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# REVISTA AIDIS

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## BLOCKCHAIN IN REVERSE LOGISTICS FOR SOLID WASTE MANAGEMENT: A PROPOSAL

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**Abstract**

*Despite the claim that blockchain will revolutionize business, existing research so far is limited regarding frameworks that categorize blockchain application potentials and their implications. In particular, the academic literature is not well-defined on how to adopt this technology for reverse logistics management. In response, this article uses a brief review of the scientific literature and the fundamentals of blockchain technology to discuss about the benefits of implementation of this tool in a reverse logistics flow to obtain greater control and security between the actors of the reverse logistics network in all material collected and directed. Five actors were listed: industry, transport, traders, waste picker cooperative, and recycler. Develop and structure a RL management model, making use of blockchain technology, has potential to enable greater transparency of the tailing's life cycle, increasing the traceability and reliability of the data obtained, and providing lower costs related to the monitoring of disposal.*

**Keywords:** blockchain, reverse logistics, solid waste management.

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## Introduction

One of the great concerns regarding sustainability is the increasing amount of urban solid waste. According to volumes mapped and measured in Brazil, for example, more than 81 million tons of solid urban waste were discarded in 2022, and its collection reached 93% of this total, which represents approximately 76 million tons. However, of these only 46.4 million tons were discarded in landfills (IPEA, 2020; ABRELPE, 2022) and 39% (29.7 million tons) were disposal in irregular places, demanding urgent action to change this scenario of lack of landfills.

In this context, reverse logistics (RL) is a mean to performance efficiency in urban solid waste management, refers to planning and implementing the flow of materials and information from the point of consumption to the point of origin, also including intermediate point for remanufacturing or recycling selection when necessary. It includes the collection of end-of-life products and recapturing their value through repairing, remanufacturing, recycling, or by ensuring proper disposal (Govindan and Soleiman, 2017; Prajapati *et al.,* 2019; Jraisat *et al*., 2022). It is important to highlight that RL is usually associated with private companies' initiatives, involving obligations to collect waste or certain substances from their own products. This tool can significantly impact the urban waste management for the wastes included in RL chains. The adoption of digital technologies in RL activities enhances capabilities such as monitoring, controlling, optimization, and automation (Nasiri *et al*., 2017). One of these technologies that have been studied is the blockchain (Abed *et al.,* 2021; Berdik *et al*., 2021). According to Mougayar (2018), blockchain offers a new paradigm to implement traditional trust in peer-to-peer computational transactions, which can be proven at any time, through operations configured in contracts and smart properties according to their validity and functionality.

Among the reasons for the increased adoption of blockchain in the logistical processes in organizations are the ability to mitigate risks and the transparency in transactions (Dasaklis *et al.,* 2020; Christodoulou *et al.,* 2019; Abu-elezz *et al.,* 2020). As a distributed ledger that ensures transparency and security, blockchain is considered to be an important tool to fix current supply chain problems (Dickson, 2016). There are several other blockchain applications like smart contracts, insurance, supply chain, healthcare (Shahnaz *et al*., 2019), registry, identity management, banking (Monrat *et al*., 2019), stock market, IoT (internet of things), energy (Andoni *et al*., 2019), intellectual property and more (Benisi *et al.,* 2020; Chen *et al.,* 2020; Liu *et al*., 2020).

Therefore, this work aims to provide a concise overview and discussion of the reverse flow in solid waste logistics, aiming to understand the implementation of blockchain by analyzing the actors involved in the reverse chain.

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*Reverse logistic*

The task of planning a RL network is important in managing a supply chain and its project is composed of a series of activities and involves several decisions. Among them, there is the determination of the number of necessary logistics facilities, their capacities, and respective locations, whose planning constitutes a complex problem to solve. These decisions directly affect the total costs of the reverse logistics network (Pishvaee *et al.,* 2010) and the adoption of blockchain technology can play a crucial role to facilitate the transition among the players (Rejeb *et al.,* 2019; Rejeb *et al.,* 2022; Chidepatil *et al*., 2020; Ranjbari *et al*., 2022).

The motivators of RL discussed in this paper were two: economic, and legal, which has a socio-environmental component. The economic aspects refer to the potential financial gains expected after the implementation of the network, through the revenue obtained in the sale of the collected waste. The legal aspect is related to the obligation imposed by the government, with supervision by a competent agent that will certainly motivate the practice of RL. Legal motivators also refer to the jurisdiction that indicates that the company must recover the product and the consumer must return it. In Brazil, there is the National Policy on Solid Waste - PNRS (Brasil, 2010), but its implementation and inspection are still timid. For some specific types of waste, there are laws or agreements that impose limits or somehow encourage reverse logistics (Mol *et al*., 2022; Gonçalves, 2021; Gonçalves *et al*., 2022).

*Blockchain*

Legally, the blockchain validates transactions, replacing previously trusted entities. Blockchain is a mechanism for replicating, sharing, synchronizing, and processing data spread across different geographic locations such as multiple websites, countries, or organizations. Thus, the main property of blockchain technology is the lack of a central administrator or centralized storage of data (Walport, 2016). Consequently, various commercial and proof-of-concept solutions based on blockchains have emerged in domains such as energy, supply chain, property, food, health, waste, identity management, elections, and collectibles (Iansiti & Lakhani, 2017; Underwood, 2016; Efanov & Roschin, 2018). The application of blockchain depends a lot on the engagement of all the links involved in the network formed. However, it is important to ratify that the technology is multifunctional, generating the possibility of application in different segments, causing changes in behavior, and procedure, and validating an adequate standard to be experienced by society (Guedes *et al.,* 2021).

The reuse and recirculation of products and materials are the basis of the concept of the circular economy. Blockchain technology has been used to integrate waste management and circular economy, applying emergent concepts that target minimizing waste generation and fluctuations of resource commodities. Blockchain can support a circular economy and green principles by enabling information transparency, reliability, and automation (Xavier *et al*., 2021;

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Bhubalan *et al*., 2022). Blockchain presents a technological capability to improve control of waste movement and waste management activity. Blockchain is an emerging distributed ledger technology that offers many benefits of data security, autonomy, transparency, auditability, privacy, immutability, efficiency, speed, and cost savings. It shares authority and responsibility, facilitating the creation of autonomous, secure, and transparent systems by providing trust between entities participating in the chain (Oropallo *et al.,* 2021; Sanka & Cheung, 2021). As described by Jraisat *et al*. (2022), blockchain technology had good results in industries in these areas: food, pharmaceutical, electronic, and toys. It also may be applied in health, education, business, financial, governance, and several areas associated with management demands, increasing transparency of processes, security, efficiency, and trust.

## Metodology

This work make a brief review of the scientific literature on RL and blockchain structures including their properties. The delineation of the problem consists of identifying how blockchain technology can be implemented in RL and its respective actors. This research contributes by leveraging information that can be useful for further in-depth studies, highlighting the potential of the technology in question. The study can be considered exploratory, since, in the course of the text, the form of operation of the blockchain will be explained, clarifying more details about the mechanism and architecture, expanding its use, in addition to exploring segments of activity. This work focused on a qualitative approach, outlining possible horizons of application.

According to the PMBOK (Project Management Body of Knowledge) guide, a process can be considered as a set of actions and activities that are performed to achieve a predefined result, which can be a product or a service. The visual presentation of the activities of a process is very important. The AS IS and TO BE processes mapping allows the organization to demonstrate the scope of an activity, being able to compare the real and the expectation, after suggested changes. AS IS process mapping is the definition of the current situation of the organizational or business process. TO BE process mapping, on the other hand, is the definition of the future situation of the organizational or business process.

A brief simulation was performed to monitor and evaluate the established parameters, as well as the behavior of the inserted variables. The simulation of the network on the blockchain had as structure a TypeScript to generate an application in Angular within the Stackblitz platform, starting to structure "nodes" of the chain and a private network, to interact in the network understanding the concept of wallets, addresses, and transfers (Xavier *et al.,* 2021). The analysis of this network on the blockchain also included the traceability of the RL chain. Inspections and records were also carried out to update the progress of the blockchain network, to validate the following information:

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a) Quality of published data;
b) Distribution of RL among the actors involved;
c) Effect of the use of blockchain technology on the result;
d) Possibility of identifying a waste disposed of incorrectly.

## Results and discussion

*Current reverse logistic model*

The RL in Brazil usually follows a system composed of at least 5 actors, namely the industry, transport, traders, waste picker cooperative, and recycler. The industry is responsible for the generation of waste and/or purchase of treated inputs; transport to the plant where the collectors' cooperative operates; traders have the responsibility of receiving waste and directing it to manufacturers; waste picker cooperative separates materials by type and color, prepares them for sale through processes such as compaction/baling, shredding, allocation in buckets for transport; recycler receives batches of waste for treatment, which can be reused.

As a proposal, a structure capable of relying on blockchain and IoT technologies was created, aiming at transparency, auditability, and immutability of the records stored. The idea would be to rely on blockchain as a layer of our system allowing the framework to also be integrated with existing traditional software systems (such as CRM and ERP). As mentioned in the literature review, it would be interesting to take advantage of modern edge devices like gateways that can be used directly as full nodes of blockchain implementation, thus increasing the resilience, decentralization, security, and trust of the entire network.

*Proposed reverse logistics model*

As mentioned before, the RL process represents one of the main challenges: the need to achieve a management process that is transparent, reliable, and auditable within the supply chain. These challenges are found in the great capillarity of involved actors, stakeholders, and business models and the lack of clear data regarding governance. In general, RL is in the consolidation phase in Brazil, with numerous actions still underway due to the complexity of the various chains proposed in national policy. As previously mentioned, a significant amount of waste is still being sent to irregular places in Brazil, posing a major challenge. Additionally, the current state of waste management services is characterized by informality. Consequently, industries are working on structuring ways to implement RL and enhance the organization of these chains. This underscores the significant opportunity for blockchain to be incorporated into these processes.

In the proposed model, we would have the actors connected to the platform, so that they can transact the waste lots through the application of the blockchain, making the process available to the entire chain, and making visible the cases where there is no cooperation to take the package

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to a correct destination. Within this context, the proposal is to have a structure capable of relying on blockchain and IoT technologies to provide immutable and tamper-proof records, along with its potential to allow trust and reliability in the environment.

The idea would be to rely on blockchain as a layer of our system allowing the framework to also be integrated with existing traditional software systems (such as CRM and ERP). The Figure 1 shows the blockchain interaction diagram.

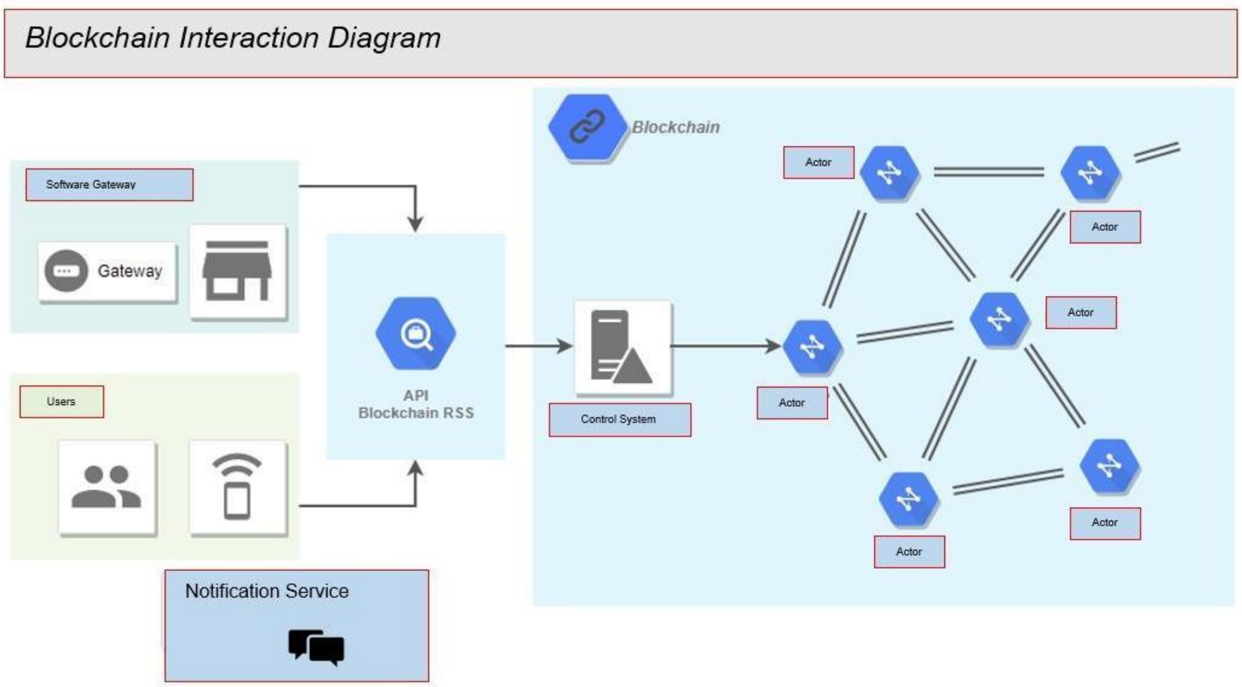


**Figure. 1.** Blockchain interaction diagram proposed.

Thus, to provide users with a complete history of the products and waste produced and disposed off correctly, it will be necessary for all participants to be registered users of the blockchain, which means that they have the correct public/private key pairs to digitally sign each transaction on the blockchain ledger. In the form of the RL chain, we would have the following nodes, according to Figure 1:

- API: An application interface containing a set of established routines and standards, so that other applications can use the features of this application, without needing to know the details of the software implementation. Allowing interoperability between applications (facility to link to public network application systems for example).

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- Blockchain: Component of the system, implemented through smart contracts, powered on Etherium, where the complexity can vary depending on the client interfaces for that blockchain.
- Delivery to the carrier: The city hall transfers ownership of the waste to the carriers, directly through the blockchain. Note: sensors and smart contracts can automate this process, or create logs whenever anomalies are detected during the delivery phase (e.g. sensor values outside certain thresholds).
- Transporters: Transport companies store data on the blockchain about the amount of waste received, and eventually the amount of waste lost during the transport phase. Note: Sensors can automate this data entry process (e.g. connected weighing scales), while smart contracts can trigger autonomously, creating records whenever anomalies are detected (e.g. quantity packed is greater than the received amount).
- Solid Waste Sorting Center (cooperatives and associations): carriers transfer ownership of the waste to the sorting center, through the blockchain, which in turn stores data on the amount of waste received, the amount prepared, and the type of process used.
- Recycler: Recyclers, in turn, store data on the amount recovered and, eventually, the amount of waste lost during the processing phase.
- Disposal: Recyclers store details about processed waste on the blockchain. Quantities and types of wastes discarded, while users across the board are able to transparently check the entire history of a batch of waste.

The need for precise planning to measure the volume required to store information should be determined before using blockchain technology (Batubara *et al*., 2018). Blockchain dumps central authorities and facilitates the creation of secure, autonomous and transparent systems by providing trust between untrusted entities. Many companies, consortia and countries have currently incorporated blockchain into their systems for its benefits after successful testing (Sanka & Cheung, 2021). The significant impact can come from the large-scale deployment of smart contracts, which could transform existing logistics systems and eliminate the need for paper-based administrative procedures and could serve as a means to reduce costs and virtually remove the possibility of human error. These smart contracts can facilitate improving the efficiency of agreements between parties throughout the reverse chain. The identification of these potential applications and categorization of usage scenarios according to their novelty and coordination effort can help managers identify suitable business opportunities and corresponding departure points.

Therefore, it is important to research the application of blockchain in RL to identify the behavior of variables concerning control mechanisms. The interface of waste with industry 4.0 can promote cost reduction, and predictability and allow gains between the links in the RL chain (Dantas *et al.,* 2021). Blockchain and the IoT have accelerated e-commerce growth and empowered online businesses to create value even in a globally competitive environment (Prajapati *et al.,* 2022).

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Also is important to highlight the possibilities of applying blockchain technology. Since the beginning of the process, as identification of waste generation refers to the primary identification of different types of wastes and their classification. This first step is essential to ensure risk management and guarantee the segregation of waste based on the present toxicity characteristics. The waste separation and packaging are the next stage and refers to the packaging of waste according to various conditions. The next stage is the waste storage containers, refer to cases of temporary storage of waste. Finally, the waste collection, treatment, and final disposal of waste (can include disposal, washing, recycling, etc., on the waste to be managed effectively), being necessary waste management regulations, including rules and regulations related to the many types of waste (these may consist of in laws).

Mechanisms designed not to manipulate information in the blockchain allow different users to inappropriate use the information contained in databases (Werbach, 2018). To improve the speed of access to information, the user is always provided with the information of the needed nodes, which is due to the nature of blockchain technology, which somehow connects all nodes (Ahram *et al*., 2017). Despite the larger possibility of application and robustness, the diversity of various software used by users of blockchain technology can be a problem. The high volume of information within the chain makes it necessary to use an operating system with a very high processing capacity, which can be challenging for the proper use of blockchain technology (Bamakan *et al*., 2022).

## Conclusion

It is necessary to expand knowledge about the potential of blockchain in RL chain, highlighting the existing possibilities in the use of this technology. There are several efforts and proposals for improving the scalability of blockchain, however, it is difficult to solve the blockchain scalability issues without compromising either the security, decentralization, or trust of the blockchain. Develop and structure a RL management model, making use of blockchain technology, has potential to enable greater transparency of the tailing's life cycle, increasing the traceability and reliability of the data obtained, and providing lower costs related to the monitoring of disposal.

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## Referências

Abed S., Jaffal, R., Mohd, B.J., Al-Shayeji, M. (2021) An analysis and evaluation of lightweight hash functions for blockchain-based IoT devices. *Cluster Computing*. **24**(4), 3065-3084. https://doi.org/10.1007/s10586-021-03324-1

ABRELPE (Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais) (2022) Panorama dos Resíduos Sólidos no Brasil, São Paulo. Acesso em: 26 dez. 2023. Disponível em: http://abrelpe.org.br

Abu-elezz, I., Hassan, A., Nazeemudeen, A., Househ, M., Abd-alrazaq, A. (2020) The benefits and threats of blockchain technology in healthcare: A scoping review. *International Journal of Medical Informatics* **142**(104246). https://doi.org/10.1016/j.ijmedinf.2020.104246

Ahram, T., Sargolzaei, A., Sargolzaei, S., Daniels, J., Amaba, B. (2017) Blockchain technology innovations. 2017 IEEE Technology and Engineering Management Society Conference, TEMSCON 2017, 137–141. https://doi.org/10.1109/TEMSCON.2017.7998367

Andoni, M., Robu, V., Flynn, D., Abram, S., Geach, D., Jenkins, D., McCallum, P., Peacock, A. (2019) Blockchain technology in the energy sector: A systematic review of challenges and opportunities. *Renewable and Sustainable Energy Reviews* **100**, 143–174. https://doi.org/10.1016/j.rser.2018.10.014

Bamakan, S. M. H., Malekinejad, P., Ziaeian, M. (2022) Towards blockchain-based hospital waste management systems; applications and future trends. *Journal of Cleaner Production* **349**(131440). https://doi.org/10.1016/j.jclepro.2022.131440

Batubara, F. R., Ubacht, J., Janssen, M. (2018) Challenges of blockchain technology adoption for e-government: A systematic literature review. *ACM International Conference Proceeding Series*. https://doi.org/10.1145/3209281.3209317

Benisi NZ, Aminian MJ, Javadi B. (2020) Blockchain-based decentralized storage networks: A survey. *Journal of Network and Computer Applications*. **162**(102656).

Bhubalan K, Tamothran AM, Kee SH, Foong SY, Lam SS, Ganeson K, Vigneswari S, Amirul AA, Ramakrishna S. (2022) Leveraging blockchain concepts as watermarkers of plastics for sustainable waste management in progressing circular economy. *Environmental Research*, **213**(113631). https://doi.org/10.1016/j.envres.2022.113631

Brasil (2010) *Lei nº 12.305, de 2 de agosto de 2010. Institui a Política Nacional de Resíduos Sólidos; altera a Lei no 9.605, de 12 de fevereiro de 1998; e dá outras providências.* Acesso em: 22 out. 2021. Disponível em: http://www.planalto.gov.br/ccivil_03/_ato2007-2010/2010/lei/l12305.htm.

Chen F, Xiao Z, Cui L, Lin Q, Jianqiang L, Yu S. (2020) Blockchain for Internet of things applications: A review and open issues. *Journal of Network and Computer Applications*. **172**(102839).

Chidepatil, A., Bindra, P., Kulkarni, D., Qazi, M., Kshirsagar, M., Sankaran, K. (2020) From trash to cash: How blockchain and multi-sensor-driven artificial intelligence can transform circular economy of plastic waste? *Administrative Sciences*, **10**(2). https://doi.org/10.3390/admsci10020023

Christodoulou, K., Ch Sirakoulis, G., Christodoulou, P., Chatzichristofis, S. A., Sirakoulis, G. C. (2019). RandomBlocks: A Transparent, Verifiable Blockchain-based System for Random Numbers Computing Material in Architecture View project RandomBlocks: A Transparent, Verifiable Blockchain-based System for Random Numbers. *Journal of Cellular Automata*, 0, 1–15. https://doi.org/10.13140/RG.2.2.21366.96328

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Dantas TET, Souza ED, Destro IR, Hammes G, Rodriguez CMT, Soares SR. (2021) How the combination of Circular Economy and Industry 4.0 can contribute towards achieving the Sustainable Development Goals. *Sustain. Prod. Consum*. **26**, 213–227. https://doi.org/10.1016/j.spc.2020.10.005

Dasaklis TK, Casino F, Patsakis C. (2020) A traceability and auditing framework for electronic equipment reverse logistics based on blockchain: The case of mobile phones. In: 2020 11th International Conference on Information, Intelligence, Systems and Applications IISA. IEEE, 2020. p. 1-7.

Dickson B. (2016) Blockchain has the potential to revolutionize the supply chain. Techrunch, 2016. Acesso em: 28 oct 2019. Disponível em: https://techcrunch.com/2016/11/24/blockchain-has-the-potential-to-revolutionize-the-supply-chain

Efanov D, Roschin P. (2018) The All-Pervasiveness of the Blockchain Technology. *Procedia Computer Science*, **123**, 116-121.

Gonçalves MFS (2021) Logística reversa aplicada em resíduos sólidos. Editora Mackenzie. Edição 1. 2021.

Gonçalves, M. F. S., Filho, G. P., Couto, A. A., Silva, A. S., Miranda, F. S., Massi, M. (2022). Evaluation of thermal plasma process for treatment disposal of solid radioactive waste. *Journal of Environmental Management*, 311, 114895. https://doi.org/10.1016/j.jenvman.2022.114895

Govindan K.; Soleimani, H. (2017) A review of reverse logistics and closed-loop supply chains: a Journal of Cleaner Production focus. *Journal of Cleaner Production*, 142, 371–384

Guedes ALA, Soares CAP, Rodriguez MVR (2021) Smart Cities Cidades Inteligentes nas Dimensões: Planejamento, Governança, Mobilidade, Educação e Saúde. 1ª Edição.

Iansiti M., Lakhani K.R. (2017) The truth about blockchain. Harvard Business Review, **95**, 118-127.

IPEA, Instituto de Pesquisa Econômica Aplicada. Relatório Anual 2020. Accessed in: 28 oct 2019. Disponível em: https://www.ipea.gov.br/cts/pt/central-de-conteudo/artigos/artigos/217-residuos-solidos-urbanos-no-brasil-desafios-tecnologicos-politicos-e-economicos

Jraisat L., Jreissat M., Upadhyayc A., Kumar A. (2022) Blockchain Technology: The Role of Integrated Reverse Supply Chain Networks in Sustainability. *Supply Chain Forum: An International Journal*, **24**(1), 17-30. https://doi.org/10.1080/16258312.2022.2090853

Liu Y., He D., Obaidat M.S., Kumar N., Khan M.K., Choo K.K. (2020) Blockchain-based identity management systems: A review. *Journal of Network and Computer Applications*. **166**(102731). https://doi.org/10.1016/j.jnca.2020.102731

Monrat, A. A., Schelén, O., Andersson, K. (2019) A survey of blockchain from the perspectives of applications, challenges, and opportunities. *IEEE Access* (7, 117134–117151). Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/ACCESS.2019.2936094

Mol, MPG., Rava, T., Arthur, Z., Neves, C., Roriz, G., Luiza, J., Tolentino, L., Tobias, R., Barros, D. V., Heller, L. (2022). Healthcare waste generation in hospitals per continent: a systematic review. *Environmental Science and Pollution Research*, **29**(28), 42466–42475. https://doi.org/10.1007/s11356-022-19995-1

Mougayar W. (2018) Blockchain para negócios: promessa, prática e aplicação da nova tecnologia da internet. Alta Books Editora.

Nasiri, M., Tura, N., Ojanen, V. (2017) Developing disruptive innovations for sustainability: A review on Impact of Internet of Things (IOT)', PICMET 2017 - Portland International Conference on Management of Engineering and Technology: Technology Management for the Interconnected World, *Proceedings*, 1–10. https://dx.doi.org/10.23919/PICMET.2017

http://dx.doi.org/10.22201/iingen.0718378xe17.2.85085
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Oropallo E, Secundo G, Vecchio P, Centobelli P, Cerchione R. (2021) Blockchain technology for bridging trust, traceability and transparency in circular supply chain. *Inf. Manag*. 103508. https://doi.org/10.1016/j.im.2021.103508

Prajapati, H., Kant, R., Shankar, R. (2019) Bequeath life to death: Stateof-art review on reverse logistics, *Journal of Cleaner Production*, **211**, 503–520

Prajapati D., Jauhar S.K., Gunasekaran A., Kamble S.S., Pratap S. (2022) Blockchain and IoT embedded sustainable virtual closed-loop supply chain in E-commerce towards the circular economy. *Computers & Industrial Engineering*. **172**(108530). https://doi.org/10.1016/j.cie.2022.108530

Pishvaee M.S., Farhani R.Z., Dullaert W. (2010) A memetic algorithm for bi-objective integrated forward/reverse logistics network design. *Computers & Operations Research*, **37**, 1100-1112.

Ranjbari, M., Shams Esfandabadi, Z., Shevchenko, T., Chassagnon-Haned, N., Peng, W., Tabatabaei, M., Aghbashlo, M. (2022). Mapping healthcare waste management research: Past evolution, current challenges, and future perspectives towards a circular economy transition. *Journal of Hazardous Materials*, **422**, 126724. https://doi.org/10.1016/J.JHAZMAT.2021.126724

Rejeb A., Zailani S., Rejeb K., Treiblmaier H., Keogh J.G. (2022) Modeling enablers for blockchain adoption in the circular economy. *Sustainable Futures*. **4**(100095). https://doi.org/10.1016/j.sftr.2022.100095

Rejeb A., Keogh J.G., Treiblmaier H. (2019) Leveraging the Internet of Things and Blockchain Technology in Supply Chain Management. *Future Internet*, **11**(7) 161, 2019.

Sanka, A. I., Cheung, R. C. C. (2021). A systematic review of blockchain scalability: Issues, solutions, analysis and future research. *Journal of Network and Computer Applications*, **195**, 103232. https://doi.org/10.1016/j.jnca.2021.103232

Shahnaz, A., Qamar, U., Khalid, A. (2019). Using Blockchain for Electronic Health Records. *IEEE Access*, **7**, 147782–147795. https://doi.org/10.1109/ACCESS.2019.2946373

Underwood S. (2016). Blockchain beyond bitcoin. Communications of the ACM, 59, 15-17.

Xavier L.H., Giese E.C., Ribeiro-Duthie A.C., Lins F.A.F. (2021) Sustainability and the circular economy: A theoretical approach focused on e-waste urban mining. *Resources Policy.* **74**(101467). https://doi.org/10.1016/j.resourpol.2019.101467

Walport M. (2016). Distributed Ledger Technology: Beyond Blockchain. UK Government Office for Science.