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Speculating on the application of blockchains in the circular economy

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Abstract

Can the blockchain be the infrastructure of the circular economy paradigm? In the present paper, we first explore the concepts of the blockchain and circular economy and consider why and how they could interact. Our inquiry of the literature provides a positive theoretical answer. However, shortcomings are also reviewed in terms of their practical implementation. Much will depend on how the blockchain technology and its functionalities (e.g., smart contracts, distributed autonomous organizations) will be able to support the circular economy ecosystem.

Keywords: Blockchain, Circular Economy

1. Introduction

While the concept of the circular economy is widely accepted[1] and its deployment envisioned mostly within available technologies and institutions, blockchain technologies promise to bring disruptive changes at several levels well beyond the realm of cryptocurrencies, in which they were first deployed. The academic literature exploring the potential institutional applications of blockchain technologies is in its infancy but is proliferating. We aim to tap into this stream, focusing on the exploration of the potential intertwining of blockchain technologies with the circular economy.

It has been claimed that government, governance, and classical economic paradigms are challenged by the possibilities that could potentially arise from the development of decentralized political and socio-economic systems (among many: Swan, 2015; Tapscott & Tapscott, 2016; Mougayar, 2016; Markey-Towler, 2018). A first systemic shift came with the Internet (Akgiray, 2019); the blockchain could prove to be the next step.

The application of this technology could result in a transformation[2] of the functioning of society, converging into decentralized networks run by trust machines[3]. Given that the blockchain has the chance to become the next dominating infrastructure, would the current market paradigm be modified? If so, how? The blockchain in its purest form (public) is completely horizontal and decentralized; therefore, there would be neither a central authority nor trusted intermediary, while nowadays hierarchy, often coupled with the linearity[4] of processes, is intrinsic in societies and enterprise models. Thus, what impact can blockchain applications such as *autonomous agent, smart contracts* and *smart properties* or *distributed network organizations* have? Such applications are already being used in finance and cryptocurrencies, but the merging of these with the big paradigm

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[1] World Economic Forum, (2014) Towards the Circular Economy: Accelerating the scale-up across global supply chains.

[2] Transformation is a process in which available capacities and competencies are rearranged to offer a new value proposition (Jonker and de Witte 2013, quoted in Faber and Jonker, 2019, p. 223).

[3] The definition was given by the Economist (The Trust Machine, Oct. 31, 2015)

[4] A linear economy is one defined as converting natural resources into waste, via production. Such production of waste leads to the deterioration of the environment in two ways: by the removal of natural capital from the environment (through mining/unsustainable harvesting) and by the reduction of the value of natural capital caused by pollution from waste. Pollution can also occur at the resource acquisition stage (Murray et al., 2015).

of the circular economy shows the premise for unsettling current market mechanisms (e.g., creating the *circular supply chain* and *circular advantage)*. This paradigmatic shift should be based on a trusted, immutable and secure technological framework that needs to ensure benefits while minimizing weaknesses and risks; the blockchain. However, when considering the implementation of this technology several challenges must still be addressed to unlock its potential. The circular economy has also failed to show its full potential so far. Will the blockchain help to unlock it? Sustainability and circularity are two of the current societal challenges which can be addressed by the pairing of the blockchain with the concept of the circular economy (Faber and Jonker, 2019). Is this true?

To answer this question, we aim to speculate and understand why blockchain technologies could be implemented in the circular economy. Research on the literature of both topics has been carried out in order to identify similarities, differences, and challenges to be faced for to the development of a relationship of mutual benefit between technology, market, and therefore society. The two concepts will be first introduced to then discuss and conclude why and how the topics could fit well according to our research. We believe this merger to be possible as long as the relevant challenges raised by the pairing of blockchain technologies and the principles of the circular economy are addressed properly. The circular economy ecosystem must still be built and the blockchain's unique qualities may play a crucial role in the large-scale implementation of this economic paradigm. However, there is still a long way to go. Future research suggestions will be presented at the end of this article.

2. Background

2.1 *An overview of the blockchain*

In 2008, Satoshi Nakamoto's paper, "Bitcoin: A Peer-to-Peer Electronic Cash System," formed the basis of modern blockchain-based cryptocurrency innovation[5], "establishing a set of rules—in the form of distributed computations—that ensured the integrity of the data exchanged among these billions of devices without going through a trusted third party" (Tapscott and Tapscott, 2016). As Markey-Towler (2017) recalls, "Our entire economic system relies on the keeping of verified public records." These public records have until now been managed by public institutions.

Beck and Muller-Bloch (2017, p. 1) define the blockchain as "a distributed ledger or list of data records of transactions that may involve any kind of value, money, goods, property, or votes. The blockchain is shared in a decentralized network of computers and based on mathematics and advanced cryptography, where each transaction can be verified by the entire network." In other

[5]The abstract of the article of Satoshi Nakamoto is the following: *"We propose a solution to the double-spending problem using a peer-to-peer network. The network timestamps transactions by hashing them into an ongoing chain of hash-based proof-of-work, forming a record that cannot be changed without redoing the proof-of-work. The longest chain not only serves as proof of the sequence of events witnessed, but proof that it came from the largest pool of CPU power. As long as a majority of CPU power is controlled by nodes that are not cooperating to attack the network, they'll generate the longest chain and outpace attackers. The network itself requires minimal structure. Messages are broadcast on a best effort basis, and nodes can leave and rejoin the network at will, accepting the longest proof-of-work chain as proof of what happened while they were gone".* The article can be found at: https://bitcoin.org/bitcoin.pdf - Consulted on March 2, 2018

words, it is a public record kept without the requirement of a public authority (Markey-Towler, 2017). “A decentralized scheme which transfers authority and trust to a decentralized virtual network and enables its nodes to continuously and sequentially record transactions on a public “block,” creating a unique “chain”; the blockchain” (Mougayar, 2016). Briefly, the blockchain is a distributed ledger representing a network consensus of every transaction that has ever occurred (Tapscott and Tapscott, 2016). There are currently three different yet complementary definitions of the blockchain: technical, business, and legal. “Technically, the blockchain is a back-end database that maintains a distributed ledger that can be inspected openly. Business-wise, the blockchain is an exchange network for moving transactions, value, assets between peers, without the assistance of intermediaries. Legally speaking, the blockchain validates transactions, replacing previously trusted entities” (Mougayar, 2016). Even though it will not be addressed here, the issue of trust is of particular interest, as highlighted by the above-mentioned legal definition. In fact, in every human transaction that occurs trust must be in place; “the market can work properly (so bringing wealth and welfare) only among people capable of cooperation and trust.”[6] Such logic can also be found in society, where a certain reciprocity and security concerning exchange and property must be guaranteed (Markey-Towler, 2017), which primarily concerns placing trust in the counterpart of the agreement or the middleman that ensures the transaction. In the emerging blockchain world, there is “apparently” no space for intermediaries, and trust moves from people to the network (and its features) and even objects on the network (Tapscott and Tapscott, 2016). That is why the blockchain has been defined as a machine for creating trust (Economist, 2015). Theoretically, the blockchain can enable the disintermediation and decentralization of all transactions of any type between all parties on a global basis (Swan, 2015). The central idea of the blockchain is that the rights to goods can be transacted whether they are financial, hard assets or ideas (Tapscott and Tapscott, 2016). Regarding applications, Mougayar (2016) suggests considering the word ATOMIC: assets, trust, ownership, money, identity, contracts. Swan (2015) is much more generous as she foresees the potential benefits of the blockchain extended into political, humanitarian, social, and scientific domains. In such a system, all property could become smart property; this means encoding every asset to the blockchain with a unique identifier ensuring that the asset can be tracked, controlled, and exchanged (M. Swan, 2015). Blockchains are a coordinating institution for creating new economies (Berg and Berg, 2017). As Mougayar (2016) states, it is a new “value exchange” network: “the blockchain enables a new form of meta-transaction where the value is represented by what it unlocks at the end of the transaction, not just by an intrinsic monetary value that gets deposited in a static account.” It is a new “organizing paradigm” for the discovery, valuation, and transfer of everything, and potentially for the coordination of all human activity (Swan, 2015). Broadly speaking, the blockchain can be defined as a new “general purpose technology” (Evans, 2014). Alternatively, it can be considered as “meta-technology because it affects other technologies, and it is made up of several technologies itself […] combining game theory, cryptography science, and software engineering” (Mougayar, 2016). The way in which these elements are combined results in three possible outputs: public, private and consortium blockchain.[7] Moreover, the implementation of these three types is strictly intertwined with the development of the capacities of blockchain systems: “Blockchain 1.0, 2.0, and 3.0. Blockchain 1.0 is currency. […] Blockchain 2.0 is contracts, the entire slate of economic, market, and financial applications using

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[6] Bruni L., (2006). Civil Happiness – Economics and Human Flourishing in historical perspective, Routledge, London.
[7] https://blog.ethereum.org/2015/08/07/on-public-and-private-blockchains/ - Consulted on July 24, 2018.

the blockchain that are more extensive than simple cash transactions. […] Blockchain 3.0 is blockchain applications beyond currency, finance, and markets—particularly in the areas of government, health, science, literacy, culture, and art.” (Swan, 2015). It means that blockchain provides three levels of application: (1) Blockchain 1.0: accounting; (2) Blockchain 2.0: contractual; (3) Blockchain 3.0: community level (Faber and Jonker, 2019).

Implementation in technology is thus reflected in the associated value proposition of the blockchain. This relation is explored by Angelis and Ribeiro da Silva (2018) as synthesized in fig. 1.

	ENABLERS	VALUE DRIVER
1 Blockchain 1.0	Decentralized consensus	Transaction cost
2 Blockchain 2.0	Smart contracts	Added services
3 Blockchain 3.0	Decentralized applications, storage and computing	Organization boundaries
4 Blockchain 4.0	Decentralized artificial intelligence	Autonomous decision-making

Fig. 1 – Source: Angelis & Ribeiro da Silva, 2018

Nowadays, a new evolution is being developed: Blockchain 4.0, the result of the joint use of blockchain and artificial intelligence (Angelis and Ribeiro da Silva, 2018), which must also be researched in detail.

Whatever the category may be, blockchain implementation should follow the seven design principles identified by Tapscott and Tapscott (2016):

1. Networked integrity: trust is intrinsic, not extrinsic. Integrity is encoded in every step of the process and distributed, not vested in any single member. Participants can exchange value directly in the expectation that the other party will act with integrity.
2. Distributed power: the system distributes power across a peer-to-peer network with no single point of control. No single party can shut the system down.
3. Value as an incentive: the system aligns the incentives of all stakeholders;
4. Security: safety measures are embedded in the network with no single point of failure, and they provide not only confidentiality but also authenticity and non-repudiation to all activity.
5. Privacy: people should control their own data. Respecting one’s right to privacy is not the same as actually respecting one’s privacy.
6. Rights preserved: Ownership rights are transparent and enforceable. Individual freedoms are recognized and respected.
7. Inclusion: the economy works best when it works for everyone. That means lowering the barriers to participation.

Respecting these principles should ensure the situating of positive blockchain impacts into three broad categories: solving problems, creating opportunities, and applying capabilities (Mougayar, 2016). These impacts can be envisaged in every field of application, enhancing the capacities of societies of resilience and coordination. Hayek (1945) believed that the path to a functioning economy—or society—was decentralization and asserted that a decentralized economy complements the dispersed nature of information spread throughout society. Taleb (2007, 2016) confirmed decentralized systems as more resilient to shock. The decentralization operated by the blockchain seems to enable what 2001 Nobel laureate M. Spence defines the "flow of value" (how digital technologies transform global value chains through the dynamics of information flows). As will be shown, the problem of the dispersed nature of information is crucial to the circular economy, and the blockchain, via its technical features (anonymous, transparent, immutable, and distributed) and applications (e.g., smart contracts), seems to offer a legitimate solution.

2.2 *The Circular Economy*

The unsustainability of the current economic paradigm has been taken for granted (Rifkin, 2012); Non-sustainability is the biggest global challenge facing humanity at the beginning of the twenty-first century (Dapp, 2018). The publication of the club of Rome (1972) and the following Brutland report (1987) clearly stated this fact many years ago. The linearity of the productive system is among its identifiable causes. Its main weakness is the "inability to extend a product's lifecycle and make its embedded components, material and energy, as valuable after its useful life ends as they originally were when going into production. Considerable value is lost, squandering material, energy, and labor" (Lacy et al., 2016). New paradigms are needed to be applied on a large scale. The so-called circular economy (CE) is currently gaining attention as an alternative model of production and consumption; a growth strategy enabling the 'decoupling' of resource use from economic growth, thereby contributing to sustainable development (Reike et al., 2018). It represents the most recent attempt to conceptualize the integration of economic activity and environmental wellbeing in a sustainable way (Murray, 2015), with the aim of rethinking and redesigning how economies work. The circular economy recognizes effective and efficient economic functioning at multiple levels – governments and individuals, globally and locally, and for both large- and small-scale businesses (Kouhizadeh et al., 2019).

Although Geissdoerfer et al. (2018) suggest that "Stahel might have introduced the concept in 1982 talking of a self-replenishing system that minimizes material and energy input as well as environmental deterioration without negative influences on growth and progress", the term was first used in the book "Economics of Natural Resources and the Environment" (D. Pearce and R. K. Turner, 1991). Then, the publication of "Cradle to Cradle: Remaking the Way We Make Things" (M. Braungart and W. McDonough, 2002) facilitated wider public discussion on the topic. Further pioneers such as Ernst U. von Weizsäcker et al., with "Factor Four: Doubling Wealth, Halving Resource Use" or Gunter Pauli and his "Blue Economy" (2010) contributed markedly to the debate. Currently "the circular economy is a generic term for an economy where growth is decoupled from scarce resource use" (Lacy et al., 2016). The term is so generic that, as highlighted by Kirchherr et al. (2017), it is possible to gather 114 definitions of a circular economy. In an attempt to find common ground among the different interpretations studied, the same authors presented the following definition:

“*A circular economy describes an economic system that is based on business models which replace the ‘end-of-life’ concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro-level (products, companies, consumers), meso level (eco-industrial parks) and macro-level (city, region, nation and beyond), with the aim of accomplishing sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations*.”

Definitions by practitioners are much more concise, placing a greater focus on the relationship between materials and products. In fact, according to the Ellen MacArthur Foundation (2015), “We can define circular an economy that is restorative and regenerative by design and which aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles.” “Material use is of two types: biological (renewable) materials, designed for reuse and ultimate return to the biosphere, and technical (nonrenewable) materials, designed to move back and forth between production and consumption with minimal loss in quality or value” (Lacy et al., 2016). Moreover, “it is conceived as a continuous positive development cycle that preserves and enhances natural capital, optimizes resource yields, and minimizes system risks by managing finite stocks and renewable flows. It works effectively at every scale” (Ellen MacArthur Foundation, 2016), being able to create a so-called *circular advantage*. This can be defined as the competitive edge gained by organizations adopting circular economy principles as a core element of their growth strategies (Lacy et al., 2016). Concisely, “its value drivers include extending the regeneration of natural capital and the useful life of finite resources, maximizing the utilization of assets and creating new use cycles for end-of-life assets” (Askoxylakis et al., 2017) thus resulting in a circular supply chain, as shown in fig. 2.

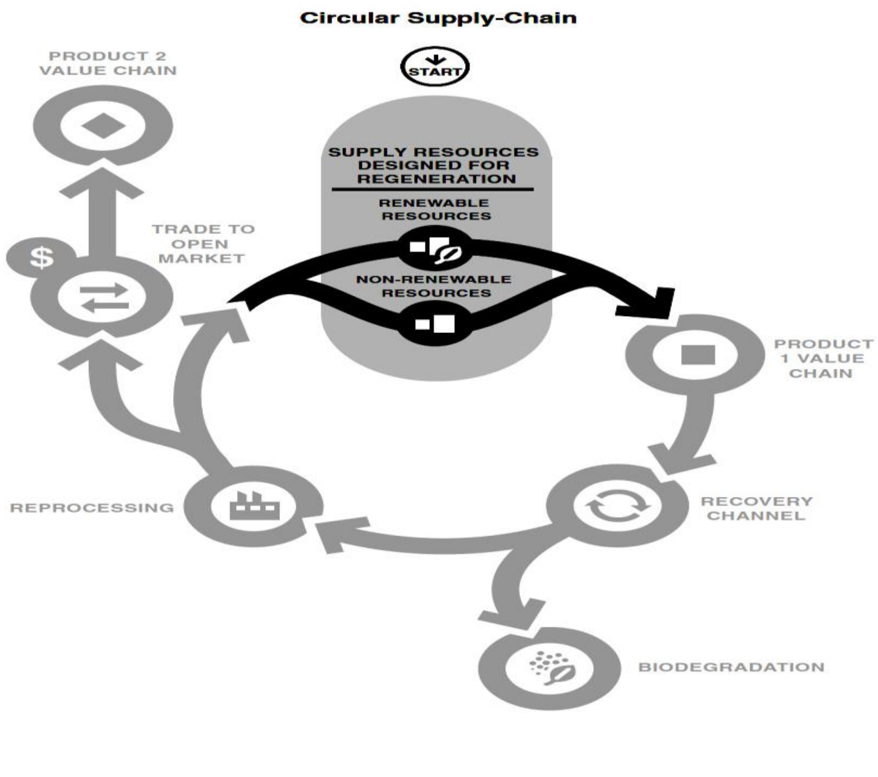

Fig. 2 – A representation of a circular supply chain. Source: Lacy, Rutqvist, 2015

The application of the blockchain in the management of the supply chain breaks traditional work paradigms in which companies are constituted (Rubio et al., 2018). Supply chain currently "depends on organizations' networks, since one single enterprise does not own the entire set of skills and resources required to deliver its value proposition (Taylor et al., 2001 cited in Geissdoerfer et al., 2018). These network configurations are variable according to specific attributes (such as dynamic behavior, level of trust between nodes, distribution of risks or benefits, geographical dispersion, etc.), characteristics of each organization representing the network node and also product type (Taylor et al., 2001 quoted in Geissdoerfer et al., 2018). The configuration can be linear or circular; each has its own way to be managed. Geissdoerfer et al. (2018) provide a definition of circular supply chain management (CSCM), viewed as "the tool to close, slow, intensify, narrow, and dematerialize material and energy loops to minimize resource input into and waste and emission leakage out of the system, to improve its operative effectiveness and efficiency and generate competitive advantages." This can lead to the development of new business models and economic interactions among market stakeholders, favored by the development of decentralized structures and integrated management for the supply chain thanks to the blockchain (Rubio et al., 2018). For example, Lacy et al. (2016) identified five new types: i) the above-mentioned *Circular Supplies* business model; ii) the *Recovery and Recycling* business model (also known as *Resource Recovery*); iii) the *Product Life Extension* business model; iv) the *Sharing Platform* business model; v) the *Product as a Service* business model. Each one of these business models has its own particular specificity that is reflected in the way the different systems are organized. Such specificity can also be observed in the blockchain; the different level of applications (accounting, contracting, and community) reflect different levels of integration with the different business models mentioned above. For example, Faber and Jonker (2019) provide a synthesis of how the interaction may work in the case of the Product Life Extension business model, as shown in fig. 3.

Strategic decoupling and blockchain levels	*Servitisation/ dematerialisation*	*Life-cycle extension*	*Recycling, conversion, substitution*
Accounting	Accounting of transactions of use during life cycle	Accounting of assets and parts; repair and refurbishment during life cycle	Track and trace of components leading to (virgin) material pools
Contractual	Enables provision and quality of delivery of functions	Enables contractual transparency in product-service systems	Enables transparent substitution of materials (part or whole)
Community	Collective valuation leading to accessibility	Governance of stock and flows of assets and materials	Enables the use of multi-transactional means

Fig. 3 Strategic decoupling at crossroads with blockchain application levels

Source: Faber and Jonker, 2019

Even if their implementation is not investigated in the present work, we believe that each of these business models can be facilitated by the unique nature of the blockchain, at least concerning the functioning and governance of the network, as shown in fig. 4. Research is beginning to investigate use cases. An example case involves the Product Life-Extension business model, in which by using the blockchain companies can monitor real information on the life cycle of materials and products and determine initiatives to extend their life cycle (Kouhizadeh et al., 2019; Faber and Jonker, 2019). Similarly, the blockchain may be suitable for the implementation of the product as a service model (Vogel et al., 2019).

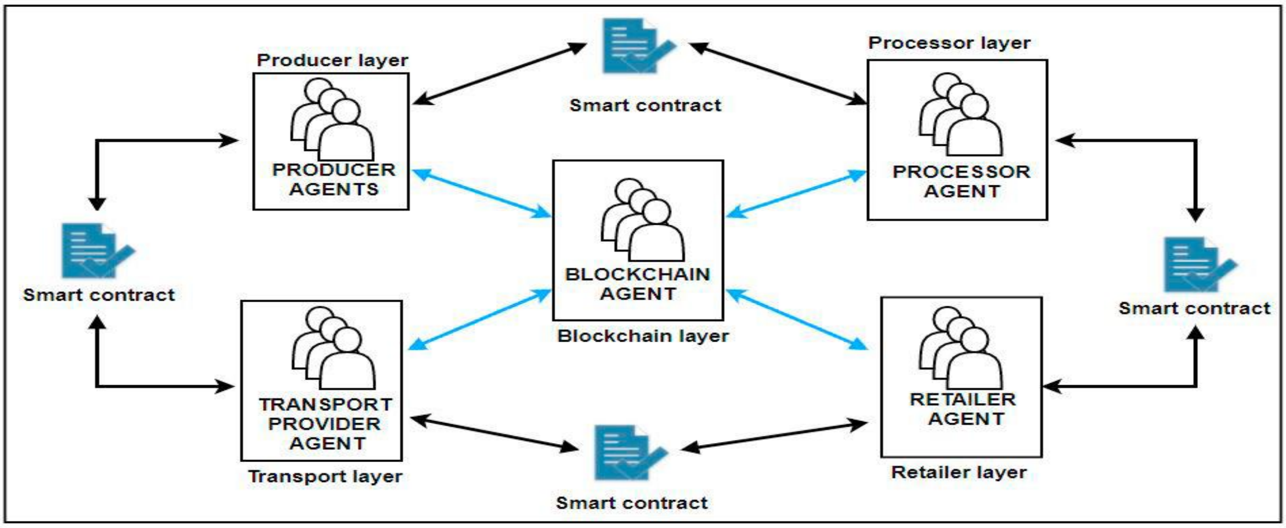

Fig. 4 - An example of an ordinary supply chain change utilizing blockchain technologies. Each layer sends data from its transactions to the blockchain. The layers that manage the articles also communicate with each other via smart contracts. These smart contracts enable the buying and selling of items.
Source: R. Casado-Vara et al., 2018

There are several initiatives currently underway to implement the circular economy. The main actors are legislative and governmental bodies, NGOs, and consultancy firms. The plurality of the implementers is reflected in the absence of common ground (Kalmykova et al., 2017). Among the primary challenges related to the circular economy, those related to business models can be mentioned, such as data ownership, data sharing, data integration, collaboration and competence requirements (Antikainen et al., 2018). Many of these can be addressed thanks to digitalization. In fact, it has been claimed that pairing digitalization with circular economy principles can transform the relationship between the economy and both materials and finite resources, unlocking additional value and generating positive outcomes (Ellen MacArthur Foundation, 2016). In practice, cloud computing, big data, and constant information innovations can lead to greater insight into a product or the price, availability, and performance of a service (Lacy et al., 2016). Synthetically, digital solutions can enable circular business models through automated monitoring, control and optimization of resources and material flow by providing accurate information on the availability, location and condition of products (Antikainen et al., 2018). Information on the quantity and quality of products and their raw material contents must be collected and retained, resulting in the need for continuous dialogue in order to create and share information. This process can be improved thanks to information systems supported by blockchain technology that will affect circular economy performance at multiple levels (Kouhizadehet al., 2019) thanks to the so-called Internet of things (IoT)[8]. The sensory networks of the Internet of things (IoT) enable the measuring of real-life phenomena (Dapp, 2018). In his book, "The zero marginal cost society" (2014), Rifkin clearly expressed its potentialities. As is now known, in order to be fully operative, the IoT requires *intelligent assets* that must be governed in the case of the circular economy "by three underlying attributes enabling circularity: location, condition, and availability" (Askoxylakis et al., 2017). These intelligent assets could be placed on the blockchain thanks to its technological features. As suggested by Askoxylakis et al. (2017), blockchain-based mechanisms can effectively enable the transfer of asset ownership directly between parties participating in the circular economy while introducing trust, efficiency, and automation in asset exchange contracts (fig. 5). On the possible integration between blockchains and the IoT, Conoscenti et al. (2016) provided a systematic literature review, while an analysis of challenges and opportunities is provided by Reyna et al., 2018.

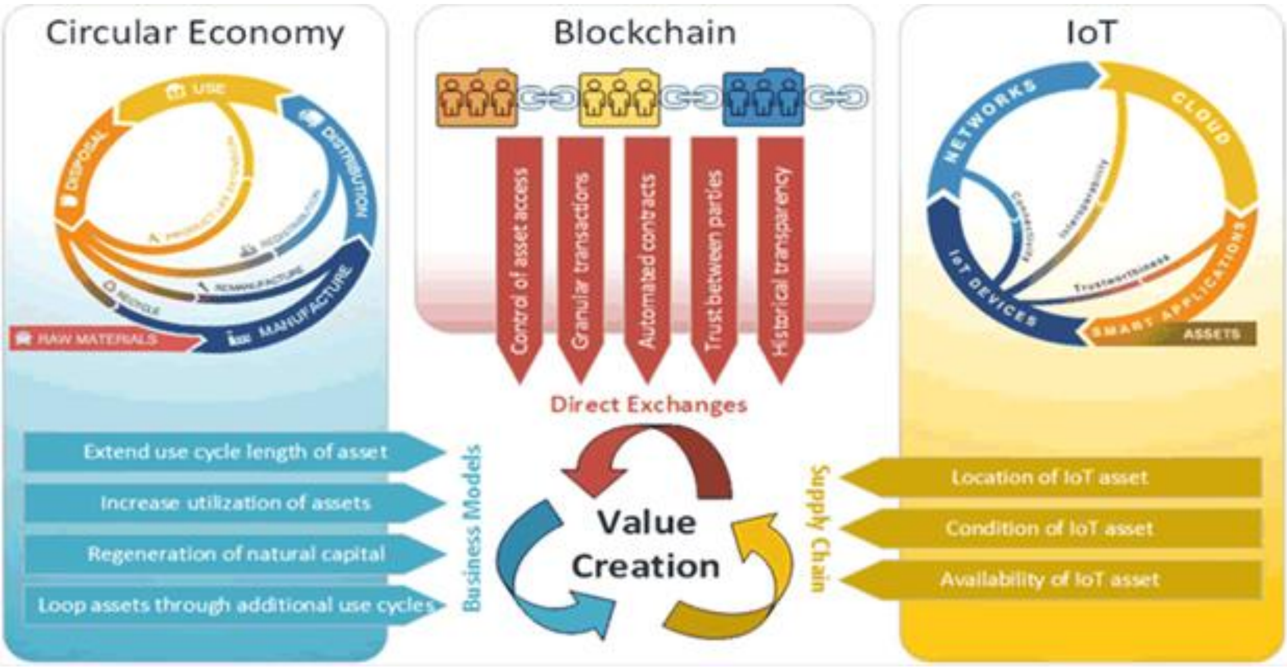

Fig. 5 - A representation of value created by the integration of the circular economy, the blockchain, and the Internet of things. Source: Askoxylakis et al., 2017

3. Discussion - Why could the blockchain be suitable for the circular economy?

As highlighted above, the coordination of material and information flows within the circular economy is crucial. Information sharing is an urgent requirement in supply chains, especially with

[8] The Internet of things (IoT) is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. See: https://en.wikipedia.org/wiki/Internet_of_things - Consulted on September 4, 2018

greater interest of industry 4.0[9] developments and digitization (Kouhizadeh et al., 2019). To this end, digitalization is considered one of the enablers of the circular economy due to its building of visibility and intelligence into products and assets (Antikainen et al., 2018). The interplay between the circular economy and intelligent asset value drivers is already proving fertile ground for innovation and value creation; "it is now people-people, people-things, and things-things."[10] In such a framework there is no space for trusted intermediaries. Blockchains are a low-cost market disruption to any business acting as a middleman. People will be able to connect, share, and transact directly with one another.[11] In practice, the blockchain allows individuals to carry out their work and be compensated inside new circular and self-contained economies with their own currency and work units (Mougayar, 2016; BitcoinBanc, 2016). Since there is no intermediary operator, the value produced within these platforms can be more equally redistributed among those who have contributed to its creation (De Filippi, 2018). Moreover, according to the Mougayar (2016) these processes will open a new chapter in the nature of work and its organization, raising the opportunity for a more equal redistribution of the means of production, both digitally and physically, as a type of "platform cooperativism" (De Filippi, 2018). However, in an assessment of the real improvements offered by the blockchain it is difficult to address potential impacts on income inequality with certainty (Novak, 2018).

The blockchain appeared on the stage as the foundation of the cryptocurrency Bitcoin, but its potential is far greater than this. It has the potential to transform traditional industry with its key characteristics: decentralization, persistency, anonymity, and auditability (Zeng et al., 2016). The potential benefits do not stop here. In his 1937 paper "The Nature of the Firm," the Nobel Prize winner N. Coase identified three types of costs in the economy: search, coordination, and contracting. The blockchain can reduce each of these by addressing two problems of traditional governance structures; (1) principal-agent dilemma, and (2) high transaction costs of coordination (Blockchain hub, 2017). The blockchain can achieve this through the application of software that can be implemented into it. Until now the most developed have been *smart contracts.* N. Szabo coined the phrase in 1994, defining a smart contract as "a computerized transaction protocol that executes the terms of a contract. The general objectives of smart contract design are to satisfy common contractual conditions (such as payment terms, liens, confidentiality, and even enforcement), minimize exceptions both malicious and accidental, and minimize the need for trusted intermediaries. Related economic goals include lowering fraud loss, arbitration and enforcement costs, and other transaction costs."[12] In other words, smart contracts contain a set of values and only unlock those values if the predefined conditions are met (Faber and Jonker, 2019). Either identified as *autonomous agents* (software that makes decisions and acts on them without human intervention)[13] applied on a large-scale, these can give rise to:

[9] The fourth industrial revolution takes the automation of manufacturing processes to a new level by introducing customized and flexible mass production technologies. The idea behind Industry 4.0 is to create a social network where machines can communicate with each other, called the Internet of Things (IoT) and with people, called the Internet of People (IoP). More at: https://www.cleverism.com/industry-4-0/ - Consulted on June 28, 2019

[10] https://blockgeeks.com/guides/blockchain-applications/ - Consulted on February 8, 2018

[11] https://www.linkedin.com/pulse/blockchain-sharing-economy-visionary-entry-digital-age-oana-grigoras – Consulted on February 6, 2018

[12] http://www.fon.hum.uva.nl/rob/Courses/InformationInSpeech/CDROM/Literature/LOTwinterschool2006/szabo.best.vwh.net/smart.contracts.html – Consulted on February 7, 2018

[13] https://github.com/ethereum/wiki/wiki/White-Paper– Consulted on February 8, 2018

- *Decentralized Autonomous Organization* – DAOs, which can be seen "as the most complex form of a smart contract, where the bylaws of the decentralized organization are embedded into the code of the smart contract, using complex token governance rules" (Blockchain hub, 2017) that requires little or no traditional management or hierarchy to generate customer value and owner wealth.
- *Decentralized collaborative organizations* – DCOs, which may represent a more cooperative form of crowdsourcing, sometimes referred to as "platform cooperativism" through which users qualify both as contributors and shareholders of the platforms to which they contribute (De Filippi, 2018).
- *Distributed application* – Dapp, a set of smart contracts that stores data on a home-listings blockchain.

The implementation of smart contracts, which can be used for supply chain process management and even process reengineering (Kouhizadeh et al., 2019), and the broad diffusion of DAOs, DCOs and Dapps, can easily reshape the boundaries of a company, dropping Coase's search costs and coordination costs and giving the opportunity to enterprises to disaggregate into more effective networks. This process seems familiar to the particular process enhanced by the circular economy; it involves entire networks of production and a diffusion of responsibility throughout these networks is prevalent (Murray et al., 2015). This decentralization, which would result in a shift in the system from vertical and hierarchical to circular and horizontal, consequently poses several challenges that must be addressed, concerning regulatory, governance and technological matters, for example. It is this last aspect, as has been shown, that represents the key point of intersection between the blockchain, its technological features, and the circular economy. As suggested, the *Circular Supply-Chain* business model that could be implemented on the blockchain can allow companies to improve the value they offer customers, operate in future-proof mode and be more competitive overall (P. Lacy et al., 2016). Moreover, the development of such an integrated technological framework could enrich the biodiversity of the market. For example, Tapscott and Tapscott (2016) identified seven network enterprises models that will be possible to adopt: i) *the Peer Producers;* ii) *the Rights Creators;* iii) *Blockchain Cooperatives;* iv) *the Metering Economy;* v) *the Platform Builders;* vi) *Blockchain Makers;* vii) *the Enterprise Collaborators*. Each of these business models promises to reshape markets and the relationships between the actors involved, resulting in an increase in the "platform cooperativism" stated by De Filippi (2018).

The blockchain may replace the model of top-down hierarchical organizations with a system of distributed, bottom-up cooperation (De Filippi, 2018) – a fundamental aspect of the circular economy is the involvement of consumers in a sharing or servicing the economy (Kouhizadeh et al., 2019) – representing a technological instrument that can enable the creation of value and provide a solid and reliable infrastructure.

4. Conclusion and future research

The blockchain could change the way both society and markets work (e.g., Swan, 2015; Tapscott and Tapscott, 2016; Mougayar, 2016). However, there remains little knowledge regarding the application of effective and applicable blockchain technology and of its subsequent societal impact.

Moreover, similarly to the internet the risk that the blockchain could evolve from a highly decentralized infrastructure into an increasingly centralized system controlled by only a few large online operators cannot be discounted (De Filippi, 2018).These aspects are not taken into consideration in the circular economy literature, in which there is an excessive emphasis on technological aspects and business models that neglect the need for incorporating more social aspects or criteria for it to function effectively (Stahel, 2016). Murray et al. (2015) take a more radical viewpoint, arguing that the concept of the circular economy does not encompass the social dimension in any great detail. The challenges facing the circular economy are manifold, some of which have been highlighted in the literature relating to governance, economic, and organizational theory (Kouhizadeh et al., 2019). This leaves great uncertainty regarding an understanding of how the implementation of this concept can lead to greater social equality, since both the circular economy and the blockchain (Tapscott and Tapscott, 2016) claim to be able to solve the "prosperity paradox." Furthermore, the blockchain aims to reduce the need for central authorities and middlemen, enabling the creation of decentralized networks that can operate using alternatives such as smart contracts and provide economic incentives to their participants via cryptocurrencies (Mougayar, 2016; BitcoinBanc, 2016). As seen, such processes may result in the blockchain contributing to a reshaping of inequality dynamics, on which there can be no certainty at this stage. However, on enhancing sustainability there are promising perspectives offered by blockchain technology (Faber and Jonker, 2019).

The decentralization initiated by the blockchain and its subsequent impact, must be studied in greater depth to find legitimate solutions to the challenges posed to the market's current functioning. As Arruñada (2018) suggests, law and regulatory agencies will have much of the responsibility in dealing with these new phenomena and they will inevitably be responsible for regulating them, assessing the limits that must not be overstepped. Blockchain implementation on a large-scale still faces several challenges before it can unlock its proclaimed potential. It is possible at this juncture to place these challenges into three categories: technical aspects (e.g., governance), the development of business models and correlated incentive mechanisms (e.g., scalability is a critical barrier originating from the immaturity of blockchain technology – Kouhizadeh et al., 2019), and legal aspects (e.g., applicable regulations). This also holds true for the application of the circular economy on a large scale. The transition towards larger scale application will require the ability to manage disruptiveness and radical innovation in the industry and to overrun the barriers suggested by the literature: financial, structural, operational, attitudinal and technological (Ritzén and Sandström, 2017). Furthermore, the availability of the right technology appears to be paramount for its implementation (Kirchherr et al., 2018), since the idea of the circular business model is that the ecosystem (such as the blockchain) and not any one company closes the loop (Antikainen et al., 2018). This shared particularity, combined with the technological features of the blockchain technology (e.g., transparency and traceability of the processes of the supply chain follow from the unique construction of the blockchain (Faber and Jonker, 2019), give rise to a suggestion that, on a theoretical level, it is possible to imagine the active cooperation and combined implementation of these two concepts to attain shared societal benefits. For example, we consider plausible the idea of the implementation of the circular economy through private blockchains or consortium models, in which public and private ledgers are integrated in order to ensure distributed governance, control, and benefits. This integration process will have to take into account the development of new business models, such as those identified by Talpscott and Talpscott (2016), which can possibly lead to a change in the structure and boundaries of the market, even resulting in the redistribution of wealth and wellbeing (Novak, 2018). However, this is another claim that must be proven. The development and implementation of novel technology does not guarantee that it will be used and be successful. For example, the principal obstacle to the proliferation of blockchain technology is the cost involved in its application (Rubio et al., 2018). Further research is required to gain a greater understanding of the underlying motivators and barriers that will lead to or discourage the adopting of blockchain technologies for supply chains (Francisco and Swanson, 2018). Most blockchain-based articles do not focus on potential use cases and motivation factors that favor the use of blockchain (Vogel et al., 2019). Moreover, this adoption will imply a change in the organizational culture of the supply chain and a more integrated vision in which there are no individual motivations but synergistic transactions in favor of the entire chain (Rubio et al., 2018). Solutions are currently under development. For example, Dapp (2018) proposes a new system which could motivate people to act more sustainably while remaining decentralized, self-organizing, multi-layered, and circular thanks to a multi-dimensional and multi-layered incentive (and feedback) system based on cryptocurrencies.

The real capacity for the unlocking of the potential benefits espoused by practitioners and enthusiasts will only become plausible via practical implementations and assessments of their impact, while bearing in mind that a circular economy requires broader and more inclusive supply chains, not only in industry but in communities, both individually and in terms of households. This dispersion and variety of actors causes difficulties in identifying, developing, and maintaining reliable circular economy sourcing (Kouhizadeh et al., 2019).

We acknowledge the limitations of the present paper, in that the findings are mainly based on academic contributions and theoretical assumptions. In order to address the relevant questions that are sure to be raised by the pairing of blockchain technologies and the principles of the circular economy, we therefore suggest that future research should focus on a detailed investigation of the above-mentioned phenomena based on the methodology of the single and multiple case study, while being accompanied by literature reviews and in-depth interviews with leading scholars and the main actors of the sectors under analysis.

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