Information & Management xxx (xxxx) xxx

Contents lists available at ScienceDirect

Information & Management

journal homepage: www.elsevier.com/locate/im

# Blockchain technology for bridging trust, traceability and transparency in circular supply chain

Piera Centobelli [a], Roberto Cerchione [b,*], Pasquale Del Vecchio [c], Eugenio Oropallo [a], Giustina Secundo [c]

[a] Department of Industrial Engineering, University of Naples Federico II, P. le Tecchio 80, 80125, Naples, Italy
[b] Department of Engineering, University of Naples Parthenope, Centro Direzionale di Napoli Isola C4, 80143, Naples, Italy
[c] Department of Management, Finance and Technology, University LUM Giuseppe Degennaro, S.S. 100, Km 18, Casamassima-Bari, Italy

A R T I C L E I N F O

*Keywords:*
Circular blockchain
Circular economy
Circular supply chain management
Distributed ledger
Platform design
Private and permissioned blockchain
Reverse logistics service providers (RLSPs)
Smart contract

A B S T R A C T

Trust, traceability, and transparency emerge as critical factors in designing circular blockchain platforms in supply chains. To bridge the three circular supply chain reverse processes (i.e., recycle, redistribute, remanufacture) and the three factors affecting blockchain technologies (i.e., trust, traceability, transparency), this paper proposes the integrated Triple Retry framework for designing circular blockchain platforms. A circular blockchain platform was designed in a supply chain, including manufacturer, reverse logistics service provider, selection centre, recycling centre, and landfill. The results highlight blockchain's role as a technological capability for improving control in the movement of wastes and product return management activities.

## 1. Introduction

The local and global pressures of the government, community, and consumers to achieve sustainability objectives motivate researchers to investigate how new technologies can support organisations in implementing environmental strategies and achieving corporate environmental performance [17, 37, 51, 69, 71, 99]. In this context, the blockchain technology could provide promising results to address the supply chain's sustainability in terms of *trust, traceability and transparency* [22, 89, 101].

One of the most critical aspects in the use of blockchain applications is related to monitoring social and environmental conditions in order to control and avoid the occurrence of health and safety problems [3]. Adopting blockchain technology along a supply chain offers the opportunity to guarantee respect for human rights and fair work practices. For instance, a transparent register of product history assures buyers that the products purchased are supplied and manufactured from eco-sustainable sources. Smart contracts may be particularly capable of independently following the rules for monitoring and verifying sustainable regulatory terms and policies (Iansiti & Lakhani, 2011; [32, 81]).

Blockchain can cause disintermediation of the supply chain in which a lower number of levels entails transaction costs and reduced time, reducing company wastes in the supply chain [23, 70, 93]. *Firstly, blockchain technology can guarantee safety and authenticity by helping to reduce resource consumption.* For instance, traditional energy systems have a centralised management model with high-pressure drops in very extended networks. On the contrary, a peer-to-peer network based on blockchain technology could lead to the network amplitude reduction and, therefore, drastically reduce the energy wasted over long distances and decrease in storage facilities [39]. As a result, there are several platforms based on blockchain technology with the scope to reduce the wastes of the supply chain (e.g., Echchain, ElectricChain, Suncontract).

*Secondly, blockchains can guarantee that products sold as environmentally friendly are really like that.* One example is the approval of the forest certification program that tracks the origin of around 740 million acres of certified forests worldwide using blockchain technology [77]. *Thirdly, in a circular economy context, the blockchain can guarantee an improvement in recycling performance.* For instance, in Northern Europe, people are motivated to recycle by providing rewards in the form of cryptographic tokens. In this direction, the blockchain-based project Social Plastic has demonstrated how it is possible to reduce plastic waste by turning it into money [79].

With these premises, trust, traceability, and transparency emerge as

* Corresponding author.
*E-mail address:* roberto.cerchione@uniparthenope.it (R. Cerchione).

https://doi.org/10.1016/j.im.2021.103508
Received 29 June 2020; Received in revised form 23 July 2021; Accepted 24 July 2021
Available online 27 July 2021
0378-7206/

Please cite this article as: Piera Centobelli, *Information & Management*, https://doi.org/10.1016/j.im.2021.103508

critical factors in designing circular blockchain platforms in supply chains. In setting up the research, it emerges the necessity to bridge the three circular supply chain reverse processes (i.e., recycle, redistribute, remanufacture) and the three main factors affecting blockchain technologies (i.e., trust, traceability, transparency). This literature gap allows us to formulate the following research question (*RQ*):

**RQ**. *'How can blockchain technology improve trust, traceability, and transparency in circular economy processes?'*

Despite the growing interest of the scientific community and the increasing number of recent theoretical contributions published on the topic, this paper proposes an experimental blockchain platform design and implementation to provide an answer to this *RQ*.

This paper aims to highlight the evolution of trust, traceability, and transparency in circular processes, before and after blockchain technology implementation. The research objectives include: (1) defining a blockchain-based circular network framework; (2) designing a proof-of-concept (PoC) of a circular blockchain platform; (3) evaluating the potential value-added in the circular economy network; and (4) providing research and managerial guidelines for creating blockchain platforms supporting the transition towards a circular economy.

This empirical approach contributes to the blockchain field translating theoretical concepts into practice and contributing to bridging the gap between industry and university.

The circular blockchain platform was firstly implemented in a reverse logistics service provider (RLSP), providing industrial waste disposal services for multinational companies operating in the automotive and railway manufacturing business. The platform's testing network included the RSLP, manufacturers, selection centers, recycling plants, and landfills. The full comprehension of the state of the art about the impact of blockchain technology in the circular economy domain requires to clarify the meaning of their single concepts and intersections. As an emerging topic arising at the intersection between digitalization and sustainability, the concept of blockchain for the circular economy is defined as "a technology for a sustainability transformation of the linear economic paradigm" ([14], p. 526). In the same direction, the paper will focus on the circular supply chain concept as the "integration of circular thinking into the management of the supply chain and its surrounding industrial and natural ecosystems" ([33], p. 884).

The remainder of this paper is organised as follows. Section 2 provides a theoretical background of blockchain implementation in the circular economy, supply chain management, and circular supply chain domains. Section 3 presents a conceptual framework for the circular blockchain implementation, whereas Section 4 provides a comprehensive definition of the proposed Triple Retry framework. Section 5 discusses the research approach and the main phases of the circular blockchain platform design were reported in Section 6. Section 7 discusses the results on the impact of the circular blockchain platform. Finally, Section 8 draws the conclusions and implications of this study.

## 2. Literature review

This section presents the main results of a literature review conducted to analyse the state of the art of blockchain in circular processes. In order to ensure a high level of the rigorousness of systematic literature review [91], the search was conducted using two academic databases (Scopus and Web of Science) from 1960 until 2020 and a set of selected keywords such as "blockchain*" AND "block chain*" was used in combination with circular economy and supply chain keywords (e.g., "circular economy", "circular process*", "circular suppl*", "closed loop*") to get all the documents dealing explicitly with the topic investigated.

As for exclusion criteria, only papers published between 2008 and 2020 were considered in the final sample, since the theoretical foundation of the blockchain concept dates back to Nakamoto [61]. Finally, to ensure the quality of review analysis, conference proceedings and book chapters were excluded as a second exclusion criterion, and only articles and reviews published in peer-reviewed journals were included in the final sample [27, 62]. It has also been adopted refinement and validation criteria to minimize the chances of missing any article on the domain (inclusion criterion) [82]. Specifically, using the academic databases' functionalities, adopted strings have been validated by comparing their keywords with other keywords used by the individual papers identified in the initial list. This validation criterion allows to identify and retrieve any important papers cited in the literature, but not selected using the selected databases and keywords [82]. The selected papers were reviewed to identify the main topic areas and evidence research gaps to be investigated. Three main topic areas are identified: 1) blockchain and circular economy; 2) blockchain and supply chain management, and 3) blockchain and circular supply chain. Three main subsections will be included to describe and discuss the literature in these three areas.

### 2.1. Blockchain and circular economy

Blockchain and smart contracts can be an effective solution for dealing with issues of counterfeits, data security and privacy, operating costs, and bureaucratic hurdles in the field of circular economy (CE) [26, 78].

Firstly, the CE is a mature domain, in which most of the dynamics are highly standardised and with a wide range of valid key performance indicators to use, providing the right inputs for smart contract coding. Secondly, the CE ecosystem is a multi-layered combination of material streams from suppliers, manufacturers, logistics service providers, distributors, retailers, producing a considerable amount of data ([28, 78]; Shazad et al., 2020). Smart contracts can deal with a massive quantity of data in few seconds, avoiding intermediaries and reducing the costs of transactions [26]. Thirdly, a huge amount of information and data are exchanged amongst parties because communications and collaborations are frequent in the CE network [48, 92]. Fourthly, the relationship between distributors and consumers is changing. A new dynamic distributor-to-consumer (D2C) process underlines the necessity to clarify the role of a smart contract-based model that may improve the efficacy of D2C transactions and prevent counterfeiting [92].

Furthermore, in the CE domain, blockchain can enable new decentralised systems and applications to improve data managing, sharing, transparency, and control level costs. For instance, the different authorities can pull the benefits while maintaining control over the blockchain application costs [21, 48, 78]. In this way, it is possible to control all potential assets [29, 48, 92], and smart contracts represent an attractive and more efficient alternative to a centralised circular economy asset monitoring system for environmental regulators [84, 92].

With blockchain implementation, smart contracts are used to make transactions between different users *faster and more effective* [20]. Smart contracts are performed automatically and independently on each network node, according to the data contained in the transaction [48].

There are many applications of blockchain technology in the CE domain. In order to achieve sustainable development, a balance between social, economic, and environmental issues was analysed [49]. Implementing blockchain solutions would simplify energy supply procedures, reduce request volatility, and allow to produce in real-time the quantity required by the market [49]. In this way, it would be possible to optimise and save natural resources [80].

### 2.2. Blockchain and supply chain management

Modern supply chains are changing radically with the introduction of Industry 4.0 enabling technologies. According to Saberi et al. [78], supply chains are becoming very complex systems, managing new partners and the evolution of old ones, geographically scattered and with the aim strictly orientated to satisfy even more demanding customers. At the same time, in a globalized supply chain, traceability and transparency have become crucial requirements. Blockchain technology can support to build supply chains with strong traceability and transparency characteristics (e.g. through the use of advanced RFID and GPS technologies) and deal with environmental, financial, and social sustainability issues.

Previous technologies, such as Electronic Data Interchange (EDI) or other similar technologies, allowed companies to move from paper-based to paperless transactions [60]. EDI enables the computer-to-computer sharing of documents in a common electronic format, resulting in lower costs, faster processing, fewer mistakes, and better traceability for partners.

Blockchain has the potential to affect the supply chain, notably as a potential successor to EDI for quickly and efficiently exchanging information between parties. The adoption of blockchain can be a game changer for the supply chain, removing the traditional system's flaws and inefficiencies.

In a typical adoption of EDI in the field of supply chain management, data processing and exchange are all controlled by separate systems. Conversely, using blockchain technology, data, information, and knowledge flows in a supply network are retrieved from a single integrated system.

EDI and blockchain, on the other hand, might be complementary rather than alternative technologies. EDI is a means of sharing information that blockchain can keep in its ledgers, process data with smart contracts, share and exchange data through its consensual mechanism. Global supply chain platforms are expected to leverage blockchain technology on EDI networks to enhance the sharing of information between companies and improve supply chain performance. Each event is validated and recorded to build an immutable and transparent book of records. As a result, the implementation of blockchain in supply chain networks may certainly minimize the challenges that are so prevalent in traditional management systems.

### 2.3. Blockchain and circular supply chain

The uses of blockchain in the context of the supply chain are still open to interpretation and development. Despite many blockchain applications tend to use public privacy systems, blockchain-based supply chain networks may require a more closed, private, and permissioned blockchain with multiple and limited players [86].

The administrators decide what information can be visualized and added based on the role of each supply chain participant. The blockchain's intrinsic configuration manages transaction nodes and defines their roles in accessing or changing the blockchain, including maintaining the identity of each supply chain participant in the blockchain network [96]. Thus, regulators are required to determine the role of each supply chain participant, even though this must be done by consensus mechanisms so that no one feels disadvantaged [36, 87].

In a blockchain-based supply chain, four main entities play a key role: *certificate authority* (who provide unique identities to the actors in the network), *network administrators* (who define standards schemes, such as blockchain policies and technological requirements for the network), *membership service provider* (who provide certifications to the actors for participating in the network), and the other *actors* (including manufacturers, reverse logistics service provider, selection centre, recycling centre, landfill, that must be certified by a registered auditor or certifier to maintain the system trust) [79, 86]. These actors ensure that the nodes and processes within the blockchain network are entirely truthful. When a new actor is added to the network, the certificate authority creates a temporary account with limited functions after conducting an initial verification of the new users' suitability for the tasks for which they have been added to the network [87]. Once this new user has been added, this inclusion is shared on the network via smart contract, and the certifiers definitively authenticate the new user through an historical analysis of his business behaviour by membership service provider. If the new actor turns out to be a truthful actor, this definitively unlocks all the permissions granted by the certificate authority in the initial phase (Hyperledger, 2020; [87]). Similarly, network administrators operate for the creation of new processes and policies.

Indeed, with the support of blockchain technology, all relevant actors can directly access product information. With limited access, it is possible to guarantee a security level through a digital key exclusively for the parts involved [25]. All information related to the product can be collected during each phase [90]. An information tag associated with the product connects physical products to their virtual identity in the blockchain [1]. The different actors will have a significant role, obtain authorisation to enter new information in product's profile, or start an exchange with another party, where obtaining authorisation can require smart contracts and consensus. Before a product is transferred or sold to another actor, both parties can sign a digital contract to authenticate the exchange. The details of the transaction subsequently update the blockchain ledger [1].

Blockchain technology can highlight and detail at least *five key product dimensions: nature, quality, quantity, location, and ownership* [98]. In this way, the blockchain offers, on the one hand, an organisation the ability to identify responsibilities for the quality of the product or service it offers, while on the other it offers customers the possibility to inspect the history of the product from raw materials to the final product.

Many blockchain applications can be found in the supply chain's circular model, and many of them are found in the *waste sector*. For example, Swachhcoin [88] is a blockchain-based platform used in the micro-management of household and industrial waste and which converts it into useful products in an efficient and environmentally friendly way. A wide range of raw materials with high economic value comes from treated waste. The Swachh ecosystem is a decentralised autonomous organisation (DAO), governed autonomously based on predefined instructions in the form of smart contracts. Swachhcoin uses a large number of innovative technologies to implement an iterative process cycle, and makes the system completely autonomous, efficient, and productive. This iterative process cycle focuses on the data exchanged between the various ecosystem players, evaluates this data, and provides real-time suggestions based on predictive methods.

A blockchain-based supply chain enables a new circular business model. While linear supply chains are mainly based on the take-make-dispose model, the blockchain-based supply chain allows implementing a make-use-recycle model. With the use of the blockchain, all products can be traced along the entire supply chain, from origin to the market and subsequent recycling. The advantage of this model is that all products are tracked with blockchain technology, and it is possible to provide a significant service to final consumers, such as guaranteeing the origin of the products [20].

## 3. Conceptual framework for the circular blockchain technology

Moving from the discussed literature, Fig. 1 illustrates a typical circular supply chain process presenting the flow of goods and the flow of information before and after the implementation of blockchain technology [73]. It is possible to distinguish two material flows in the circular value chain: a linear loop and a closed loop. The first is a loop of the direct material stream, whereas the second regards reverse material [50]. There are several possibilities for materials to circulate in the loop: as remanufactured materials, redistributed materials, or recycled materials. However, the information flow has different directions depending on the adoption of blockchain technology. After the blockchain implementation, each actor is able to share information with all the supply chain partners. Each transaction is processed through a smart contract and written in a block. In this way, each member of the supply chain is able to interrogate the system to have information about products and processes.

The role of blockchain technology for bridging *trust, traceability, and transparency* to circular supply chain processes represented in Fig. 1 is analysed in the following sections.

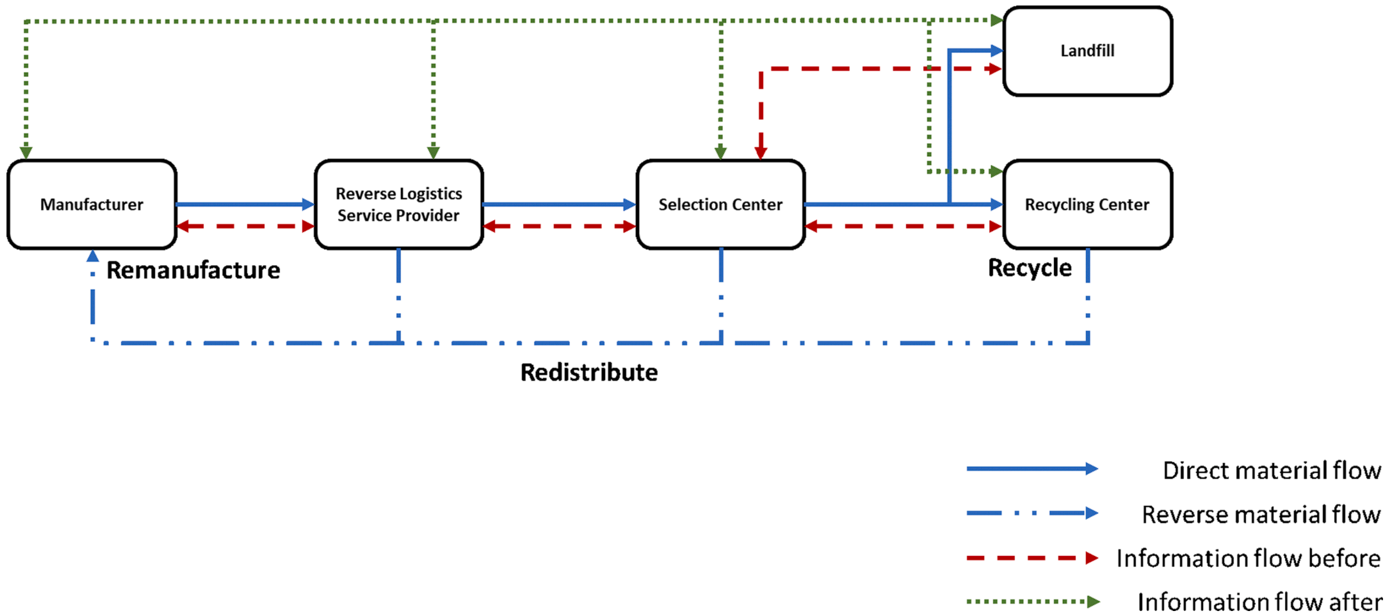


**Fig. 1.** Representation of typical circular supply chain reverse processes.

### 3.1. Trust

Trust indicates an exchange of partner expectations that the other party can rely on, behave as expected, and act reasonably [57]. Trust is one of the main characteristics of blockchain technology [64]. The main feature of blockchain protocols is to provide an immutable recording of transactions, combining a distributed database whose transaction blocks are connected chronologically and cryptographically through decentralised consensus mechanisms [63]. This structure prevents the diffusion of wrong/counterfeit information and self-regulates agents' behaviour without central authorities' need [30].

Through smart contracts, the technology has grown enough to exceed the cryptocurrencies level and finds applications also in various commercial and industrial sectors [44, 61]. In public and permissionless blockchain, high energy and time are required to verify blocks. In private networks, there is a reduction in the risk of Sybil attacks [66]. In practice, the Proof of Work (PoW), Proof of Stake (PoS), Byzantine Fault Tolerance (BFT) mechanisms artificially create costs for the addition of new blocks and, therefore, discourage potentially harmful nodes from interference [13, 53].

On the other hand, the energy, time, and scalability costs increase, and consequently, the efficiency of the system is affected [46]. If the participants are known in the private network, there is no threat of attacks, and therefore the costs related to security issues decrease. Therefore, identity-based authentication (e.g. hash-based users) offers more efficient alternatives that allow for different privacy levels [59, 83].

The data structure mainly consists of two parts: the first is represented by the block header, which contains the previous block hash, where the hash value is used to connect the previous block and meets the blockchain integrity needs; the second part instead contains the primary information of the block and related transactions (e.g., position, ID, status). Since cyber-attacks have become even more frequent and sophisticated, solutions are needed to preserve the nodes' reliability without asking for excessive energy and time costs [1].

### 3.2. Traceability

Traceability offers the possibility to track products and provide information about them (e.g., originality, components, positions) during production and distribution [85]. Researchers are paving growing attention to related areas of visibility and traceability in the supply chain [4].

In line with these problems, customers require greater traceability and knowledge of products' origin by manufacturers and retailers [9]. Therefore, the real economic and social challenge is to bridge the gap in the traceability of the supply chain related to control even if the production is ethical, respect for sanctions, or safe [34]. Defining the origin is often difficult due to the complexity of the supply chains and products flows over extended networks. This complexity requires that products are followed throughout the entire life cycle, from the procurement of raw materials to production, distribution, and consumption [54, 95].

An example of traceability architecture in the supply chain is the OriginChain proposed by Xu et al. [95]. OriginChain currently uses several private blockchains distributed geographically to the traceability service provider. The aim is to establish a reliable traceability platform involving other organisations, including government-certified laboratories, large suppliers, and retailers with a strong relationship with the company. Compared to a public blockchain, this platform has better performance and lower costs. OriginChain stores two types of data on the chain as variables of smart contracts to be preserved: the hash of traceability certificates and the necessary traceability information required by the regulation [10, 55].

### 3.3. Transparency

Transparency is the extent to which information is easily accessible to both counterparties in exchange and external observers [10]. Transparency is, therefore, a fundamental parameter in assessing the performance of the supply chain, given the emerging secure environment associated with the blockchain. Even before reaching the final consumer, products travel through a vast network in which different actors are present (e.g., extractors, producers, retailers, distributors, conveyors, storage facilities) [68, 76].

In this sense, it is possible to manage transparent and accurate information for each phase, guaranteeing compliance, safety, and accuracy, focusing on sustainable and social responsibility requirements [42, 101]. Current markets require transparency of supply chain information and sustainable economic dynamics for both the environment and society [1, 55, 101].

For this reason, many companies are adopting these practices in conjunction with emerging technologies to improve the opening and transparency of the supply chain, especially where markets are very competitive, scattered, and complex.

Blockchain has the potential to increase system transparency, resulting in fewer failures [97]. No great hardware investments are required for upgrading the blockchain, but changes in the current system are necessary to improve network speed and processing times [2, 101]. Greater transparency enhances the ability to increase productivity, provide better service to customers and reduce expenses. Thus, transparency becomes a fundamental key to increase the performance of the supply chain [97].

## 4. Definition of the triple retry framework

Starting from the analysis of the most critical factors affecting reverse circular supply chain processes, this paper proposes a blockchain-based circular supply chain framework combining trust, traceability, and transparency (Fig. 2). The proposed Triple Retry framework aims to bridge the three circular supply chain reverse processes (i.e., REcycle, REdistribute, REmanufacture) and the three main factors affecting circular blockchain technologies (i.e., TRust, TRaceability, TRansparency) presented above. The Triple Retry framework can be adopted for designing circular blockchain models and deploying blockchain platforms.

The interactions between the partners in the supply chain are based on trust relationships between them; each player believes in the other players' good practices. Due to this trust, the supply chain allows to increase its networking responsiveness [12, 38]. After the blockchain technology integration into the supply chain network, each interaction between players is recorded through a smart contract. Nevertheless, another characteristic of the blockchain technology is the distributed ledger. In this way, by eliminating information distortions and increasing information velocity, the supply chain is pushed towards a high degree of transparency that increases collaborations [5, 23].

Information stored in the blockchain offers the actors who can access the blockchain the ability to trace all the transactions to improve supply management performances, to reduce not only the cost of distribution systems but also recall expenses and expand the sales of products with attributes that are difficult to discern [7]. However, total network traceability enhances a second trust level where each actor increases its own confidence in the network.

### 4.1. Technological environment

As discussed before, the blockchain is a technology based on the concept of the distributed database, in which data is not stored on a centralised server (Client-Server) but on several interconnected machines, called nodes (Peer-to-Peer) [15]. The blockchain makes it possible to innovate the current management of transactions through a process that connects distributed, cryptographic primitives useful to guarantee the security and traceability of information [47]. The main advantage of distributed systems in a circular economy domain is the presence of information on all the machines connected to the network [49]. This type of database is based on two fundamental processes, useful for guaranteeing correct operations and limiting the number of information lost to zero [49]:

- *Database replication*: there is a software to identify any logical internal change to the database; once the database has been identified, this software allows to replicate the change on all the machines connected to the circular economy network
- *Duplication*: This is a useful process to ensure that the same data is present on each machine connected to the circular economy network. This process allows identifying a master database that will be taken as a model to be duplicated on all the other devices on the network.

The functioning of the blockchain is based on the following components [74]:

- *Transaction*: Logical processing unit which coincides with a sequence of elementary operations that need to be verified, approved, and then archived
- *Node:* Representation of a single blockchain actor and physically constituted by a server
- *Block*: Logical unit represented by the union of a set of transactions that are grouped to be verified, approved, and archived

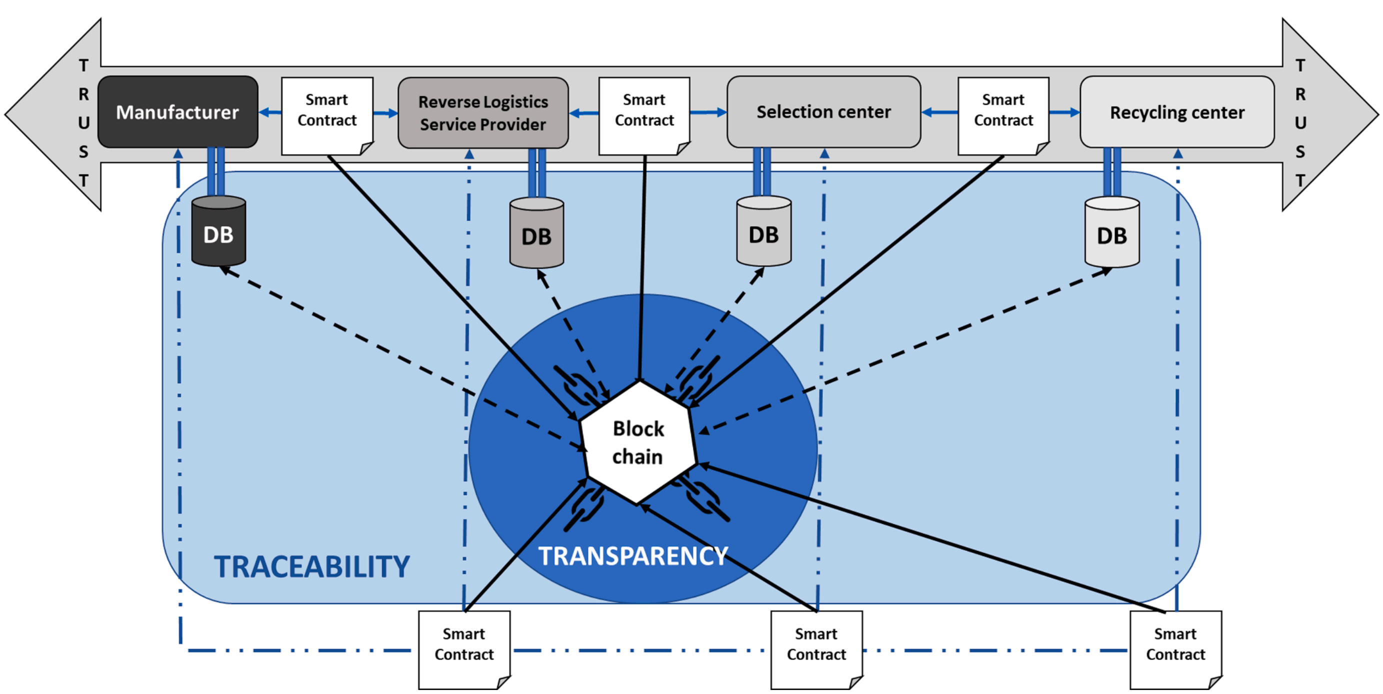


**Fig. 2.** Triple Retry framework.

- *Ledger*: Master book in which all transactions are immutably recorded and sequentially ordered
- *Hash*: Non-invertible algorithmic function allows to represent a text and/or numeric string of a variable length in a unique string of predefined length.

The blockchain is a chain of blocks, and in this context, the block is represented by the set of transactions linked together, which must be verified, approved, and finally stored by the nodes present in the circular economy network [49]. Therefore, the block can be considered a container of transactions including useful information to temporally and spatially reconstruct the chain of blocks [92]. Each block contains within it a pointer called hash, located in the header, which records the information relating to the block in position "n" and the information related to the block placed in the position "n-1″. Based on this principle, the entire chain of blocks can be built [59, 83].

From the IT perspective, the hash, or fingerprint, results from an algorithm called hash function [72]. Hash functions have two main features [56]: 1) they are characterised by a string of arbitrary length (input) and a string of defined length (output); 2) they are irreversible functions. Each block contains a hash, and this allows a unique and secure identification; moreover, the hash allows the construction of spatial mapping of the entire blockchain, which is continuously updated as new blocks are added [59, 83].

In addition to the hash, there is also a timestamp in the block through the practice of timestamping. This practice consists of a specific character sequence that allows the unambiguous block identification and, therefore, of its transactions. This timestamp enables the development of a timeline map useful for understanding the order in which the transactions occur. To sum up, in a distributed system applied to the blockchain, it is necessary to be able to know the hash and the temporal brand in order to be able to recreate the chain of blocks spatially and temporally. Instead, the transaction contains the following information [74]: 1) IP address of the sender and recipient; 2) the cryptographic signature necessary to guarantee the security of the transaction; and 3) information regarding the content and characteristics of the transaction.

Since the number of transactions varies continuously over time, the blockchain can be continually updated on all nodes in the network; this is possible thanks to the use of cryptographic primitives that guarantee the correct functioning of the system. Furthermore, the transactions are unchangeable; any change requires the consent of all the nodes present in the network. Many types of transactions can be carried out with the blockchain (e.g., transactions related to dyadic relationships between partners, management of information pertaining to contracts through smart contract). All transactions are noted with maximum transparency and in an unchangeable manner in the ledger.

The ledger can be considered as the aggregation of several blocks interconnected using cryptographic primitives and hash. The blockchain is the realisation of the distributed ledger, which is the evolution of centralised and decentralised logic [70, 94]. In the centralised logic (centralised ledger), each transaction is managed by a central node, which has a centralised authority, acts as an intermediary, and verifies the correctness and security of information. In the case of decentralised logic (decentralised ledger), there is no single centralised authority to refer to, but more central subjects are set up in a logic of local centralisation.

The blockchain is based on distributed logic and there is no longer any centralised authority between the circular economy network actors. Consensus between circular economy network nodes, essential requirements in the centralised system, is replaced by cryptographic primitives and protocols, and the figure of the intermediation nodes is definitively eliminated [6]. There is no central point of vulnerability in blockchain platforms that can be attempted to tamper with the system. These characteristics substantially distinguish the blockchain from centralised databases [26]. Due to modifying a transaction within a block, it is necessary to change the value identifying that particular transaction and, consequently, the change of the block in which the single transaction is contained [48]. This modification should be replicated simultaneously with the existing technologies. These factors guarantee the security of the network's information [63].

As for the mechanism that leads to the creation of blocks starting from transactions, the following procedure is followed to interact with the system: 1) creation of the transaction and the public cryptographic key; 2) creation of the block containing the transaction mentioned above; 3) verification and approval of the block by the actors of the circular economy network; 4) verification of the truthfulness of the information by the actors of the circular economy network; 5) evaluation of previous checks and additions to the block to the network; 6) authorisation and validation of the transaction; and 7) publication of the transaction in the ledger.

## 5. Research approach

Moving from the above framework, the research aims to evaluate the circular supply chain management processes and identify the technical and functional specifications that the technological architecture of the blockchain must possess to favour the development and consolidation of the relationships between the various actors of the circular supply network. Specifically, the characteristics of the reference sector, the socio-economic and technological context, and the companies' innovative, technological and productive processes will be considered.

A single in-depth case study (Yin, 2009) was associated with a primary data collection made directly in the company: interviews, mapping of the supply chain circular processes, operations, skills and times, and validation workshops. Secondary data were also collected, such as order reports, order modification reports and databases from the past 12 months, activity descriptions, ERP reports, Excel reports, product requirements, and monthly/quarterly reports. Secondary data were used to integrate and triangulate sources with primary data. Triangulation of data was necessary to strengthen the validity and reliability of this research. The first data collection consisted of over 80 h of direct contact:

1 Face-to-face interviews with company managers for the supply chain management, operations management, and information management departments
2 Shadowing operations by direct observation. The researchers followed a sample of operations through the process, mapping the activities and timing them.

The other data collection method that was used over 12 months of the study included:

1 Active remote dyadic (back-and-forth) interactions. For example, multiple questions and clarifications over the phone, e-mail, and Skype
2 A validation workshop with managers

The implementation in the circular economy sector of a platform based on blockchain technology is very favoured, especially for SMEs that deal with waste management for companies belonging to high-tech and complex sectors. The innovative waste management provider analysed in this study is located in the South of Italy and provides industrial waste disposal services for multinational companies operating in the automotive and railway manufacturing business. It is currently based and has its facilities in a relevant district for mechanical and railway engineering and production at the national level. This context of investigation seems to be a suitable choice because sustainability management is a critical factor in a complex industry, and rethinking waste management processes plays a crucial role.

## 6. Design of the circular blockchain platform

This section discusses the process of design and implementation of the circular blockchain platform and represents the empirical contribution of this research. The design process of the application of a circular economy blockchain-based platform is organised into two main phases:

1 PoC framework design and deployment
2 Circular supply network modelling

A detailed description of each phase is provided in the paragraphs that follow.

### 6.1. *PoC framework design and deployment*

In computer science, a Proof of Concept (PoC) is a practical demonstration of a software application's basic operations or an entire system, integrating it into an already existing environment. The PoC development is used to demonstrate a vulnerability in a software or in a computer system, the exploitation of which may allow unauthorised access to the data contained in the system or compromise its functionality.

For the realisation of this structure, the research team involved in this project decided to use Hyperledger Fabric, an open-source project founded by Linux Foundation in 2015, created to enable the construction of blockchain. The feature that distinguishes Hyperledger Fabric is represented by modularity that allows defining consensus mechanism and membership management [18].

Compared to permissionless blockchains, permissioned blockchains work amongst a set of known, recognized, and often verified participants who follow a governance scheme that provides a certain level of confidence. A permissioned blockchain is a way to protect interactions between entities who have a common objective but may not completely trust one another. The participants are known, and all activities, whether submitting application transactions, altering network settings, or executing a smart contract, are recorded on the blockchain in accordance with a previously agreed endorsement policy. The responsible actor is quickly identified, and the event is addressed in accordance with the governance model's requirements. In this context, the probability of a participant purposefully adding harmful code via a smart contract is reduced. Based on the foregoing premises, a permissioned blockchain usually employs Crash Fault Tolerant (CFT) or Byzantine Fault Tolerant (BFT) consensus algorithms that do not necessitate costly mining. In particular, for a single firm, fully byzantine fault tolerant consensus may be unneeded since it could affect speed and throughput, and a CFT consensus protocol may be more adequate. However, the traditional BFT consensus mechanism is required in multi-party decentralized applications.

Hyperledger Fabric also offers the possibility of creating private channels, allowing a group of participants to create a ledger where transactions are recorded completely privately, which can only be viewed by the nodes that participated in it, namely a fundamental prerequisite for the creation of a supply blockchain. Compared to alternative private and permissioned solutions, Hyperledger Fabric was selected for its stability, flexibility, and conformity to the specific functional requirements (e.g., absolute control of access, transactions, and information between the various players in the network). Furthermore, Hyperledger Fabric features a modular design that is fully configurable and capable of meeting a number of requirements related to data confidentiality and cloud configuration. Cloud configuration was necessary to implement the blockchain at the supply chain level. The leading cloud service providers (e.g., IBM Bluemix, Microsoft Azure, Google Cloud Platform, AWS Amazon Web Services) are all compatible with Hyperledger Fabric. Therefore, it was selected as the best platform to support the functional requirements identified.

Currently, the blockchain application has been configured on-premises. Installing an on-premises program means installing it on a local device, such as a machine that physically resides within the company that uses it or is still owned by it (a company server). The software components used are the following:

- Operating System: Windows 10 64-bit, Ubuntu Linux 14.04 / 16.04 LTS 64-bit
- Virtual Machine: Oracle Virtual Box
- Required software: Code editor VSCode and Atom editor plugins; Docker Engine: Version 17.03; Docker-Compose: Version 1.8 or higher; JavaScript SDK; LoopBack Connector; Node: 8.9 or higher; npm: v5.x; git: 2.9.x or higher; Python: 2.7.x; REST Server; Yeoman code generator

### 6.2. *Circular supply network modelling*

The network modelled in Fig. 3 was used to identify the main actors to be involved as nodes of the blockchain platform to be developed.

The specific testing network included:

1 *Manufacturer (M)*: This node represents the manufacturing company entertaining dyadic relationships with the *RLSP*
2 *Reverse Logistics Service Provider (RLSP)*: This node represents the reverse logistics service provider analysed in the case study and establishes the governance framework of the blockchain network
3 *Selection centre (SC):* This node differentiates non-reusable and recyclable wastes
4 *Recycling centre (RP):* This node collects recyclable wastes and transfers recycled products to *M*
5 *Landfill (L):* This node disposes of non-reusable wastes

A differentiated waste management system was based on the following flow of materials:

1 The specific waste is collected in dedicated containers at the *Manufacturer*
2 The *Reverse Logistics Provider* collects the waste and transfers it to a *Selection centre*
3 The recycled product is brought to a *Recycling centre,* which produces materials that fall within the production cycle
4 *Selection centre* and *Recycling centre* discard non-reusable material which is transferred to *Landfills*

A fundamental aspect of the circular blockchain platform is the possibility to create private channels to carry out operations with each of the actors participating in the network to allow the individual companies to maintain privacy on their information, further strengthening their position in the network. On the other hand, the circular blockchain platform allows displaying any movement of wastes and documents that occur between the various nodes in the network, although it does not participate directly in operations. In addition to greater transparency in the origin and reliability of the waste services provided, this would also simplify the control carried out on possible returns of products.

#### 6.2.1. *Identification of the circular supply chain partners*

Fig. 4 highlights the main features that are necessary for identifying circular blockchain partners. These features were used to identify the main functional requirements for the development of a circular blockchain platform. The functional requirements establish the permissions to visualise and/or approve transactions. Based on a private and permissioned blockchain model, the *Reverse Logistics Management Provider* has full permission to visualise and approve transactions, whereas *Manufacturer, Selection centre, Recycling centre* and *Landfill* can only visualise and approve their transactions.

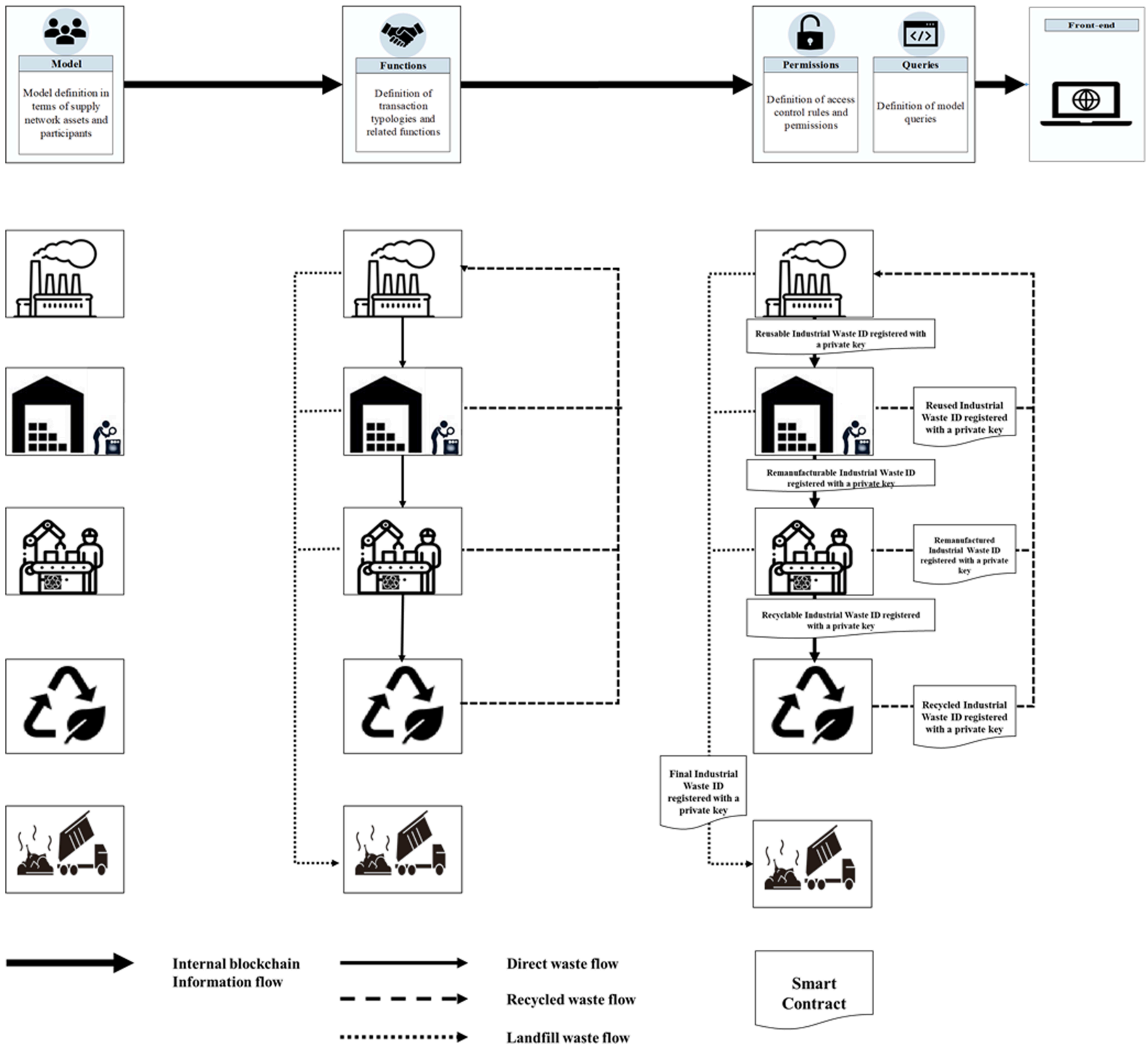


**Fig. 3.** PoC framework and business network deployment.

### 6.2.2. *Definition of assets*

An asset is identified by any property owned by a company that can be monetised. Tracking company assets is a fundamental process and an investment for a company that wants to save money and time: developing and implementing asset traceability reduces administration costs and streamlines the business, improving the quality of customer service and pushing to the scalability of its business. All these processes favour organisational efficiency: warehouse, offices, and stocks become automatically accessible, reducing waste in management costs and at the same time managing to anticipate needs through the administration of company assets.

In the business case developed, the *Waste* and *Document* classes represent the assets of network transactions.

The *Document* class is identified by *ID Protocol* and *Type*:

- *ID Protocol*
  1 ID: ID is a code that uniquely identifies a document.
  2 Protocol Type (PT): PT represents the type of document to be transmitted within the network.
  3 Notes.
- *Type*
  1 Request for Quotation (RfQ): RfQ is a request in which a Manufacturer asks RLSP to submit a quote on the possibility of providing certain services. In addition to the price, RfQs usually also include details of payment such as terms and deadlines.
  2 Quotation (Q): Q represents the list of services that the RLSP is willing to sell according to the established conditions.
  3 Statement of Work (SoW): SoW is a document to define the specific activities, tasks, results, and deadlines expected. This document also includes requirements and detailed prices with annexed terms, regulatory and governance conditions.
  4 Waste Service Order (WSO): WSO is a commercial document and represents the first official offer issued by a Manufacturer to a RLSP, which indicates the types, tasks, and prices agreed for services. The issue of a WSO does not constitute a final contract but

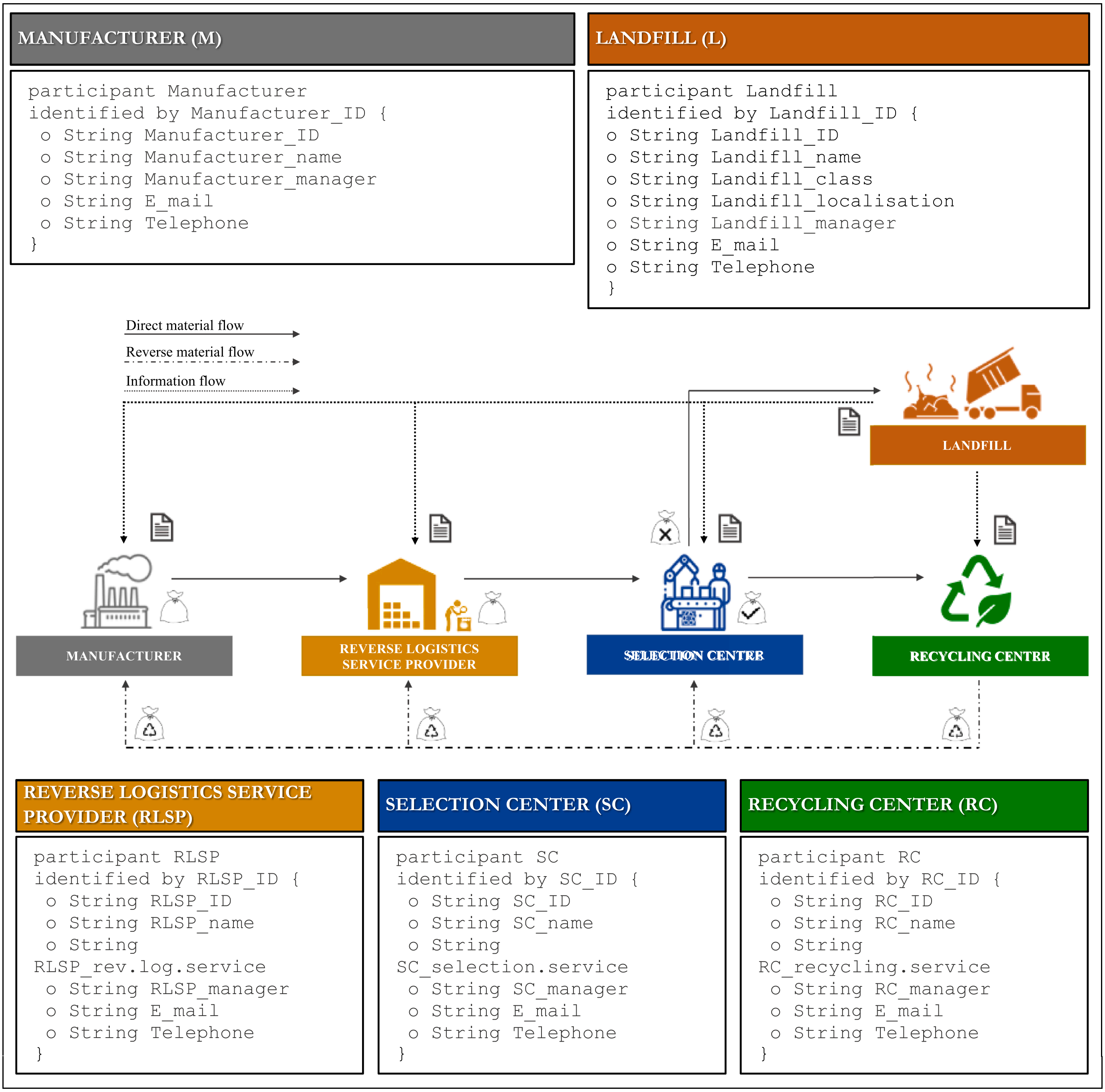


**Fig. 4.** Identification of circular blockchain partners.

can serve as a legally binding document when accepted by the two parties.

5 Delivery Plan (DP): If at the time of specifying a contract, the details of the time delivery are already known, a DP is used. A DP is not a real program, but a program solution for the generation of WSO promptly.
6 Quality Notification (QN): QN is a document describing the conformity of service with respect to a quality requirement and contains a request to take appropriate actions within it.
7 Waiver (W): W is an agreement or additional clause attached to a policy that excludes a specific type of loss, limits the amount of the claim to a specified amount, and finally extends the coverage to include items not included in a standard policy.

The *Product* class is identified by *Waste ID* and *Category*:

- *Waste ID:*
  1 ID: ID is represented by Part Number_Serial Number.
  2 Waste Category (WC): WC represents the category of waste belonging to the classes described below.
  3 Waste Management Service (WMS): WMS represents the code of the specific waste management service provided.
  4 Notes.
- *Category:*
  1 Solid (S): Category of solid material.
  2 Liquid (L): Category of liquid material.
  3 Gaseous (ME): Category of gaseous material.

#### 6.2.3. Analysis of the main transactions

The *Move Waste* and *Send Document* classes describe the operations that will be executed in the circular blockchain. These operations will be recorded on the distributed platform. In this way, all the waste movements that will be made in the network and the related documentation will be traced uniquely and irrevocably. The various nodes will thus have a platform that can overcome the problems related to the integration of information from different information systems, which often have a significant impact on management costs.

## 7. Discussion of results

This section adopts the proposed Triple Retry framework to discuss blockchain technology's impact on the circular supply chain. The designed blockchain platform can be considered a pilot implementation to analyse and discuss the effects on the circular supply chain. Therefore, blockchain technology's pre- and post-implementation characteristics are clarified by checking the impact on trust, traceability, and transparency in the circular supply chain processes examined, namely recycling, redistributing, and remanufacturing.

### 7.1. Blockchain impact on trust

The implementation of blockchain technology modifies the concept of trust amongst the circular supply chain management partners. Storing and maintaining data, information, and transaction records in a decentralised and distributed ledger promotes trustworthiness and trust amongst supply chain partners, regardless the presence of a centralised authority [64].

The use of a circular blockchain technology affects the current development trust process amongst partners. Trust in individual partners or circular supply chain was replaced by trust in the blockchain technology [63]. That, in turn, has ensured that it can do without trusted partners or intermediaries in managing data, information, contracts, and transactions. Before the implementation of the circular blockchain platform, the processes of recycling, remanufacture, and redistribution operated within the development of centralised mechanisms, the adoption of individual local databases, the need for trusted parties, and the consequent creation of trusted dyadic relationships amongst partners.

In coherence with the study of Farooque et al. [33] on the meaning of a circular supply chain management, the study highlights that after the implementation of the platform, circular supply chain process operations are moving toward a more trustless, coordinated, and automated global network, while simultaneously being redesigned to reduce trusted parties. After the blockchain implementation, the trust in the individual partners operating in the circular supply chain was integrated by the trust in the blockchain technology [92]. Blockchain enables circular supply chain processes with less intermediation without centralised authorities. This means the blockchain platform has a motivating and positive effect for both the trustor and the trustee [6].

Additionally, the blockchain platform adoption enables information disclosure, guarantees responsibility attribution, reduces business expense, solves the vulnerability of information flows and transactions, and transforms the circular supply chain into a trustless system. Finally, the verification that the process is direct and trustful, as well as the absence of centralised intermediaries that should increase trust between the participants, in turn, guarantees the automation of the agreement, the fight against fraud, and the malfunction of the traditional third parties, and avoids uncertainties related to system malfunctions due to tampering or attacks with fraud intents. In summary, the blockchain implementation provides a mechanism of trust for the multiple partners in the supply chain's circular ecosystem [33, 92].

### 7.2. Blockchain impact on traceability

Traceability focuses on the dynamic tracking and tracing response of both direct and indirect material and information flows crossing the circular supply chain. Before the implementation of blockchain technology, tracking processes used labour resources for the acquisition, storage, and distribution of updated and confirmed information regarding the localisation of materials. Individual firms used different traditional methods for the purpose of managing the technical details of status tracking.

Main traditional tracking methods ranged from e-mail correspondence, phone calls, EDI, value-added network (VAN), or ERP systems. Nevertheless, individual firms did not adopt a coordinated tracking system based on the different available resources, which in turn reduces the overall circular supply chain efficiency. From a managerial point of view, managing exchanges of large data volumes between multiple partners and decision support for process monitoring have always represented costly and time-consuming activities, specifically in harmonising and certifying data from different systems and external actors, with the inevitable consequent potential profits and efficiency loss. EDI, VAN and ERP system can solve these problems but are not able to prevent tampering or malevolent actions on data.

After implementation, blockchain technology enables an almost unique and real-time tracking system that allows timely and automatic updates of status data in order to make efficient and effective business decisions. The proposed value-added tracking process will enable participants in the supply chain to share ledger and use smart contracts to trace and track changes in the state of material information. Through the adoption of smart contracts, individual circular supply chain partners can track and trace a status change triggered by an automated event mechanism [89, 101]. The updated process status could be tracked and traced in a timely way by the partners that are registered on specific contacts since smart contracts may automatically activate information push mechanisms. According to the company managers, having the information in a single format allows to save a significant amount of time in harmonising the data, which typically involves the duplication of information and worksheets. Furthermore, the capability of having certified actors and information implies the option of bypassing the verification of authenticity. These features are significant since they enabled the recovery of a considerable amount of time that could be spent on other pursuits.

The proposed blockchain platform guarantees a better level of efficiency of operations through a real-time notification of information changes based on push mechanisms. Therefore, circular supply chain partners can decrease costs associated with traditional tracking methods to achieve information synchronisation amongst partners [95]. In summary, blockchain platform implementation allows the circular supply chain to achieve synchronisation of tracking information and reduce resources required to confirm process status, which in turn accelerates the process automation and disintermediation using smart contracts [23, 70, 93].

### 7.3. Blockchain impact on transparency

Demand for transparency across circular supply chain processes influenced the motivation to design and implement a blockchain platform. Eliminating centralised authorities enhances transparency, which affects the mode of collaboration amongst circular supply chain partners. Higher transparency is also achieved through an inherent tampering-proof mechanism characterising blockchain technology. Storing distributed records in a blockchain platform enhances transparency in the flow of process status information, which improves the operational efficiency of individual firms and circular supply chain in terms of time efficiency and system automation.

Typical hand-off points, such as change/return in status and ownership transfer, tend to be removed as a result of the increase of transparency amongst circular supply chain processes. The actors involved in these processes can benefit from full transparency to enable timely controls of necessary steps by using automated smart contracts ([32]; Iansiti & Lakhani, 2011; [81]). Furthermore, recording data on the blockchain platform makes unnecessary the combination of on-chain data sources and off-chain systems. Blockchain platform enables transparency and privacy since data is stored in a private-permissioned ledger, allowing individual firms to manage their employees' identities to assure privacy.

A private-permissioned blockchain achieves better transparency requiring access control to authorised data, thereby making information access more effective and secure. Finally, the distributed ledger's immutability guarantees transparency over time through irrevocable and node-verified mechanisms, disintermediation and automatic processes, convenience, and simplification in terms of data extraction and comprehension [52, 89, 101].

### 7.4. Additional impacts

As for blockchain's impact on operational performance, blockchain platform allows to achieve higher throughput and lower latency when using private and permissioned ledgers. Secondly, a supply chain in which a blockchain system is not implemented requires a vast amount of manual inspections and transactions, involving numerous intermediaries and generating efficiency problems [41]. A blockchain and smart contract-based approach can reduce manual registration and verification and enable the automation of many supply chain processes and activities with a consequent improvement in terms of efficiency [23, 70].

The blockchain implementation allows for significant disruption in system efficiency and security: using blockchain, existing technological systems, such as EDI, can be used with increased operational performances. Data and information are standardised and automatically transferred. This aspect results in significant operational time and management cost savings, and also allows staff or managers to focus more on data analysis. The energy to support the blockchain system erodes some of this boost in operational efficiency, but it is contained given the use of a permissioned system.

Furthermore, the blockchain platform achieves customizable configurations (e.g., consensus protocols, off-chain data calculation, block size) and, therefore, higher efficiency of the entire supply system. A decrease in costs and times is due to the lack of need to control and trace data and flows through intermediation actors' involvement. Moreover, anticipating the fluctuation of demand in a supply chain due to the tracing and transparency aspects of a blockchain system also allows to manage cost more efficiently and to reduce volatile components.

From the specific waste management point of view, blockchain technology is able to favour the adoption of circular practices thanks to a double integration: 1) a horizontal integration that allows to trace the waste flows throughout their life allowing for better flow management, 2) a vertical integration that clearly and unambiguously identifies those responsible for the entire lifecycle of waste. This double integration entails the possibility to optimise waste flows, with a reduction in management costs and control time [49].

## 8. Conclusions and implications

The paper highlighted that there is an emerging and rapidly growing body of blockchain literature in the domain of the circular supply chain. Alongside the large theoretical contribution, the growing interest in the topic requires more empirical research on the design and implementation of blockchain platforms (Avital et al., 2016; [58, 65, 75]) to understand further the feasibility and actual advantages of this enabling technology. Brennan et al. [16], Kim and Laskowski [45], and Carter and Koh [19] support the fundamental need to improve current supply chains with blockchain technology, with particular attention to the effects on trust, traceability, and transparency.

In this context, to combine the three reverse supply chain processes (i.e., recycle, redistribute, remanufacture) and the three main factors that influence circular blockchain technologies (i.e., trust, traceability, transparency), this paper proposed an integrated Triple Retry framework to design circular blockchain models and implement blockchain platforms.

The research proposed here investigates the blockchain implementation in a circular supply chain and demonstrates the main effects on trust, traceability, and transparency of the reverse supply chain processes and transactions [19, 67]. This study contributes to the supply chain literature, demonstrating how circular blockchain models are designed and how circular blockchain platforms are implemented.

It highlights the main features necessary for identifying the main functional requirements for the development of a blockchain platform, establishing the permissions to visualise and/or approve transactions, identifying and tracking the assets of network operations that are executed. These operations are recorded on the distributed platform. In this way, all the waste movements made in the network and the related documentation are traced uniquely and irrevocably. Therefore, the various circular supply chain actors involved have at their disposal a digital platform that is able to overcome the problems related to the integration of information from different information systems, which often have a significant impact on management costs.

The proposed Triple Retry framework has been used to evaluate the impact of blockchain technology on the circular supply chain investigated. More in detail, the characteristics of the pre- and post-implementation of blockchain technology are elucidated by checking the three main factors (i.e., trust, traceability, transparency) affecting the circular supply chain processes investigated, namely recycle, redistribution, and remanufacturing.

### Implications

As for the theoretical implications, this research contributes to the supply chain theory by providing theoretical and practical implications according to Industry 4.0 technological advances and circular economy [78]. By building a theoretical model that applies the principles of blockchain technology to the supply chain, it has been possible to understand how it is possible to combine the characteristics of these principles in a circular supply chain domain and how this synergy has positive implications for the conception and execution of its transition towards circular economy [14, 33]. In particular, it has emphasised how to connect the blockchain concepts of trust, traceability, and transparency to the circular supply chain management processes [78, 86].

As for the managerial implications, this research highlighted the blockchain implementation path for a circular supply process, as shown by the blockchain design and implementation analysis. This path provides clear guidelines for management regarding the implementation of the blockchain within circular economy networks. The fact that the system has been developed independently and without support of third parties and relatively low use of financial resources shows that the implementation of blockchain solutions can take place in a reasonably economical way. The Triple Retry framework allows managers to identify the critical factors to achieve a successful blockchain implementation. The case considered in this work concerns the reverse circular supply chain processes, but it is possible to extend the theoretical model to other supply chain processes (e.g., order fulfilment, delivery).

### Limitations

This research is based on an in-depth case of a single circular supply chain that aims to be tested in different contexts in the near future. However, it can be argued that the results are generalisable, and future research will investigate the impact of blockchain on different processes and actors in the supply chain, including customer-supplier dyadic relationships and supply network relationships.

*Future directions*

In the next future, the supply chain as well as the blockchain applications will be interested by radical transformation. In this context, a pivotal role concerns the time-limited privacy in blockchain and transactional privacy, enabling applications where privacy is managed and guaranteed by regulations.

Furthermore, a research direction concerns the necessity to conduct further research on the role of blockchain technology in managing trust, traceability, and transparency of public and private companies operating in developing countries to underline the research advancements and highlight similarities and differences with developed countries. Finally, an additional research direction concerns the opportunity to adopt blockchain to bridge trust, traceability, transparency factors affecting knowledge flows during pandemics.

To achieve this aim, future contributions could design novel blockchain models to assure the immediate need for personal protective equipment (PPI) like medical gowns, surgical masks, gloves, as well as the acquisition and deployment lifecycle of equipment like ventilators respirators, and medical tests. More in detail, future contributions could provide fertile ground for experimentation of private and permissioned blockchain platforms to manage material and information flows of PPI supply processes, including different actors, namely medical device suppliers, pharmacies, hospital procurement departments, and local governments.

## CRediT authorship contribution statement

**Piera Centobelli:** Conceptualization, Methodology, Software. **Roberto Cerchione:** Conceptualization, Software, Writing – original draft, Supervision. **Pasquale Del Vecchio:** Visualization, Validation, Investigation. **Eugenio Oropallo:** Formal analysis, Investigation, Writing – review & editing. **Giustina Secundo:** Visualization, Validation, Investigation.

## References


[1] S.A. Abeyratne, R.P. Monfared, Blockchain Ready Manufacturing Supply Chain Using Distributed Ledger, Int. J. Res Eng. Technol. 5 (9) (2016) 1–10.

[2] G.V.R.K. Acharyulu, RFID in the healthcare supply chain: improving performance through greater visibility, J. Manag. Res. 6 (11) (2007) 32–45.

[3] Adams, R., B. Kewell, and G. Parry (2018). "Blockchain for Good? Digital Ledger Technology and Sustainable Development Goals. Handbook of Sustainability and Social Science Research, pp. 127–140.

[4] L. Agnoli, R. Capitello, M. de Salvo, A. Longo, M. Boeri, Food fraud and consumers' choices in the wake of the horsemeat scandal, British Food J. 118 (8) (2016) 1898–1913.

[5] H.A. Akkermans, P. Bogerd, E. Yucesan, L.N. van Wassenhove, The impact of ERP on supply chain management: exploratory findings from a European Delphi study, Eur. J. Oper. Res. 146 (2) (2003) 284–301.

[6] G. Alexandris, V. Katos, S. Alexaki, G. Hatzivasilis, Blockchains as Enablers for Auditing Cooperative Circular Economy Networks, in: *IEEE International Workshop on Computer-Aided Modeling and Design of Communication Links and Networks, CAMAD, 2018-Septe*, 2018, pp. 1–7.

[7] M.M. Aung, Y. Chang, Traceability in a food supply chain: safety and quality perspectives, Food Control 39 (2014) 172–184, https://doi.org/10.1016/j.foodcont.2013.11.007.

[9] A. Awaysheh, R.D. Klassen, The impact of supply chain structure on the use of supplier socially responsible practices, Inter. J. Operat. Produc. Manag. 30 (12) (2010) 1246–1268, https://doi.org/10.1108/01443571011094253.

[10] C. Bai, J. Sarkis, International Journal of Production Research A supply chain transparency and sustainability technology appraisal model for blockchain technology A supply chain transparency and sustainability technology appraisal model for blockchain technology, Int. J. Prod. Res. (2020), https://doi.org/10.1080/00207543.2019.1708989.

[12] M. Barratt, Understanding the meaning of collaboration in the supply chain, Supply Chain Manag. 9 (1) (2004) 30–42, https://doi.org/10.1108/13598540410517566.

[13] M. Bellare, C. Namprempre, G. Neven, Security proofs for identity-based identification and signature schemes, J. Cryptology 22 (1) (2009) 1–61, https://doi.org/10.1007/s00145-008-9028-8.

[14] A. Böckel, A.K. Nuzum, I. Weissbrod, Blockchain for the Circular Economy: analysis of the Research-Practice Gap, Sustainable Production and Consumption 25 (2021) (2021) 525–539.

[15] E. Bonsón, M. Bednárová, Blockchain and its implications for accounting and auditing, Meditari Accountancy Research 27 (5) (2019) 725–740.

[16] G. Brennan, M. Tennant, F. Blomsma, Business and production solutions: closing the Loop, in: H. Kopnina, E. Shoreman-Ouimet (Eds.), Sustainability: Key Issues 10, EarthScan, 2015, pp. 219–239.

[17] R.-J. Bryan Jean, R.R. Sinkovics, D. Kim, The impact of technological, organizational and environmental characteristics on electronic collaboration and relationship performance in international customer-supplier relationships, Informat. Manag. 51 (7) (2014) 854–864.

[18] C. Cachin, Architecture of the Hyperledger Blockchain Fabric, IBM Research, Zurich, 2016. https://www.semanticscholar.org/paper/Architecture-of-the-Hyperledger-Blockchain-Fabric-Cachin/f852c5f3fe649f8a17ded391df0796677a59927f.

[19] Carter, C., and Koh, L. (2018), "Blockchain disruption on transport: are you decentralised yet?", available at: https://s3-eu-west-1.amazonaws.com/media.ts.catapult/wp-content/uploads/2018/06/06105742/Blockchain-Disruption-in-Transport-Concept-Paper.pdf (accessed 30 January 2019).

[20] R. Casado-Vara, J. Prieto, F.de la Prieta, J.M. Corchado, How blockchain improves the supply chain: case study alimentary supply chain, Procedia Comput Sci 134 (2018) 393–398, https://doi.org/10.1016/j.procs.2018.07.193.

[21] F. Casino, T.K. Dasaklis, C. Patsakis, A systematic literature review of blockchain-based applications: current status, classification and open issues, Telematics and Informatics 36 (2019) 55–81, https://doi.org/10.1016/j.tele.2018.11.006.

[22] P. Centobelli, R. Cerchione, E. Esposito, E. Oropallo, Surfing blockchain wave, or drowning? Shaping the future of distributed ledgers and decentralized technologies, Technol. Forecast Soc. Change 165 (2021), 120463, https://doi.org/10.1016/j.techfore.2020.120463.

[23] S.E. Chang, Y.C. Chen, M.F. Lu, Supply chain re-engineering using blockchain technology: a case of smart contract based tracking process, Technol. Forecast Soc. Change 144 (2019) 1–11.

[25] S. Chen, X. Liu, J. Yan, G. Hu, Y. Shi, Processes, benefits, and challenges for adoption of blockchain technologies in food supply chains: a thematic analysis, Informat. Syst. E-Business Manag. (2020) 1–27.

[26] K. Christidis, M. Devetsikiotis, Blockchains and Smart Contracts for the Internet of Things, in: IEEE Access 4, Institute of Electrical and Electronics Engineers Inc., 2016, pp. 2292–2303, https://doi.org/10.1109/ACCESS.2016.2566339.

[27] R.J. David, S.K. Han, A systematic assessment of the empirical support for transaction cost economics, Strat. Manag. J. 25 (1) (2004) 39–58.

[28] D. di Francesco Maesa, P. Mori, Blockchain 3.0 applications survey, J. Parallel Distrib. Comput. 138 (2020) 99–114, https://doi.org/10.1016/j.jpdc.2019.12.019.

[29] di Francesco Maesa, D., Mori, P., & Ricci, L. (2017). Blockchain based access control. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 10320 LNCS*, 206–220. 10.1007/978-3-319-59665-5_15.

[30] Douceur, J.R. (2002). The sybil attack. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 2429, 251–260. 10.1007/3-540-45748-8_24.

[32] B. Fahimnia, J. Sarkis, H. Davarzani, Green supply chain management: a review and bibliometric analysis, in: International Journal of Production Economics, 162, Elsevier, 2015, pp. 101–114, https://doi.org/10.1016/j.ijpe.2015.01.003.

[33] M. Farooque, A. Zhang, M. Thürer, T. Qu, D. Huisingh, Circular supply chain management: a definition and structured literature review, J. Clean Prod. 228 (2019) 882–900.

[34] J.F. Galvez, J.C. Mejuto, J Simal-Gandara, Future challenges on the use of blockchain for food traceability analysis, in: TrAC - Trends in Analytical Chemistry 107, 2018, pp. 222–232, https://doi.org/10.1016/j.trac.2018.08.011.

[36] M. Gupta, Blockchain For Dummies, 2nd ed., John Wiley & Sons, Inc, Hoboken, 2018.

[37] G. Gupta, I. Bose, Digital transformation in entrepreneurial firms through information exchange with operating environment, Informat. Manag. (2019), https://doi.org/10.1016/j.im.2019.103243.

[38] R.B. Handfield, C. Bechtel, The role of trust and relationship structure in improving supply chain responsiveness, Indust. Market. Manag. 31 (4) (2002) 267–382.

[39] J. Hou, C. Wang, S. Luo, How to improve the competitiveness of distributed energy resources in China with blockchain technology, Technol. Forecast Soc. Change 151 (2020), 119744.

[41] D. Ivanov, A. Dolgui, B. Sokolov, The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics, Int. J. Prod. Res. 57 (3) (2018) 829–846.

[42] R.M. Kashmanian, Building Greater Transparency in Supply Chains to Advance Sustainability, Environ. Qual. Manage. 26 (3) (2017) 73–104, https://doi.org/10.1002/tqem.21495.

[44] Kiayias, A., Russell, A., David, B., & Oliynykov, R. (2017). Ouroboros: a provably secure proof-of-stake blockchain protocol. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics, 10401 LNCS*, 357–388. 10.1007/978-3-319-63688-7_12.

[45] Kim, H., Laskowski, M. (2017). A Perspective on Blockchain Smart Contracts: reducing Uncertainty and Complexity in Value Exchange, 2017, pp.1–6. DOI: 10.1109/ICCCN.2017.8038512.

[46] P. Kochovski, S. Gec, V. Stankovski, M. Bajec, P.D. Drobintsev, Trust management in a blockchain based fog computing platform with trustless smart oracles, Future Generation Comput. Syst. 101 (2019) 747–759, https://doi.org/10.1016/j.future.2019.07.030.

[47] J. Kokina, R. Mancha, D. Pachamanova, Blockchain: emergent industry adoption and implications for accounting, J. Emerg. Technol. Account. 14 (2) (2017) 91–100.
[48] M. Kouhizadeh, J. Sarkis, Q. Zhu, At the nexus of blockchain technology, the circular economy, and product deletion, Applied Sciences (Switzerland) 9 (8) (2019), https://doi.org/10.3390/app9081712.
[49] E. Krajnakova, M. Svazas, V. Navickas, Biomass blockchain as a factor of energetical sustainability development, Entrepreneurship and Sustainability Issues 6 (3) (2019) 1456–1467, https://doi.org/10.9770/jesi.2019.6.3(28.
[50] N. Kshetri, Blockchain's roles in meeting key supply chain management objectives, Int. J. Inf. Manage. 39 (2018) 80–89, https://doi.org/10.1016/j.ijinfomgt.2017.12.005.
[51] H. Latan, C.J. Chiappetta Jabbour, A.B. Lopes de Sousa Jabbour, S.F. Wamba, M. Shahbaz, Effects of environmental strategy, environmental uncertainty and top management's commitment on corporate environmental performance: the role of environmental management accounting, J. Clean Prod. 180 (2018) 297–306, https://doi.org/10.1016/j.jclepro.2018.01.106.
[52] J. Leng, D. Yan, Q. Liu, K. Xu, J.L. Zhao, R. Shi, X. Chen, ManuChain: combining permissioned blockchain with a holistic optimization model as bi-level intelligence for smart manufacturing, IEEE Transac. Syst., Man, and Cybernetics: Syst. 50 (1) (2019) 182–192.
[53] C.T. Li, C.Y. Weng, C.C. Lee, C.C. Wang, A Hash Based Remote User Authentication and Authenticated Key Agreement Scheme for the Integrated EPR Information System, J Med Syst 39 (11) (2015) 144, https://doi.org/10.1007/s10916-015-0322-3.
[54] Q. Lu, X. Xu, Adaptable Blockchain-Based Systems: a Case Study for Product Traceability, IEEE Softw. 34 (6) (2017) 21–27, https://doi.org/10.1109/MS.2017.4121227.
[55] S. Mann, V. Potdar, R.S. Gajavilli, A. Chandan, Blockchain technology for supply chain traceability, transparency and data provenance, in: ACM International Conference Proceeding Series, 2018, pp. 22–25, https://doi.org/10.1145/3301403.3301408.
[56] R. Martino, A. Cilardo, Designing a SHA-256 processor for blockchain-based IoT applications, Internet of Things 11 (2020), 100254.
[57] R. Mayer, J. Davis, F. Schoorman, An Integrative Model of Organizational Trust, The Academy of Management Review 20 (3) (1995) 709–734, https://doi.org/10.2307/258792.
[58] B. McLannahan, Goldman Sachs quits R3 Blockchain Consortium, Financial times, 2016. https://www.ft.com/content/598934e0-b010-11e6-9c37-5787335499a0.
[59] W. Meng, E.W. Tischhauser, Q. Wang, Y. Wang, J. Han, When intrusion detection meets blockchain technology: a review, IEEE Access 6 (2018) 10179–10188, https://doi.org/10.1109/ACCESS.2018.2799854.
[60] H. Min, ELECTRONIC DATA INTERCHANGE IN SUPPLY CHAIN MANAGEMENT, in: P.M. Swamidass (Ed.), Encyclopedia of Production and Manufacturing Management, Springer, Boston, MA, 2000, https://doi.org/10.1007/1-4020-0612-8_284.
[61] Nakamoto, S. (2008). *Bitcoin: a Peer-to-Peer Electronic Cash System*. www.bitcoin.org.
[62] L.S. Newbert, Empirical research on the resource-based view of the firm: an assessment and suggestions for future research, Strateg. Manag. J. 28 (2007) 121–146.
[63] M. Nofer, P. Gomber, O. Hinz, D. Schiereck, Blockchain, Bus. Inform. Syst. Eng. 59 (3) (2017) 183–187, https://doi.org/10.1007/s12599-017-0467-3.
[64] Notheisen, B., Jacob, Cholewa, B., Arun, & Shanmugam, P. 2017 (n.d.). *Trading Real-World Assets on Blockchain An Application of Trust-Free Transaction Systems in the Market for Lemons*. 10.1007/s12599-017-0499-8.
[65] W. Nowiński, M. Kozma, How Can Blockchain Technology Disrupt the Existing Business Models? Entrepren. Bus. Econom. Rev. 5 (3) (2017) https://doi.org/10.15678/EBER.2017.050309.
[66] O'Dwyer, K.J., & Malone, D. (2014). *Bitcoin Mining and its Energy Footprint*. http://blockchain.info/charts.
[67] Palfreyman, J. (2016), "Blockchain for Asset Registration", available at: https://www.ibm.com/blogs/insights-onbusiness/government/Blockchain-asset-registration/ (accessed 30 January 2019).
[68] G. Perboli, S. Musso, M. Rosano, Blockchain in Logistics and Supply Chain: a Lean Approach for Designing Real-World Use Cases, IEEE Access 6 (2018) 62018–62028, https://doi.org/10.1109/ACCESS.2018.2875782.
[69] A. Perdana, A. Robb, V. Balachandran, F. Rohde, Distributed ledger technology: its evolutionary path and the road ahead (2020), Informat. Manag. (2020) art. no. 103316.
[70] J. Pereira, M.M. Tavalaei, H. Ozalp, Blockchain-based platforms: decentralised infrastructures and its boundary conditions, Technol. Forecast Soc. Change 146 (2019) 94–102.
[71] N.T. Pham, T. Vo-Thanh, M. Shahbaz, T.L. Duc Huynh, M. Usman, Managing environmental challenges: training as a solution to improve employee green performance, J. Environ. Manage. 269 (2020), https://doi.org/10.1016/j.jenvman.2020.110781 art. no. 110781.
[72] M. Pilkington, Blockchain technology: principles and applications. Research Handbook On Digital Transformations, Edward Elgar Publishing, 2016.
[73] L. Poppo, K.Z. Zhou, J.J. Li, When can you trust "trust"? Calculative trust, relational trust, and supplier performance, Strateg. Manag. J. 37 (4) (2016) 724–741, https://doi.org/10.1002/smj.2374.
[74] D. Puthal, N. Malik, S.P. Mohanty, E. Kougianos, G. Das, Everything you wanted to know about the blockchain: its promise, components, processes, and problems, IEEE Consumer Electron. Magaz. 7 (4) (2018) 6–14.
[75] M. Risius, K. Spohrer, A Blockchain Research Framework, Busin. Inform. Syst. Eng. 59 (2017) 385–409, https://doi-org.ezproxy.unibg.it/10.1007/s12599-017-0506-0.
[76] D. Roeck, H. Sternberg, E. Hofmann, Distributed ledger technology in supply chains: a transaction cost perspective, Int. J. Prod. Res. 58 (7) (2020) 2124–2141, https://doi.org/10.1080/00207543.2019.1657247.
[77] L. Rosencrance, Blockchain Technology Will Help The World Go Green, Bitcoin Magazine, 2017.
[78] S. Saberi, M. Kouhizadeh, J. Sarkis, Blockchains and the supply chain: findings from a broad study of practitioners, IEEE Eng. Manage. Rev. 47 (3) (2019) 95–103.
[79] S. Saberi, M. Kouhizadeh, J. Sarkis, L. Shen, Blockchain technology and its relationships to sustainable supply chain management, Int. J. Prod. Res. 57 (7) (2019) 2117–2135, https://doi.org/10.1080/00207543.2018.1533261.
[80] Ó.J. Sánchez, C.A. Cardona, Trends in biotechnological production of fuel ethanol from different feedstocks, in: Bioresource Technology 99, 2008, pp. 5270–5295, https://doi.org/10.1016/j.biortech.2007.11.013.
[81] R. Selmi, W. Mensi, S. Hammoudeh, J. Bouoiyour, Is Bitcoin a hedge, a safe haven or a diversifier for oil price movements? A comparison with gold, Energy Econom. 74 (2018) 787–801.
[82] Shashi, P. Centobelli, R. Cerchione, M. Ertz, Agile supply chain management: where did it come from and where will it go in the era of digital transformation? Indust. Market. Manag. 90 (2020) 324–345.
[83] W. She, Q. Liu, Z. Tian, J.-S. Chen, B. Wang, W. Liu, Blockchain Trust Model for Malicious Node Detection in Wireless Sensor Networks, IEEE Access 7 (2019) 38947–38956, https://doi.org/10.1109/ACCESS.2019.2902811.
[84] Shermin, V. (2017). Disrupting governance with blockchains and smart contracts. *Strate. Change*, 26(5), 499–509. 10.1002/jsc.2150.
[85] M.M.S. Sodhi, C.S. Tang, Corporate social sustainability in supply chains: a thematic analysis of the literature, Int. J. Prod. Res. 56 (1–2) (2018) 882–901, https://doi.org/10.1080/00207543.2017.1388934.
[86] Steiner, J., and J. Baker. (2015). "Blockchain: the Solution for Transparency in Product Supply Chains." https://www.provenance.org/whitepaper.
[87] I. Surjandari, H. Yusuf, E. Laoh, R. Maulida, Designing a Permissioned Blockchain Network for the Halal Industry using Hyperledger Fabric with multiple channels and the raft consensus mechanism, J. Big Data 8 (1) (2021) 10, https://doi.org/10.1186/s40537-020-00405-7.
[88] Swachhcoin Foundation. (2018). *Whitepaper v1.2 #May 2018*.
[89] M. Swan, Blockchain: Blueprint for a New Economy, 2015, O'Reilly Media, Inc., 2015.
[90] F. Tian, A supply chain traceability system for food safety based on HACCP, blockchain & Internet of things, in: 14th International Conference on Services Systems and Services Management, ICSSSM 2017 - Proceedings, 2017, https://doi.org/10.1109/ICSSSM.2017.7996119.
[91] D. Tranfield, D. Denyer, P. Smart, Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review, British J. Manag. 14 (3) (2003) 207–222.
[92] Q. Wang, R.Y.K. Lau, X. Mao, Blockchain-Enabled Smart Contracts for Enhancing Distributor-to-Consumer Transactions, IEEE Consumer Electron. Magaz. 8 (6) (2019) 22–28, https://doi.org/10.1109/MCE.2019.2941346.
[93] Ward, T. (2017). Blockchain Could Help Us Save the Environment. Here's How. https://futurism.com/blockchain-could-help-save-environment-heres-how/.
[94] A. Wright, P. de Filippi, Decentralised Blockchain Technology and the Rise of Lex Cryptographia, SSRN Electronic J. (2015), https://doi.org/10.2139/ssrn.2580664.
[95] X. Xu, Q. Lu, Y. Liu, L. Zhu, H. Yao, A.v. Vasilakos, Designing blockchain-based applications a case study for imported product traceability, Future Generat. Comput. Syst. 92 (2019) 399–406, https://doi.org/10.1016/j.future.2018.10.010.
[96] H. Yusuf, I. Surjandari, Comparison of performance between kafka and raft as ordering service nodes implementation in hyperledger fabric, Int. J. Adv. Sci. Tech. 29 (7S) (2020) 3549–3554.
[97] P.J. Zelbst, K.W. Green, V.E. Sower, P.L. Bond, The impact of RFID, IIoT, and Blockchain technologies on supply chain transparency, J. Manufact. Technol. Manag. (2019), https://doi.org/10.1108/JMTM-03-2019-0118.
[98] J.L. Zhao, S. Fan, J. Yan, Overview of business innovations and research opportunities in blockchain and introduction to the special issue, Financ. Innovat. 2 (28) (2016) 2–7.
[99] X. Zhou, Z. Pan, M. Shahbaz, M. Song, Directed technological progress driven by diversified industrial structural change, Struct. Change and Economic Dynam. 54 (2020) 112–129, https://doi.org/10.1016/j.strueco.2020.04.013.
[101] Q. Zhu, P. Shah, J. Sarkis, Addition by subtraction: integrating product deletion with lean and sustainable supply chain management, Int. J. Prod. Econ. 205 (2018) 201–214, https://doi.org/10.1016/j.ijpe.2018.08.035.

**Piera Centobelli (MEng, PhD)** is Professor of Business Economics and Organization at the Department of Industrial Engineering - University of Naples Federico II. From 2013 until 2016 she joined the Fraunhofer Joint Laboratory of Excellence on Advanced Production Technology (J-LEAPT) in partnership with Fh-IWU of Chemnitz. She published more than fifty papers in top journals and conference proceedings. She acts as member of the editorial board, guest editor and reviewer for several peer-reviewed journals. Her research interests focus on knowledge and technology management, corporate social responsibility, logistics and supply chain management, decision support systems, blockchain and Industry 4.0 technologies, circular economy, environmental, economic and social sustainability.

**Roberto Cerchione (MEng, PhD)** is Chair of IEEE Blockchain Italy, Delegate of Engineering Management Committee and Director of SGu at the University of Naples Parthenope. He is Professor of Technology, Innovation and Management Faculty at the University

of Bergamo and the University of Naples Federico II and teaches 'Advanced Logistics Systems and Sustainable Supply Chain Management' at the Aerotech Academy. After his PhD, he was Adjunct Faculty at University of Maryland University College and Scientific Coordinator of technology transfer and R&D projects with large companies, SMEs and startups. He serves as Co-Editor-in-Chief the Journal of Entrepreneurship Education and the Academy of Strategic Management Journal, and acts as managing guest editor, section editor and editorial board member for many journals. His-research interests focus on blockchain and 4.0 transition, knowledge and technology management, sustainability management, logistics and supply chain management, entrepreneurship and technology transfer. He has co-authored more than 100 publications including articles published in leading peer-reviewed journals, book chapters, conference proceedings, research reports.

**Pasquale Del VECCHIO (PhD)**is a senior researcher in Management Engineering at the Department of Management, Finance and Technology of the University LUM Giuseppe Degennaro, Italy. In 2007 he was a visiting PhD student in the Center for Business Intelligence at MIT's Sloan School of Management. His research field concerns the issues of open innovation, digital transformation, data driven business models and circular economy. These research activities have been documented in approximately 50 publications spanning international journals, conference proceedings and book chapters.

**Eugenio Oropallo (MEng)** is PhD Candidate at the Department of Industrial Engineering - University of Naples Federico II (Italy). He received the Master. degree in Engineering Management. His-current scientific interests concern the role of Industry 4.0 enabling technologies, knowledge management, blockchain, big data and business analytics in supply chain management domain.

**Giustina Secundo** is Associate Professor in Management Engineering at University LUM Giuseppe Degennaro (Bari, Italy). She has been the Director and Project Manager for the Contamination Lab at University of Salento (Lecce, Italy). She teaches Digital Transformation and Project Management. She is the Director of the Master in *Digital transformation of the Public Administration* at University LUM (Bari). Her research regards the Digital transformation of the Academic entrepreneurship, Technology Entrepreneurship and Open Innovation. In these reserach areas she authored more than 180 international papers for which she received several awards such as, the Emerald Literati award, the best papers award and the highly commended award from Emerald. Across the 2014 – 2015 she has been visiting research at the Innovation Insights Lab at University of the Arts London (UK).