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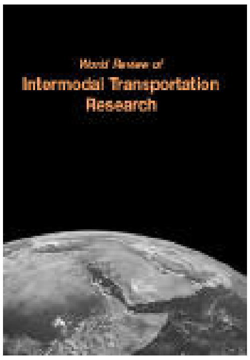

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Evolution of blockchain technology in sustainable supply chain management: a theoretical perspective

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Abstract: This article aims to identify the relationships and applications of blockchain technology in sustainable supply chain management and reverse logistics in the literature supporting recycling processes and the reuse of waste. The methodology was based on the planning and execution of a systematic literature review and the discussion of the results of the exploratory research. It was found that emerging technologies allow viable implementations of blockchain architectures in logistics networks, favouring sustainable processes, mitigating intrinsic problems in logistics networks, and allowing circular practices. However, the effective implementation of blockchain faces barriers such as low environmental awareness, disbelief in the effectiveness of this technology, and low technical capacity of human resources. Given the novelty of the subject, more scientific studies should be produced on the traceability of waste in recycling and reuse processes with evidence of the benefits associated with blockchain in the reverse and sustainable chain.

Keywords: reverse logistics; circular economy; Industry 4.0; systematic literature review; traceability; decentralisation; smart contracts.

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1 Introduction

Changes in the business environment require quick and flexible responses from the industry and supply chains to balance sustainability, performance, and resilience (Bekrar et al., 2021). Sustainable business management is essential to mitigate environmental impacts and raise awareness of sustainability in all its dimensions, overcoming any resistance to it (Ajwani-Ramchandani et al., 2020). The strategy adopted by corporate performance management must still consider the balance between sustainability, profitability, and brand image, requiring long-term investments to improve sustainable logistics (Russell et al., 2018).

However, problems related to delivery delays, order errors, logistics operators' overload and environmental impacts caused by the emission of fossil fuels (Tijan et al., 2019), characteristic of the traditional logistics process, are economic, social and environmental challenges faced by traditional supply chains making it impossible to track material and waste data in real-time in the supply chain (Cole et al., 2019). The need to face all these challenges enabled the emergence of concepts such as sustainable supply chain management (SSCM), which is based on the intersection of the supply chain and sustainable development to manage socioeconomic and environmental relationships with stakeholders, as defined by Dubey et al. (2017). In addition, it strengthened practices such as reverse logistics (RL), which contributes to environmental actions by collecting, separating, dismantling, and reusing waste, supporting the circular economy (Bekrar et al., 2021), contrary to the unsustainable linear economy model that focuses on landfill disposal (Voorter and Koolen, 2021).

Therefore, to enable circular and reverse processes, blockchain technology is adopted to benefit the traceability of materials and waste throughout the supply chain (Oropallo et al., 2021), allowing the reuse and recycling of these products in closed chains (Shojaei et al., 2021). The security and immutability of blockchain technology are based on the consensus mechanism known as proof of work (Nakamoto, 2008), in which the process of verification and validation of data blocks of the blockchain network takes place. Through this process, the new verified and validated blocks are inserted into the blockchain network (Bekrar et al., 2021). The blocks, in turn, are encrypted and highly secure against any attempt to tamper with the registry (Nakamoto, 2008).

Therefore, blockchain technology is a solution to improve the reliability and traceability of real-time transactions through decentralised recording of data in a shared and immutable ledger (Khanfar et al., 2021), increasing information security (Dietrich et al., 2021) and according to Rane and Thakker (2020), has the disruptive potential over sectors such as energy and real estate, due to benefits related to user and information security, transaction transparency, and efficient and quick monitoring of processes.

According to Khanfar et al. (2021) and Jardim et al. (2021), blockchain technology has a great potential to revolutionise supply chain management and it is expected that by 2025, investments in blockchain solutions will reach the mark of $176 billion. Blockchain is seen as a fundamental tool to improve data management and service quality, making companies and economies more competitive (Khanfar et al., 2021).

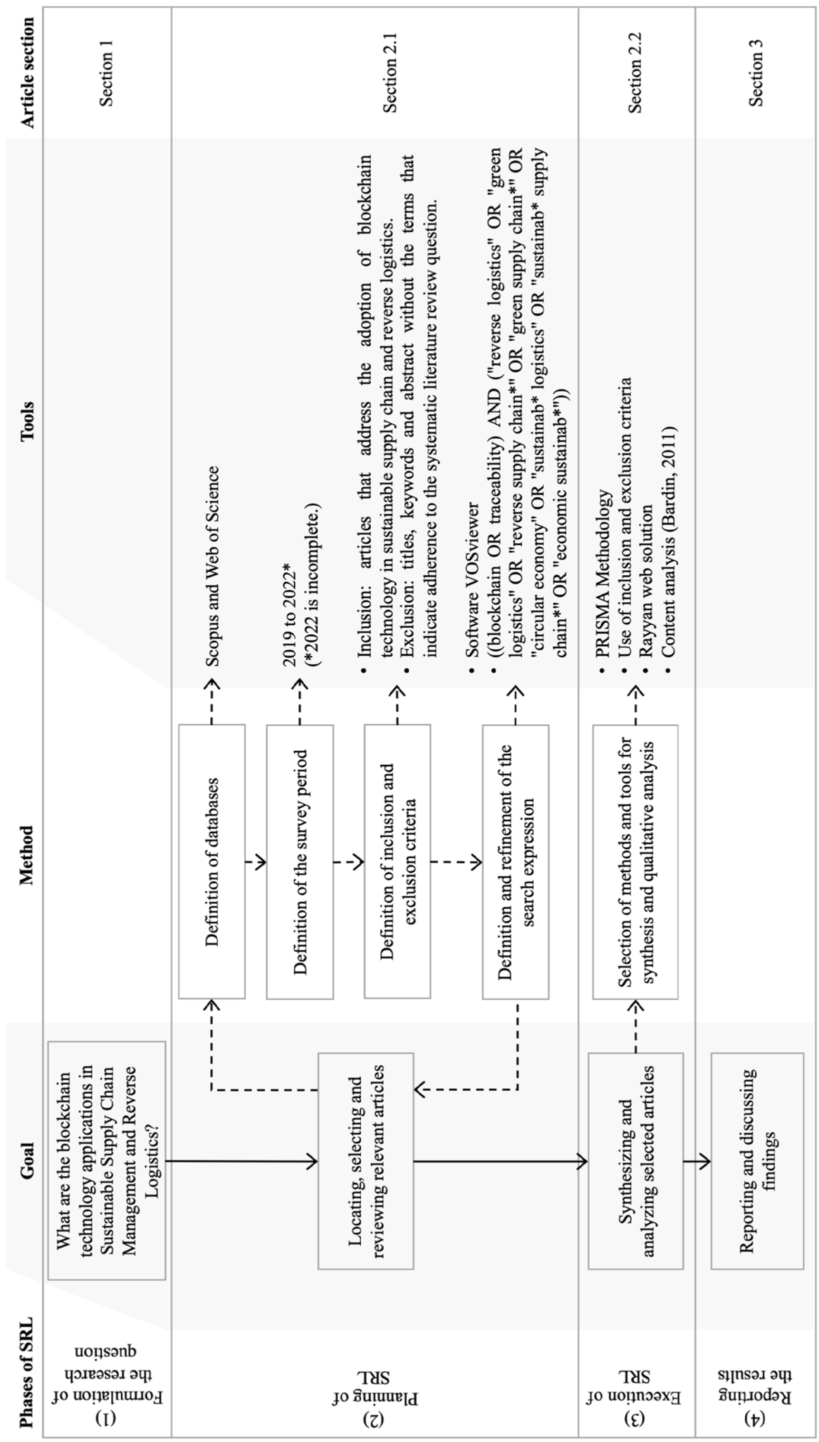
Stakeholders are interested in improving logistics processes due to their complexity and lack of transparency, and blockchain technology is seen as the ideal solution to these challenges (Tijan et al., 2019). Furthermore, blockchain technology applications can contribute to the sustainability of logistical processes by allowing the traceability of waste in the recycling process, as proposed by Tijan et al. (2019). Blockchain can also promote sustainable RL due to the possibility of locating waste in real-time with security and reliability among the members of the supply chain, according to Bekrar et al. (2021).

According to the context presented, the impacts of Industry 4.0 technologies in the supply chain need to be discussed and understood from the perspective of the circular economy (Gong et al., 2022) and sustainability (Zhang et al., 2019). New technologies such as the internet of things (IoT) combined with intelligent algorithms can bring economic gains in vehicle routing management and reduce stress for logistics operators (Hossin and Sabuj, 2019). IoT can help in collecting data at any stage of the product life cycle through smart sensors, ensuring continuous traceability (Alves et al., 2022). When combined with blockchain technology, data collection becomes immutable and transparent, allowing supply chain members to make effective real-time decisions about material management (Ellen MacArthur Foundation, 2019).

To sum up, the combination of IoT and blockchain allows supply chain members to access relevant product information, enabling more efficient and sustainable management. Applying blockchain technology to logistics processes can make them more sustainable and promote sustainable RL (Hrouga et al., 2022). Therefore, to understand the application of blockchain technology and its relationship with RL and sustainability in supply chains, this study aims to answer the following question: what are the blockchain technology applications in SSCM and RL? Therefore, this study aims to identify blockchain technology applications in sustainable processes and practices of supply chain management and RL through an exploratory systematic literature review.

The following sections will cover the following topics: Section 2 presents the methodology of this study; Section 3 discusses the results obtained and, finally, Section 4 draws the conclusions of the study.

Figure 1 Phases of the systematic literature review



Source: Adapted from Tranfield et al. (2003) and Garza-Reyes (2015)

2 Methodology

To answer the research question of this study, a systematic literature review (SLR) was conducted, as this method allows the development of a broad investigation in the literature through specific and reproducible expressions and search criteria to emphasise the necessary rigor for the analysis methodology of existing studies, identifying evidence, or even expanding the possibility of new studies (Tranfield et al., 2003). The SLR framework, adapted from Tranfield et al. (2003) and Garza-Reyes (2015) as shown in Figure 1 consists of four phases:

1 Formulation of the research question.

2 SLR planning that defines the research protocol.

3 Execution of the SLR that uses the PRISMA methodology to conduct data extraction in the Scopus and Web of Science databases, data analysis with the Rayyan web solution and content analysis using metrics of Bardin (2011).

4 Reporting the results where the results of this study are presented through the evolutionary analysis of blockchain technology in SSCM and RL.

Phase 1 was presented in Section 1 of this article. Phases 2, 3, and 4 are detailed below.

2.1 Planning of SLR

Phase 2 planning of SLR provides the foundation for carrying out exploratory research to answer the research question that is the focus of this study. The protocol of this phase comprises the information referring to the selected databases, the definition of the research period and the inclusion and exclusion criteria for the articles, as well as the refinement of the search expression of the exploratory research using the VOSviewer software. The Scopus and Web of Science (WoS) databases, selected in this SLR, are the bases generally used for bibliometric analysis, according to Steinhardt et al. (2017). WoS has a strong coverage with citation and bibliographic data dating back to 1990, bringing scope to the study (Mascarenhas et al., 2018) and Scopus can obtain documents that explicitly address the investigated topic (Oropallo et al., 2021). Therefore, the refinement of the search expression presented the following expression: [(blockchain OR traceability) AND (‘RL’ OR ‘green logistics’ OR ‘reverse supply chain*’ OR ‘green supply chain*’ OR ‘circular economy’ OR ‘sustainab* logistics’ OR ‘sustainab* supply chain*’ OR ‘economic sustainab*’)].

2.2 Execution of SLR

Phase 3 execution of SLR was based on the application of the PRISMA methodology (Pahlevan-Sharif et al., 2019) and the use of the Rayyan web solution to select the relevant articles for content analysis through the method proposed by Bardin (2011). The PRISMA methodology consists of four steps:

1 identification

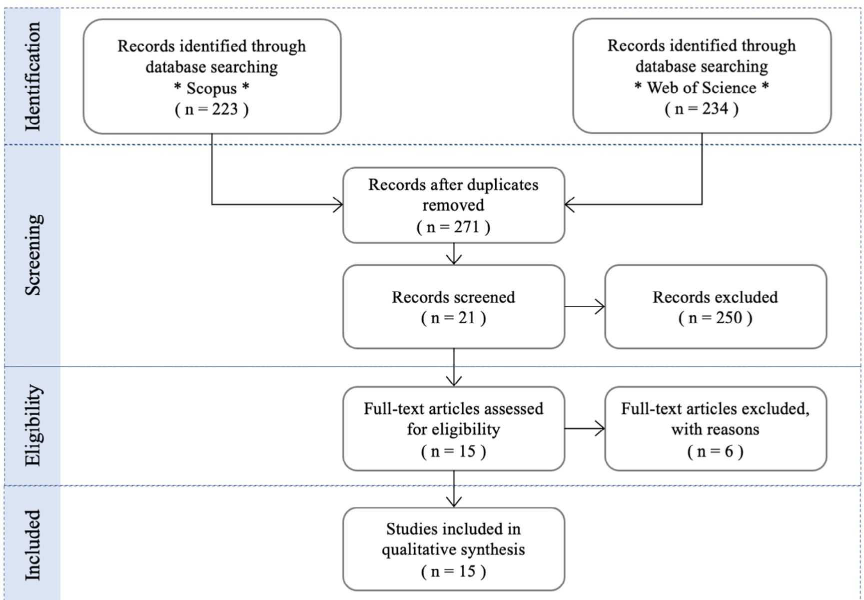
2 screening

3 eligibility

4 included, illustrated in Figure 2.

The first identification stage comprised the application of the search expression in the databases defined in the search protocol and returned 223 publications from Scopus and 234 from WoS. Then, the snowballing approach that includes the inclusion of references of articles with important information for the scientific basis of the systematic review (Wohlin, 2014) was applied in this phase to identify relevant citations for blockchain and SSCM and RL. Thus, the article by author Satoshi Nakamoto (2008) that presents the foundations of blockchain technology (Cole et al., 2019; Kouhizadeh and Sarkis, 2018; Sahoo et al., 2021), was added to SLR as a seminal article.

Figure 2 Execution of SLR based on the PRISMA methodology – selection of articles (see online version for colours)



Source: Adapted from Pahlevan-Sharif et al. (2019)

In step 2 screening, duplicate articles were removed. The analysis was carried out with the support of the Rayyan web solution, in which 186 documents were eliminated, when considering exclusion criteria of the same title, keywords, and abstract, resulting in 271 articles. These articles were screened using the double-blind assessment of Rayyan, adding more rigor and credibility to the systematic review (Ouzzani et al., 2016). The screening was based on analysing the inclusion and exclusion by reading the summary of 271 documents. The inclusion criteria considered articles that address blockchain technology adoption in sustainable supply chains and RL. The exclusion criteria considered titles, keywords, and abstracts without the terms that indicate adherence to the systematic literature review question. During the double-blind evaluation, some conflicts related to articles included by one researcher and not by another were analysed and discussed case by case. These evaluations generated a new database with 21 articles relevant to the subject of the study.

In phase 3, execution of the SLR, the eligibility and included steps allowed for a more detailed investigation through the complete reading of the articles to confirm their eligibility and inclusion, in which six articles were eliminated within the exclusion criteria, totalling 15 eligible articles.

Finally, phase 4 reporting the results consisted of the evolutionary analysis of the selected articles, presented in the following sections.

3 Findings and discussion

First, the results of the SLR present the analysis of the impact indicators of the articles and journals considered in this study, and a qualitative data analysis of the textual body of the articles. Subsequently, an evolutionary analysis of blockchain technology in SSCM and RL is outlined.

3.1 Analysis of article citation impact indicators

Table 1 presents the citation impact indicators of CiteScore (CS) and journal citation indicator (JCI) articles referring to the Scopus and Web of Science databases, respectively.

A journal's CS represents the number of citations for a given article received in other publications during the recent four-year period divided by the total number of publications from this journal during the same period (Elsevier, 2022). In turn, the JCI uses the journal citation reports (JCR) metric to show the average citation impact of articles published by a journal during a recent three-year period, according to Clarivate (2023).

An important distinction between these indicators is related to the type of publication of the period considered in the calculation of the indicator in which the JCI indicator considers only articles and reviews in its calculation; the CS recognises all publications without exception (Clarivate, 2023; Elsevier, 2022). The higher the impact indicator of the article citation, the better ranked the journal will be (Clarivate, 2022).

Thus, both citation indicators demonstrate the potential impact of the topics addressed in this study on the scientific literature and corroborate the relevance of this work in analysing the applications of blockchain technology in SSCM and RL processes.

3.2 Qualitative data analysis

The qualitative data analysis was supported by the visual resource Cloud of Words, in which the most frequent words in the eligible articles are grouped and organised, shown in Figure 3. This analysis is based on the lexical and semiotic investigation of the textual corpus to identify, code, and categorise the latent meanings of the selected articles, according to Georgousis et al. (2022), using the IRaMuTeQ software (Idoiaga et al., 2020). The textual corpus represents all texts grouped into a single text, according to the IRaMuTeQ Application Manual (Salviati, 2017).

Table 1 Citation impact indicators of articles

#	*Title*	*Author, year*	*Journal*	*CS (2021)*	*JCI (2021)*
1	Blockchain technology implementation in logistics.	Tijan et al. (2019)	Sustainability	5.0	0.6
2	Blockchain technology: implications for operations and supply chain management.	Cole et al. (2019)	Supply Chain Management	13.4	1.9
3	Blockchain-based life cycle assessment: an implementation framework and system architecture.	Zhang et al. (2019)	Resources, Conservation and Recycling	17.9	1.6
4	A blockchain-based framework for green logistics in supply chains.	Tan et al. (2020)	Sustainability	5.0	0.6
5	Redesigning supply chains using blockchain enabled circular economy and COVID-19 experiences.	Nandi et al. (2020)	Sustainable Production and Consumption	8.1	1.4
6	Towards a circular economy for packaging waste by using new technologies: the case of large multinationals in emerging economies.	Ajwani-Ramchandani et al. (2020)	Journal of Cleaner Production	15.8	1.5
7	Blockchain technology for bridging trust, traceability and transparency in circular supply chain.	Oropallo et al. (2021)	Information and Management	13.1	2.5
8	A unified blockchain-based platform for global e-waste management.	Sahoo et al. (2021)	International Journal of Web Information Systems	1.9	0.2
9	Digitalising the closing-of-the-loop for supply chains: a transportation and blockchain perspective.	Bekrar et al. (2021)	Sustainability	5.0	0.6
10	Enabling a circular economy in the built environment sector through blockchain technology.	Shojaei et al. (2021)	Journal of Cleaner Production	15.8	1.5
11	The traceability of construction and demolition waste in Flanders via blockchain technology: a match made in heaven?	Voorter and Koolen (2021)	Journal for European Environmental and Planning Law	1.4	1.1

Table 1 Citation impact indicators of articles (continued)

#	*Title*	*Author, year*	*Journal*	*CS (2021)*	*JCI (2021)*
12	Preventing return fraud in RL a case study of ESPRES solution by Ethereum.	Shih et al. (2021)	Journal of Theoretical and Applied Electronic Commerce Research	3.1	0.9
13	Tunnelling the barriers of blockchain technology in remanufacturing for achieving sustainable development goals: a circular manufacturing perspective.	Govindan (2022)	Business Strategy and the Environment	11.9	2.2
14	Blockchain-based recycling and its impact on recycling performance: a network theory perspective.	Gong et al. (2022)	Business Strategy and the Environment	11.9	2.2
15	The potentials of combining blockchain technology and IoT for digital reverse supply chain: a case study.	Hrouga et al. (2022)	Journal of Cleaner Production	15.8	1.5

According to the word cloud generated (Figure 3), the strength of the relationship between blockchain technology and the following most relevant words stands out:

1 ‘Supply’, ‘chain’, ‘management’, ‘waste’, ‘recycle’ and ‘traceability’, highlighting the relationship of blockchain with SSCM (Tijan et al., 2019; Zhang et al., 2019) and with waste management (Ajwani-Ramchandani et al., 2020; Voorter and Koolen, 2021; Hrouga et al., 2022).

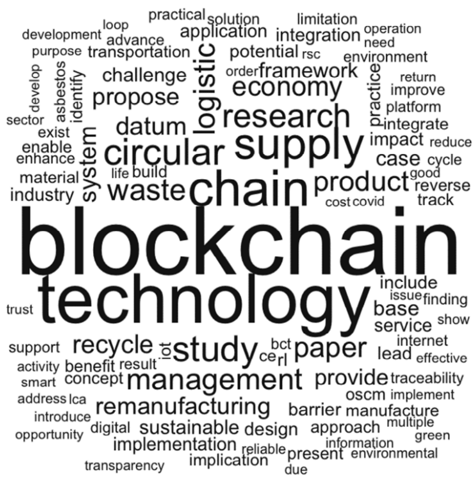
2 ‘Framework’: presenting conceptual and feasible models, platforms and architectures (Zhang et al., 2019; Tan et al., 2020; Bekrar et al., 2021).

3 ‘Circular’, ‘economy’ and ‘remanufacturing’: highlighting the feasibility of sustainable practices along the supply chain and circular manufacturing that are mitigated by efficient return systems through the tracking of materials, providing recycling and remanufacturing (Govindan, 2022). This finding reflects the integration of blockchain with circular practices initially raised by Nandi et al. (2020), Shojaei et al. (2021), Voorter and Koolen (2021), and later by Gong et al. (2022).

4 ‘Product’: product traceability is ensured by the immutability and cryptography of the blockchain during the exchange of information in sustainable supply chains (Oropallo et al., 2021) and also as a circular economy facilitator (Shojaei et al., 2021).

5 ‘rl’, ‘logistic’ and ‘reverse’: finding that blockchain promotes collaboration and information sharing between supply chain members, supporting RL processes (Tijan et al., 2019), allowing the protection of stakeholder data against fraud and falsification in reverse processes (Shih et al., 2021) and ensuring waste management through RL (Ajwani-Ramchandani et al., 2020).

Figure 3 Cloud of words



Note: Image generated by IRaMuTeQ, version 0.7 alpha 2.

3.3 Blockchain evolution in SSCM and RL

Table 2 presents a chronological analysis of several important studies on blockchain applications in SSCM. It is evident that blockchain is becoming increasingly central to facilitating sustainable practices and logistics, whereby studies indicate its relevance in terms of integrating it with emerging technologies, improving recycling performance and building trust between supply chain partners.

The results show an evolution in the role of blockchain in supply chain management. Initially, the focus was on introducing conceptual platforms and architectures (2019), which were followed by introducing deployable architectures (2020) and later integration with emerging technologies such as IoT and smart contracts (2021). More recently (2022), the emphasis is on tokenising transactions, improving smart contracts, manufacturing and the circular economy.

In 2019, conceptual architectures and applications based on blockchain technology were presented, which contributed to the traceability of waste in reverse processes and the elimination of information errors in logistical processes through data encryption and immutability of information exchanged between the links in the logistics network, thus favouring the circular economy and sustainability in more sustainable supply chains. Tijan et al. (2019) relate blockchain technology to supply chain management and sustainable logistics. According to the authors, using blockchain-based applications on digital platforms can bring security to the sustainable logistical processes of supply chain management, minimising or eliminating problems of late orders, errors, multiple data entries, and damage to goods, intrinsic to the logistics processes, contributing preventively to the operations of sustainable supply chains. They argue that the basic properties of decentralisation, transparency and security of the blockchain bring visibility to the supply chain, that is, the real-time monitoring of goods throughout the logistical process can reduce errors and delays by rapidly identifying problems, thus fostering new business opportunities and concepts that can be explored. Zhang et al. (2019) highlight the use of an architecture of a conceptual nature based on the application of blockchain in devices equipped with IoT technology to capture reliable input data that will be stored in a big data database to manage the environmental performance of supply chains through a product's LCA, which is widely used to assess the potential environmental impacts of a product or service. To enable the LCA, the authors point out that the blockchain can support the secure collection of reliable data along the supply chain. The authors also highlight the existence of interorganisational, intraorganisational, technical, and external barriers in the implementation of blockchain technology already explored in the scientific literature by other authors, but of equal relevance in adopting this technology. On the other hand, Zhang et al. (2019) point out that, even considering existing risks and costs associated with blockchain implementation, large companies are better positioned to encourage cooperation among their supply chain partners in adopting blockchain technology.

Moreover, Cole et al. (2019) point out that blockchain can be a solution to the problem of a lack of transparency throughout the supply chain due to the concern of the members of the logistics network with the origin of shared data and information. In addition, blockchain contributes to supply chain management operations by reducing the costs of chain transactions due to the decentralisation of financial transactions and elimination of third parties, the management and replenishment of inventories by reducing intermediaries, and the improvement of product security and protection through immutable, encrypted data sharing. Blockchain Peer to Peer networks provide real-time data on the origin of materials, transactions sent and received, purchase orders, and inventory levels. Cole et al. (2019) point out that each transaction, stored in a blockchain network block, can be verified at any time by consensus between the different members of the supply chain. Once verified, the transaction cannot be modified or deleted as modifying or deleting a block requires the consensus of the entire blockchain network (Cole et al., 2019), and thus the immutability provided by the blockchain, which contributes by imputing security to reverse operations and reliability to members of sustainable supply chains.

In 2020, blockchain technology and the adoption of smart contracts based on it allowed the automation of logistical negotiations and the development of applications that supported circular practices in supply chains by managing energy savings, vehicle routing and the location of materials, both in real-time, in addition to the digitisation of logistical activities and development of incentive policies focused on SDGs, allowing more sustainable practices for supply chains. Tan et al. (2020) propose a framework that integrates blockchain technology with IoT and big data technologies for SSCM in which material data can be collected in real-time and used in applications designed to develop sustainable logistics for interested parties, generating positive impacts on sustainable logistics operations, as they guarantee the reliability and immutability of data open to supply chain users.

Furthermore, Tan et al. (2020) highlight the use of smart contracts, applications developed on blockchain platforms, designed to facilitate, verify and automatically execute negotiations between supply chain partners without the need for central authorities, and may even stimulate new business models that can be investigated in future research. The authors add that, even with the potential benefits of using a blockchain based structure to enable sustainable logistics processes, there are costs related to devices, training, operation, and maintenance that infer high risks related to the large investment in implementing the presented structure.

Table 2 Blockchain evolution in SSCM

Year	*Authors*	*Blockchain evolution in SSCM*
2019	Tijan et al. (2019), Cole et al. (2019), Zhang et al. (2019)	Digital platforms and conceptual architectures that enable blockchain-based applications were presented. These applications favour circular practices in logistics management, in addition to improving security and transparency in the supply chain. The use of blockchain in IoT devices to capture reliable data and manage environmental performance was also discussed. Barriers to adopting blockchain technology were also identified.
2020	Tan et al. (2020), Nandi et al. (2020) and Ajwani-Ramchandani et al. (2020)	Deployable blockchain architectures were introduced to facilitate sustainable logistical processes and minimise errors and delays in the supply chain. A framework that integrates blockchain with IoT and big data for SSCM was proposed. The authors pointed out the positive impacts of blockchain-based applications on sustainable logistics operations. The relevance of smart contracts to facilitate negotiations in the supply chain was emphasised. Costs and risks associated with implementing the technology were acknowledged.
2021	Oropallo et al. (2021), Sahoo et al. (2021), Bekrar et al. (2021), Shojaei et al. (2021), Voorter and Koolen (2021) and Shih et al. (2021)	Blockchain integration with emerging technologies, the development of robust architectures for sustainable practices and improvements in recycling performance were noted. Blockchain is beneficial for building trust between partners in SSCM through the immutability of data and decentralised recording of transactions. Blockchain, IoT and smart contracts are proposed to enable the reverse supply chain in an electronic waste management system, promoting recycling. Blockchain-based architecture is suggested to ensure immutable and reliable transaction records in reuse and recycling processes. Blockchain is also used for data traceability in solid waste management in the construction industry. Blockchain is presented as a means of preventing fraud in the retail merchandise return process, by creating a secure and traceable structure. Data protection of the consumer, retailers and other interested parties is ensured while executing smart contracts.
2022	Govindan (2022), Gong et al. (2022) and Hrouga et al. (2022)	Integrating blockchain technologies in logistics activities is highlighted, focusing on tokenisation of transactions and the improvement of smart contracts. The importance of blockchain in manufacturing and circular economy is discussed, focusing on recycling and reuse processes. The authors highlight the advantages of blockchain decentralisation for recycling processes but also point out barriers to its adoption. Digitising information and sharing data in real-time are seen as benefits of blockchain in waste management. However, barriers to technology implementation are also pointed out, including stakeholder reticence and lack of technical skills.

According to Nandi et al. (2020), the characteristics of location, agility, and digitisation (LAD) of supply chains associated with the principles of the circular economy can be enhanced through blockchain technology. According to the authors, circular practices enabled by blockchain technology can support traceability processes, and therefore improve supply chain responsiveness. They also emphasise the importance of digital transformation in organisations as a way to make the blockchain data structure viable through the digitisation of supply chain processes and the ability to visualise data, reducing the complexity and uncertainty of information. Thus, blockchain can contribute to building sustainable and resilient supply chains and strengthen the transition process to the circular economy (Nandi et al., 2020). The integration of process digitisation with blockchain highlights the management of packaging waste through RL for emerging countries focusing on the UN Sustainable Development Goals (Ajwani-Ramchandani et al., 2020).

Barriers to the implementation of blockchain are a way of measuring benefits, the exchange of information in which responsibilities are not clear, the integration of operational technology, and the necessary professional competence (Ajwani-Ramchandani et al., 2020).

The year 2021 was marked by the integration of blockchain with emerging technologies applied in more robust architectures that contributed to more sustainable practices in supply chains, supporting the performance of recycling and reuse of materials in manufacturing (Oropallo et al., 2021). The authors demonstrate applications of blockchain technologies, smart contracts, IoT and big data in LR, prioritising circular processes through more powerful architectures that enable real-time traceability of waste.

Moreover, 2021 was marked by integrating blockchain with emerging technologies, the development of more robust architectures that support sustainable practices in supply chains, and ensuring improvements in recycling performance (Oropallo et al., 2021). The authors demonstrate applications of blockchain technologies, smart contracts, IoT, and big data in RL, prioritising circular processes. According to Oropallo et al. (2021), the implementation of blockchain favours the concept of reliability between partners in the sustainable management of the supply chain through the immutability of data and information exchanged on the blockchain network, as well as the decentralised recording of transactions, eliminating the need for a centralised authority.

Sahoo et al. (2021) propose the use of blockchain, IoT, and smart contracts to enable the reverse supply chain applied in an electronic waste management system arising from the consumption of electrical and electronic equipment to provide complete coverage of the life cycle of these products and the promotion of recycling by creating incentive mechanisms. Bekrar et al. (2021) propose an architecture based on blockchain technology to ensure that transaction records in reuse and recycling processes are immutable and reliable, and thus can help RL processes considering the fragility and limits of supply chains during the COVID-19 pandemic. The authors point out that the application of smart contracts facilitates logistical transactions by attributing responsibility to RL actors while analysing quality requirements in delivery. In the meantime, blockchain contributes to the efficiency of transactions in the logistics network by developing smart contracts.

Within the scope of the circular economy, recycling processes are explored by Shojaei et al. (2021) who presented a study on blockchain applications as a robust and comprehensive infrastructure for solid waste management in the civil construction sector that enables the traceability of important data for the recycling process. Voorter and

Koolen (2021) highlight the importance of tracking construction and demolition waste of proven quality to ensure the circular economy in the civil construction sector.

The authors point out that blockchain can bring more trust and cooperation throughout the supply chain by improving data and information management related to waste generation and its possible reuse. The traceability system, therefore, enables the precise identification of storage, transfer, and reception locations for waste transparently and cooperatively among supply chain users. The introduction of this system, therefore, contributed to the waste management cycle to be circular, guaranteed by the decentralisation of financial transactions that eliminates the need for a third party to manage the financial supply chain and by the cryptographic security that blockchain technology provides to the links in the supply chain.

With the evolution of blockchain technology, Shih et al. (2021) present the application of blockchain in RL through a structure developed on the Ethereum platform that creates a secure and traceable framework to prevent fraud in the process of returning retail goods. In addition, according to the authors, digital footprints, that is, the data traces left by users when using the internet and visiting websites, sending e-mails, or even information sent online, and the rights of consumers, retailers, and other stakeholders are protected from forgery while executing smart contracts on the Ethereum blockchain in RL activities. Moreover, this brings new perspectives to develop research on adopting blockchain technology against fraud and counterfeiting in reverse operations of sustainable supply chains.

It should be mentioned that in 2022, the automation of logistical activities of recycling and remanufacturing processes made possible by enhanced smart contracts (Govindan, 2022), for the tokenisation of supply chain transactions (Gong et al., 2022) based on blockchain technology, helped to promote circular economy principles and practices in manufacturing. It also contributed to the security, reliability and immutability of supply chain transactions making them more sustainable (Hrouga et al., 2022). Govindan (2022) points out that the introduction of blockchain sheds light on the unreliability of data transferred between partners in the remanufacturing value chain. According to the author, blockchain contributes to the integration of circular economy principles and practices into manufacturing through recycling and product reuse processes to implement a sustainable supply chain. In this context, Gong et al. (2022) corroborate the explanation of Govindan (2022), emphasising that the main features of blockchain decentralisation and its transparent and traceable performance can be applied to recycling processes with excellent results, in addition to improving recycling performance through the tokenisation of logistic processes imputing more security to the transactions carried out in the chain. Blockchain, therefore, is an approach to promote waste stream tracking and recycling chain integration, according to the authors.

On the other hand, Gong et al. (2022) highlight the uncertainties and cognitive, technological, internal, and external barriers to blockchain adoption in recycling processes. The authors draw attention to cognitive recycling deficits and to the low knowledge of senior managers about blockchain that reverberates in barriers within organisations, limiting capital invested both in the implementation of the technology and in the development of technical capabilities. This is also reflected in the lack of industrial and government cooperation policies, particularly in mutual support between industries and in the development of public policies that encourage the operation of new businesses related to recycling, eliminating local monopolies that limit circular practices.

Digitising information and sharing data in real-time is highlighted by Hrouga et al. (2022) in the case study in which blockchain is presented as a response to the asbestos treatment problem that has a great impact on human health and the environment. Even with the development of smart contracts leveraged and used in more supply chain activities, the authors describe the reticence of stakeholders to adopt this technology and the lack of technical skills to use blockchain as barriers to implementation. Hrouga et al. (2022) ratify the work of De Oliveira et al. (2022) in which they point out that blockchain technology needs to be further explored in supply chains, in the same way, that emerging technologies such as artificial intelligence and machine learning are under-explored in supply chains and, in turn, sheds light on new business models by integrating blockchain technology within the scope of artificial intelligence.

Therefore, the contributions of blockchain technology to more sustainable supply chains, identified in this work, encompass new concepts introduced in the literature, including the combination of blockchain with IoT and smart contracts to enable the reverse supply chain. Additionally, blockchain has been presented as a means of preventing fraud in the retail merchandise return process, offering a new perspective on merchandise return processes.

In short, blockchain is evolving and shaping SSCM, introducing new concepts and perspectives. However, it also highlights the need for more research to explore these new concepts and address barriers to their implementation.

4 Conclusions

This research is based on a systematic literature review of the connections between blockchain technology, SSCM, and RL. The features and advantages of using blockchain, such as trust, traceability, transparency, and data security, are highlighted as important for minimising logistical problems and increasing the supply chain's resilience. The literature presents conceptual frameworks that integrate blockchain with emerging technologies such as IoT, big data, cloud computing, and smart contracts to increase effectiveness, resilience, and sustainability in supply chain management, including assisting product life cycle assessment systems. More recent studies, from 2021, presented blockchain-based structures with concrete applications in circular processes involving SSCM and RL. These frameworks integrate blockchain with IoT and RFID based smart devices, big data storage, digitalisation of processes through a digital transformation of organisations, cloud computing with the construction of geographically located data centres, and smart contracts that allow the adoption of circular and sustainable business models.

Literature from 2022 presents blockchain applications in sustainable processes in supply chain management and RL secured by the development of smart contracts that guarantee the decentralisation of transactions and the traceability of information in a more efficient, secure, and dynamic manner, ensuring the principles and practices of the circular economy. Digital transformation is seen as an important mechanism for companies to adopt technologies that allow for the sharing and traceability of information throughout the supply chain. However, blockchain implementation still has barriers, such as a lack of awareness about recycling and regulatory uncertainty.

While technological advancements have facilitated the implementation of blockchain, there are still challenges that need to be overcome for the success of these blockchain-based architectures and business models. Some of these challenges include a lack of awareness about the importance of recycling, uncertainties about the success of this technology's application, limitations of capital and technical capabilities of organisations, difficulty in integrating blockchain with existing processes and systems, and the absence of public policies to encourage sustainable practices through partnerships between the public administration and industries.

This work contributes to highlighting the importance of using an implementable and concrete architecture based on blockchain technology to carry out circular practices and RL activities, supporting the transition process from the traditional supply chain to a sustainable chain that is, replacing the concept of end-of-life linear economy by circular flows of reuse and recycling. This, in turn, answers the research question of this study, identifying the applications of blockchain technology in SSCM and RL. It can also be observed, by the results and discussions of this study, that blockchain technology effectively contributes to the recycling processes and is viable since it allows the tracking of the life cycle of materials along the supply chain and the sharing of information in real-time so that the return of a given product is returned to the manufacturer due to its tracking, immutability, and security features.

Thus, the strategic concept of the sustainable supply chain is highlighted and made possible by the architecture based on the blockchain that ensures waste management and the recycling of materials, thus allowing the redesign of processes with environmental, social, and governance (ESG) practices, products and new models of more sustainable businesses and, consequently, reducing the consumption of natural resources. Therefore, the sustainable management of the supply chain, through applications of circular and reverse practices, is presented as a catalyst for competitiveness, promoting innovation and stimulating sustainability.

Finally, this study concludes that blockchain technology can effectively be used to promote sustainable practices in SSCM and RL, but only if combined with other advanced technologies, such as IoT and big data, to optimise the interaction between these themes. Recent innovations, especially smart contracts, have been associated with blockchain to create stronger and more efficient solutions in supply chain management and RL. This study highlights the increasing importance of this topic in scientific literature.

Although few studies still present practical results of blockchain based applications, this systematic review paves the way for future research on the subject. However, it is important to mention that the systematic literature review has its limitations, as it depends on the quality and availability of the studies included in the research. As a suggestion, future studies can investigate the opportunities of sustainable business models in RL, using blockchain technology combined with other emerging technologies such as artificial intelligence, among others.

Although few studies still present practical results of blockchain-based applications, this systematic review paves the way for future research on the subject. However, it is important to mention that the systematic review of the literature has its limitations, as it depends on the quality and availability of the studies included in the research. As a suggestion, future research opportunities can investigate proposals for sustainable business models with logistical activities automated by smart contracts and artificial intelligence implemented in manufacturing and supported by RL that may allow the remanufacturing of waste ensured by its real-time and grounded traceability in public policies to encourage recycling focusing on SDGs, to achieve more sustainable supply chains. It is also important to note gaps and opportunities for future research. Barriers to blockchain implementation such as stakeholder reticence and lack of technical skills have been identified, which highlights the need for more research to overcome these barriers. Furthermore, blockchain decentralisation, despite its benefits, still presents challenges for adoption, indicating another potential area for future study.

Furthermore, more in-depth studies, such as descriptive or normative empirical simulations of blockchain, could expand the understanding of the use of technology in supply chain management and equally contribute to the development of standards that will allow the interoperability of blockchain technology for members of the sustainable supply chain.

References

Ajwani-Ramchandani, R., Figueira, S., Torres de Oliveira, R., Jha, S., Ramchandani, A. and Schuricht, L. (2020) 'Towards a circular economy for packaging waste by using new technologies: the case of large multinationals in emerging economies', *Journal of Cleaner Production*, Vol. 281, https://doi.org/10.1016/j.jclepro.2020.125139.

Alves, L., Ferreira Cruz, E., Lopes, S.I., Faria, P.M. and Rosado da Cruz, A.M. (2022) 'Towards circular economy in the textiles and clothing value chain through blockchain technology and IoT: a review', in *Waste Management and Research*, Vol. 40, No. 1, pp.3–23, SAGE Publications Ltd., https://doi.org/10.1177/0734242X211052858.

Bardin, L. (2011) *Análise de Conteúdo*, 1st ed., Almedina, Edições 70 Lda/Almedina Brasil.

Bekrar, A., Cadi, A.A.E., Todosijevic, R. and Sarkis, J. (2021) 'Digitalizing the closing-of-the-loop for supply chains: a transportation and blockchain perspective', *Sustainability – MDPI*, Vol. 13, No. 5, pp.1–25, https://doi.org/10.3390/su13052895.

Clarivate (2022) *Journal Citation ReportsTM: Reference Guide*, Clarivate, June [online] https://clarivate.com/wp-content/uploads/dlm_uploads/2022/06/JCR-2022-Reference-Guide.pdf (accessed 18 March 2023).

Clarivate (2023) *Journal Citation Reports*, Clarivate [online] https://clarivate.com (accessed 18 March 2023).

Cole, R., Stevenson, M. and Aitken, J. (2019) 'Blockchain technology: implications for operations and supply chain management', *Supply Chain Management*, Vol. 24, No. 4, pp.469–483, https://doi.org/10.1108/SCM-09-2018-0309.

De Oliveira, M.R., de Sousa, T.B., da Silva, C.V., da Silva, F.A. and Costa, P.H.K. (2022) 'Supply chain management 4.0: perspectives and insights from a bibliometric analysis and literature review', *World Review of Intermodal Transportation Research*, Vol. 11, No. 1, pp.70–107.

Dietrich, F., Ge, Y., Turgut, A., Louw, L. and Palm, D. (2021) 'Review and analysis of blockchain projects in supply chain management', *Procedia Computer Science*, Vol. 180, pp.724–733, https://doi.org/10.1016/j.procs.2021.01.295.

Dubey, R., Gunasekaran, A., Papadopoulos, T., Childe, S.J., Shibin, K.T. and Wamba, S.F. (2017) 'Sustainable supply chain management: framework and further research directions', *Journal of Cleaner Production*, Vol. 142, pp.1119–1130, https://doi.org/10.1016/j.jclepro.2016.03.117.

Ellen MacArthur Foundation (2019) *Ellen MacArthur Foundation, Artificial Intelligence and the Circular Economy – AI as a Tool to Accelerate the Transition*, Ellen MacArthur Foundation [online] https://www.ellenmacarthurfoundation.org/publications (accessed 4 February 2023).

Elsevier (2022) *CiteScore Metrics – Scopus*, Elsevier, 22 July [online] https://service-elsevier-com.ez31.periodicos.capes.gov.br/app/answers/detail/a_id/36048/supporthub/scopus (accessed 18 March 2023).

Garza-Reyes, J.A. (2015) 'Lean and green-a systematic review of the state of the art literature', *Journal of Cleaner Production*, Vol. 102, pp.18–29, https://doi.org/10.1016/j.jclepro.2015.04.064.

Georgousis, E., Savelidi, M., Savelides, S., Mosios, S., Holokolos, M-V. and Drinia, H. (2022) 'How Greek students perceive concepts related to geoenvironment: a semiotics content analysis', *Geosciences*, Vol. 12, No. 4, p.172, https://doi.org/10.3390/geosciences12040172.

Gong, Y., Xie, S., Arunachalam, D., Duan, J. and Luo, J. (2022) 'Blockchain-based recycling and its impact on recycling performance: a network theory perspective', *Business Strategy and the Environment*, https://doi.org/10.1002/bse.3028.

Govindan, K. (2022) 'Tunneling the barriers of blockchain technology in remanufacturing for achieving sustainable development goals: a circular manufacturing perspective', *Business Strategy and the Environment*, https://doi.org/10.1002/bse.3031.

Hossin, M.A. and Sabuj, S.R. (2019) 'An IoT-based dynamic traffic management system in perspective of Bangladesh', in *World Review of Intermodal Transportation Research*, Vol. 8, No. 4, pp.391–409.

Hrouga, M., Sbihi, A. and Chavallard, M. (2022) 'The potentials of combining blockchain technology and internet of things for digital reverse supply chain: a case study', *Journal of Cleaner Production*, Vol. 337, https://doi.org/10.1016/j.jclepro.2022.130609.

Idoiaga, N., Berasategi, N., Eiguren, A. and Picaza, M. (2020) 'Iramuteq_exploring children's social and emotional representations of the COVID-19 pandemic', *Frontiers in Psychology*, Vol. 11, https://doi.org/10.3389/fpsyg.2020.01952.

Jardim, L., Pranto, S., Ruivo, P. and Oliveira, T. (2021) 'What are the main drivers of blockchain adoption within supply chain? – An exploratory research', *Procedia Computer Science*, Vol. 181, pp.495–502, https://doi.org/10.1016/j.procs.2021.01.195.

Khanfar, A.A.A., Iranmanesh, M., Ghobakhloo, M., Senali, M.G. and Fathi, M. (2021) 'Applications of blockchain technology in sustainable manufacturing and supply chain management: a systematic review', in *Sustainability (Switzerland)*, Vol. 13, No. 14, MDPI AG, https://doi.org/10.3390/su13147870.

Kouhizadeh, M. and Sarkis, J. (2018) 'Blockchain practices, potentials, and perspectives in greening supply chains', *Sustainability – MDPI*, Vol. 10, No. 10, https://doi.org/10.3390/su10103652.

Mascarenhas, C., Ferreira, J.J. and Marques, C. (2018) 'University-industry cooperation: a systematic literature review and research agenda', *Science and Public Policy*, Vol. 45, No. 5, pp.708–718, https://doi.org/10.1093/SCIPOL/SCY003.

Nakamoto, S. (2008) *Bitcoin: A Peer-to-Peer Electronic Cash System* [online] https://www.bitcoin.org (accessed 27 March 2023).

Nandi, S., Sarkis, J., Hervani, A.A. and Helms, M.M. (2020) 'Redesigning supply chains using blockchain-enabled circular economy and COVID-19 experiences', in *Sustainable Production and Consumption*, Vol. 27, pp.10–22, Elsevier B.V, https://doi.org/10.1016/j.spc.2020.10.019.

Oropallo, E., Secundo, G., Vecchio, P. Del, Centobelli, P. and Cerchione, R. (2021) 'Blockchain technology for bridging trust, traceability and transparency in circular supply chain', *Information and Management*, https://doi.org/10.1016/j.im.2021.103508.

Ouzzani, M., Hammady, H., Fedorowicz, Z. and Elmagarmid, A. (2016) 'Rayyan-a web and mobile app for systematic reviews', *Systematic Reviews*, Vol. 5, No. 1, https://doi.org/10.1186/s13643-016-0384-4.

Pahlevan-Sharif, S., Mura, P. and Wijesinghe, S.N.R. (2019) 'A systematic review of systematic reviews in tourism', *Journal of Hospitality and Tourism Management*, Vol. 39, pp.158–165, https://doi.org/10.1016/j.jhtm.2019.04.001.

Rane, S.B. and Thakker, S.V. (2020) 'Green procurement process model based on blockchain – IoT integrated architecture for a sustainable business', *Management of Environmental Quality: An International Journal*, Vol. 31, No. 3, pp.741–763, https://doi.org/10.1108/MEQ-06-2019-0136.

Russell, D.M., Swanson, D. and Blinge, M. (2018) 'Sustainable logistics and supply chain management: a holistic view through the lens of the wicked problem', in *International Journal of Logistics Economics & Globalization*, *Journal of Retailing and Journal of Business Logistics*, Vol. 7, No. 1, pp.36–56.

Sahoo, S., Mukherjee, A. and Halder, R. (2021) 'A unified blockchain-based platform for global e-waste management', *International Journal of Web Information Systems*, Vol. 17, No. 5, pp.449–479, https://doi.org/10.1108/IJWIS-03-2021-0024.

Salviati, M.E. (2017) *Manual do Aplicativo Iramuteq* [online] https://www.iramuteq.org/documentation/fichiers/manual-do-aplicativo-iramuteq-par-maria-elisabeth-salviati (accessed 11 May 2022).

Shih, D.H., Huang, F.C., Chieh, C.Y., Shih, M.H. and Wu, T.W. (2021) 'Preventing return fraud in reverse logistics – a case study of espres solution by ethereum', *Journal of Theoretical and Applied Electronic Commerce Research*, Vol. 16, No. 6, pp.2170–2191, https://doi.org/10.3390/jtaer16060121.

Shojaei, A., Ketabi, R., Razkenari, M., Hakim, H. and Wang, J. (2021) 'Enabling a circular economy in the built environment sector through blockchain technology', *Journal of Cleaner Production*, Vol. 294, https://doi.org/10.1016/j.jclepro.2021.126352.

Steinhardt, I., Schneijderberg, C., Götze, N., Baumann, J. and Krücken, G. (2017) 'Mapping the quality assurance of teaching and learning in higher education: the emergence of a specialty?', *Higher Education*, Vol. 74, No. 2, pp.221–237, https://doi.org/10.1007/s10734-016-0045-5.

Tan, B.Q., Wang, F., Liu, J., Kang, K. and Costa, F. (2020) 'A blockchain-based framework for green logistics in supply chains', *Sustainability (Switzerland)*, Vol. 12, No. 11, https://doi.org/10.3390/su12114656.

Tijan, E., Aksentijević, S., Ivanić, K. and Jardas, M. (2019) 'Blockchain technology implementation in logistics', in *Sustainability (Switzerland)*, Vol. 11, No. 4, MDPI, https://doi.org/10.3390/su11041185.

Tranfield, D., Denyer, D. and Smart, P. (2003) 'Towards a methodology for developing evidence-informed management knowledge by means of systematic review', *British Journal of Management*, Vol. 14, pp.207–222.

Voorter, J. and Koolen, C. (2021) 'The traceability of construction and demolition waste in Flanders via blockchain technology: a match made in heaven?', *Journal for European Environmental and Planning Law*, Vol. 18, No. 4, pp.347–369, https://doi.org/10.1163/18760104-18040003.

Wohlin, C. (2014) 'Guidelines for snowballing in systematic literature studies and a replication in software engineering', *ACM International Conference Proceeding Series*, https://doi.org/10.1145/2601248.2601268.

Zhang, A., Zhong, R.Y., Farooque, M., Kang, K. and Venkatesh, V.G. (2019) 'Blockchain-based life cycle assessment: an implementation framework and system architecture', *Resources, Conservation and Recycling*, Vol. 152, https://doi.org/10.1016/j.resconrec.2019.104512.