, management reluctance, and lack of human resource training could slow the CE transition. Finally, Rejeb *et al.* (2022) identified a lack of knowledge and management support, resistance to change, and technological immaturity as the most important barriers to BC adoption in the CE. On the other hand, investment costs, security threats, and scalability limitations represent the least significant barriers.

4.7. Comprehensive BC-CE framework

This paper develops a framework for evaluating the conceptual boundaries of BC and the CE, summarizing the current state of the art to aid future scholars and practitioners (see Fig. 5). Using the abbreviation 4W1H, the framework lays out in detail the stakeholders' role (who), the steps they take in a BC-enabled CE (how), the industrial sectors (where), the barriers to BC adoption faced by CE stakeholders (what), and the motivation for implementing BC in the CE (why). Despite its straightforwardness, this approach provides a framework for comprehending all relevant aspects of the phenomenon under study (Nevstad *et al.*, 2018).

Using the 4W1H conceptual framework, this study lays out the fundamentals of investigating the interface between BC and the CE. The "who" element of the framework refers to the stakeholders of the CE who can take advantage of BC to contribute to the overall realization of the CE vision. Based on the framework, all relevant parties must collaborate to facilitate the transition toward a BC-enabled CE. Suppliers, organizations, customers, and leaders at all levels of government play a key role in this transformation. The "how" element of the framework refers to the specific strategies and practices to which BC can add substantial value. Developing sustainable business models, smart manufacturing, reverse logistics and SCM, and other CE practices like sustainable product management, collaboration, auditing, and recycling, are just some concrete areas where BC can unleash its full potential. The "where" element of the framework refers to the various industrial sectors where BC can be deployed to support the CE transition. These include the plastics, construction, energy, apparel, agri-food, and electrical and electronic equipment sectors. There are vast opportunities to implement and promote CE principles to ensure significant improvements in industrial activities. The "what" element of the framework emphasizes the difficulties facing the development of a BC-enabled CE, including BC's technical, organizational, and regulatory issues. If not addressed properly, these adoption barriers can negatively influence the transition toward a BC-enabled CE and slow its pace. As a result, there is a need to

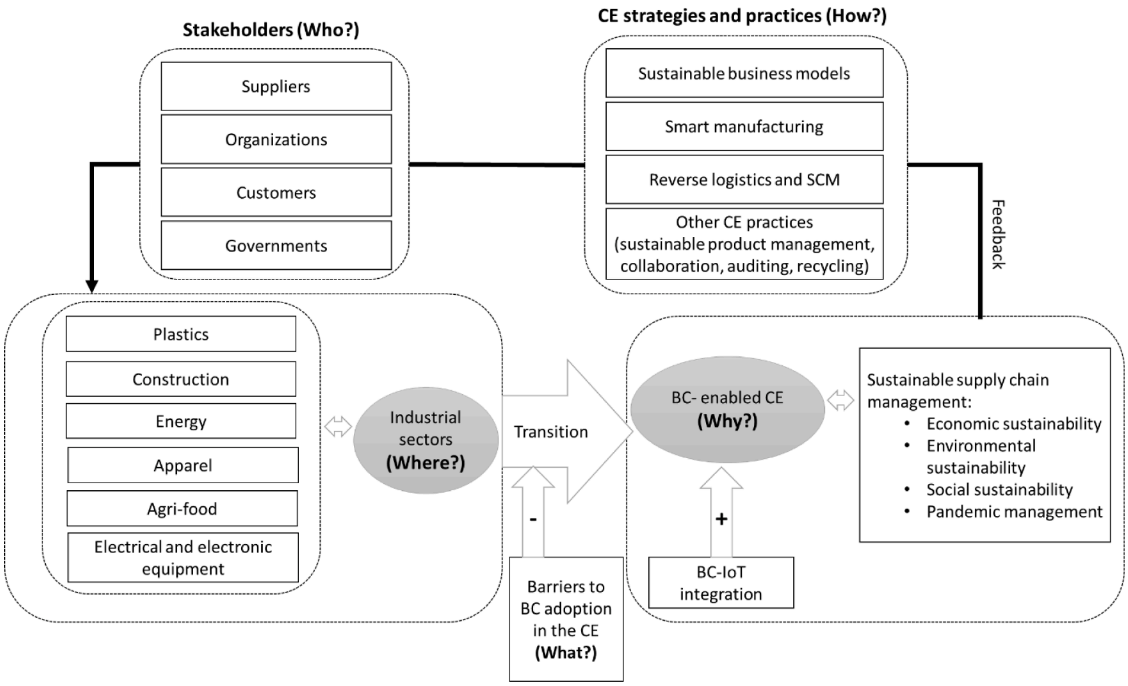

Fig. 5. BC-enabled CE framework.

develop efficient and scalable BC systems, technical know-how, and regulations compatible with the technology. Finally, the framework concludes by explaining why a BC-enabled CE is necessary for achieving economic, environmental, and social sustainability in the supply chain. When supported with IoT, BC can contribute to CE sustainability and be harnessed to mitigate the effects of disruptions like the current COVID-19 pandemic, thereby ensuring increased resilience and adaptation.

The suggested framework unifies the existing literature and calls attention to the need for further study in this area. Future scholars may build upon the framework's foundational elements by adding their insights and expanding its scope. Concerns about climate change, carbon footprint, waste generation, and social inequalities have prompted an uptick in research on BC applications in the CE. This has resulted in new theoretical frameworks and concrete initiatives to address these issues (Kouhizadeh *et al.*, 2020). BC, as a peer-to-peer, open-source, and distributed system with automation and advanced capabilities have the potential to facilitate more environmentally friendly practices of conducting business and bring about the long overdue equilibrium and harmony between the world's three most important spheres of influence, namely, economy, the environment, and society. Through the development and varied use of BC, the CE transition can be accelerated, resulting in a cleaner production of products and services and more ethical agenda of sustainable development. Given that there has been a rise in research on BC's role in offering effective solutions to confront sustainability issues and advance the CE, there is a need to draw conclusions about the state of this knowledge field as a whole and to outline the next steps. Furthermore, as far as we can tell, there are very few SLRs on the BC and CE interface.

5. Discussion

This section aims to examine the current state of research, identify areas where more work needs to be done, suggest future research avenues, and develop a holistic framework that combines the main themes identified at the intersection of BC and the CE.

5.1. Future research agenda

A thorough review of the prior literature has uncovered several research gaps. We matched the gaps to the themes discovered in the systematic review to fill these voids. Table 4 presents the knowledge gaps for future research.

5.2. Theoretical implications

The current research has some significant theoretical implications. A growing body of work is dedicated to elucidating BC's role in the CE transition. However, there is no thorough synthesis of the extant research, and no comprehensive review has been conducted. Accordingly, this research was carried out to synthesize and integrate the current literature at the intersection of BC and the CE. The authors summarized the existing literature on this emerging topic, including its primary thematic areas.

This work's fundamental contribution is synthesizing main themes, followed by identifying gaps and potential future research pathways. We also developed a comprehensive framework for a BC-enabled CE that would help researchers focus on the most important questions from a theoretical and practical perspective. In this way, the literature at the nexus of BC and the CE may benefit from the next researcher's summary of the existing literature. Theory development in the field of BC and the CE, in particular the consolidation of current knowledge in topical study areas, would benefit greatly from the in-depth debate presented herein.

Second, academics and practitioners can present a more nuanced view of this growing field of study after obtaining a firmer grasp of the gaps highlighted by the existing body of research. Many obstacles must be overcome before BC can unlock its value in developing sustainable supply chains and accelerating the CE transition. Three issues, in particular, stand out: enhancing the technical capabilities of BC, developing the necessary organizational capabilities to embrace BC, and introducing supportive policy and regulatory initiatives. Several knowledge gaps in BC research in the CE context are also highlighted in the review. Therefore, a research agenda for future inquiries has been established. In addition, the present review emphasizes the need to introduce BC to achieve holistic sustainability, boost organizational

Table 4
Knowledge gaps and research questions according to the identified themes.

Theme/Sub-theme	Knowledge Gaps
CE approaches and practices	1 A comprehensive analysis of BC's potential for the 9R principles of the CE 2 The role of various stakeholders in the BC-enabled CE system 3 The role of BC to support sharing platforms, circular supplies, and modular designs in the CE 4 The potentials and challenges of BC in circular private/ public procurement
Sustainable business models	1 The role of BC in sustainable business model innovation 2 The role of BC in servitized business models 3 The quantitative evaluation of the wider influences (i.e., impacts, trade-offs, benefits) of BC-enabled sustainable business models
Smart Manufacturing	1 The interoperability of multiple BC platforms in smart manufacturing 2 Modeling the enablers and barriers to BC adoption in smart manufacturing in the CE context 3 The role of BC in supporting smart manufacturing platforms to anticipate supplier susceptibility to disruptions and the effect on supply chain performance
Reverse logistics and SCM	1 The impact of BC on reverse logistics capabilities and performance 2 The willingness of firms, suppliers, and customers to engage in BC-enabled reverse logistics 3 The synergy of BC and reverse logistics and SCM to achieve operational excellence and sustainable organizational performance
Other CE practices (sustainable product management, collaboration, auditing, and recycling)	1 The role of BC to support high-quality end-of-life product management policies and strategies 2 Developing a BC-based circular supply chain collaboration framework to improve coordination and cooperation among CE stakeholders 3 The focus on how BC's auditing capabilities affect the purchasing and production decisions of the supply chain 4 The potential of BC for monitoring and improving the efficiency of recycling systems
BC-IoT integration	1 Modeling the enablers and barriers to BC and IoT adoption in various CE activities 2 Exploration of governance issues in integrating BC and IoT in the CE 3 Optimization of BC-IoT-enabled circular supply chain processes
Sustainable supply chain management (SSCM)	1 The impact of BC on CE profitability, competitiveness, and material cost savings 2 The environmental issues associated with BC adoption in the CE 3 The impact of BC on social sustainability dimensions (e.g., job satisfaction, workers' health and safety conditions, equity) during the CE transition
BC and the CE in the COVID-19 era	1 The drivers and obstacles to developing BC-enabled circular supply chains during and after pandemics 2 The role of BC in increasing the preparedness, responsiveness, and resilience of circular supply chains against the COVID-19 pandemic and similar disasters 3 The use of BC to overcome the ripple effects of natural disasters and pandemics
Sector-specific BC applications	
Plastics	1 Exploration of BC to promote the production and usage of bioplastics 2 The impact of BC on consumer behaviour and perception of plastics use
Construction	1 The interface between BC and circular construction approaches 2 The implementation of BC in lean construction practices (e.g., modular buildings, efficient construction layouts, construction waste reduction)
Energy	1 The sustainability dimensions in BC energy application 2 Modeling the antecedents of BC adoption for green and renewable energies
Agri-food	1 The implementation of BC in circular food supply chains 2 Impact of deploying BC in food packaging as a critical element of food waste minimization
Electrical and electronic equipment	1 The potential of BC to ensure proper electrical and electronic equipment production and waste management 2 The technical and economic feasibility of incorporating BC in the development of sustainable and traceable electrical and electronic equipment supply chains
Barriers to BC adoption in the CE	1 Practical solutions to overcome the technical limitations of BC systems in the CE context 2 Policy and legislative tools to support BC adoption in the CE transition 3 A rigorous analysis of BC's barriers across multiple case firms that constitute linear incumbents and circular start-ups, as well as various firm sizes, sectors, and customer segments

resistance, and foster the CE.

Third, the current review highlights the importance of deploying BC to support CE principles and resolve various industrial challenges. Including those minimizing waste, optimizing reverse logistics and SCM, and dealing with problems related to supply chain traceability and inefficiencies, information opacity, and unsustainable business processes, among others. Empirical studies conducted by researchers in this field may attest to the efficacy of BC systems in increasing sustainability in diverse economic sectors. Finally, the current review highlighted the main methodological approaches in the literature by providing a detailed research profile of the existing publications.

5.3. Practical implications

The present review has a few relevant implications for managers and practitioners involved in the CE. Managers and decision-makers have a major role in advancing CE implementation; thus, they need a thorough understanding of BC's role in this transformation. This SLR will provide the practitioners with the information necessary to develop a BC-enabled CE, which aims to improve resource management, minimize waste, and make a lasting impact via sustainable practices. Four specific recommendations for practice are provided in this review as a result of the research. First, the practitioners need to understand the transformative potential of BC in advancing the CE agenda. However, reaping the perks of this technology requires the elimination of several obstacles, including the low readiness of CE stakeholders to engage in a BC ecosystem, the infancy of the technology, the high operating and adoption cost, energy consumption, and uncertainties surrounding technological transitioning (Sarkis *et al.*, 2021). To be more specific, the practitioners and decision-makers need to understand that an integrated BC-enabled CE is necessary since it considers sustainability issues, SCM relationships and complexities, technology, and sustainability. Second, the thematic analysis emphasizes how BC can be applied to support various CE strategies and practices so that the practitioners will have a complete grasp of the value-adding areas of BC. Based on the results, it is clear that the CE transition has much room for improvement in resource states and flows, operational efficiencies, circularity, and sustainability. Third, the difficulties of switching from the unsustainable linear economy to the CE have been the subject of a sizable portion of the existing literature. Assimilating the key role of BC throughout this transition, this review provides a comprehensive overview of important fields of action for BC adoption and the most pressing concerns that must be addressed. In particular, CE implementation necessitates collaborative relationships and cross-sectoral connections, which presents governance concerns and practical difficulties for individuals in invoking adequate technology solutions. Finally, the study emphasizes vital issues such as the sufficiency of current regulations. Policymakers may use the review findings to formulate measures to facilitate the progress of BC applications to CE principles. This research also informs policymakers of the need to devise effective policy interventions, incentives, and favorable regulations to foster the wide-scale adoption of BC in the CE.

6. Conclusions, limitations, and future research

This study adds to the existing body of knowledge by thoroughly examining the state-of-the-art research that explores the relationship between BC and the CE. The SLR addressed the following questions: (1) What is the current state of the literature at the intersection of BC and the CE? (2) What are the main themes discussed in the literature? and (3) What are the current research gaps in the reviewed literature?

The literature analysis shows that research on BC and the CE is dispersed among various academic disciplines. The selected publications span several methodological approaches, journals, and topical themes. Overall, six main themes were uncovered at the nexus of BC and the CE: (1) CE approaches and practices, (2) BC-IoT integration, (3) Sustainable supply chain management, (4) BC and the CE in the COVID-19 era, (5) Sector-specific BC applications, and (6) Barriers to BC adoption in the CE. Out of these, the development of sustainable business models, smart manufacturing, optimal reverse logistics, efficient product management, strong collaboration, reliable auditing, and effective recycling have been identified as the main benefits of integrating BC into CE principles. Moreover, incorporating the technology to support IoT systems and increase the resilience of organizations against severe disruptions (i.e., pandemics) should be the primary emphasis of the policy direction and coping strategy. This SLR at the crossroads of BC and the CE will aid in realizing United Nations Sustainable Development Goal 12 by promoting sustainable production and consumption and ending resource waste via BC's support of reuse and recycling. According to the thorough analysis of the relevant literature, the intricate structure of the CE environment, which includes several players and resource flows, represents one of the major obstacles to adopting BC in the CE. The analysis also showed that academics had recognized the enabling role of BC to establish a collaborative environment to involve all stakeholders in CE processes. Integrating BC into organizational practices can also promote the CE and provide positive environmental sustainability and economic growth results. Guaranteeing and easing the incorporation of BC into the CE requires the collaboration of firms, academic institutions, the public, and governments. Finally, the paper discussed potential directions for further framework development and studies.

Despite its contributions, the present study has certain caveats that may be addressed by further assessment of related publications. To begin with, the analysis was limited to scholarly journals that were available via Scopus, the Web of Science, or a Google Scholar search. Therefore, the authors recognize that some significant works may have been overlooked, and studies published in journals not included in these databases may have been overlooked. Additionally, books, chapters, conference papers, and reports were excluded from the review. However, the present study has carried out backward and forward searches and has exhausted all other conceivable avenues for capturing all potentially relevant publications. Future researchers may broaden their search to include books, chapters, and conference papers.

Studies on new topics, such as BC applications for the CE during the COVID-19 pandemic, are in their early development stages, so research on such topics is sparse. As a result, it is recommended that future studies provide an updated review of this theme and its future directions when more studies are conducted, and new research gaps emerge. Despite the drawbacks mentioned earlier, the present SLR has offered an in-depth analysis of BC's role in the CE transition and the new trends at this nexus. Future academic studies in this area are expected to rely heavily on the current review as their foundation.

Declaration of Competing Interest

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

Data availability

No data was used for the research described in the article.

Supplementary materials

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.rcradv.2022.200126.

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