LogForum

> Scientific Journal of Logistics <

2020, 16 (3), 363-372

http://doi.org/10.17270/J.LOG.2020.467

http://www.logforum.net p-ISSN 1895-2038 e-ISSN 1734-459X

ORIGINAL PAPER

BLOCKCHAIN AND SUPPLY CHAIN SUSTAINABILITY

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ABSTRACT. **Background:** Supply chain sustainability is a central concern of most organizations. The main objective of sustainable supply chains is to create and maintain long term economic, social, and environmental value for all stakeholders involved in delivering products and services to markets. As sustainability constitutes one of the critical drivers of innovation, the recent emergence of blockchain technology typifies the disruptive impact of digital innovation on supply chain sustainability. Blockchain is a foundational technology that poses a shift in the development of supply chain sustainability.

Methods: Despite the increasing importance of blockchain in improving supply chain efficiencies and bringing societal changes, research investigating its potentialities from the lens of sustainability is scarce. Therefore, the primary goal of this paper is to fill this knowledge gap and synthesize the literature from leading journals on the topic of blockchain and its relation to supply chain sustainability. Papers were collected from different scientific databases and carefully analyzed. The possibilities of blockchains are identified and classified according to the triple bottom line framework, namely the economic, social, and environmental dimensions of sustainability.

Results and conclusions: The majority of studies focused on the economic implications of blockchains on supply chains. The sustainable economic aspects of the technology identified in the reviewed literature are mostly the transformational potentials of blockchains and their capabilities to drive new disintermediated business models, higher operational efficiencies, cost advantages, and additional sources of value creation. The social empowerment of supply chains is found through the ability of blockchain to create trustful relationships among supply chain partners, increase food safety, support humanitarian logistics, and promote social equity. Moreover, firms attempting to move forward in their environmental policies and strategies can use blockchain to extend their efforts to improve their environmental practices across the supply chain, reduce the strain on energy and natural resources, and offer environmentally friendly products.

Key words: blockchain technology, supply chain, sustainability, economic, social, environmental.

INTRODUCTION

The recent emergence of blockchain technology typifies the disruptive impact of digital innovations on supply chain sustainability. Blockchain is defined as a "digital, decentralized and distributed ledger in which transactions are logged and added in chronological order with the goal of creating permanent and tamper-proof records" [Treiblmaier 2018]. Similarly, blockchain technology can also be described as a distributed database of records, transactions, and digital events that have been executed and shared among networked participants. Blockchain is not a standalone technology; instead, it is a configuration of multiple technologies, tools, and methods that address specific problems or use cases [Rejeb et al., 2018]. Unlike several digital solutions, blockchain technology breaks away from traditional centralized approaches allowing to securely managing chain data across a distributed and interlinked network of nodes. The first application of blockchain was the cryptocurrency Bitcoin, where the technology underpins the mechanism of recording transactions. Cryptocurrency systems remain the most significant use case of the concept, however, blockchain technology can be applied to diverse fields such as healthcare,

Citation: *Rejeb A., Rejeb K., 2020. Blockchain and supply chain sustainability. LogForum 16 (3), 363-372, http://doi.org/10.17270/J.LOG.2020.467*

Received: 19.02.2020, Accepted: 24.04.2020, on-line: 30.06.2020.

insurance, identity management, smart energy grids, logistics and supply chain management [Fosso Wamba et al., 2020].

In this paper, we view blockchain as a foundational technology [Iansiti, Lakhani 2017] that poses a shift in the development of supply chain sustainability. From this perspective, we seek to investigate the relationship between blockchain technology and the triple bottom line (TBL) approach of sustainability, namely, the economic, social, and environmental performance of supply chains. Although the scholarly interest in the blockchain phenomenon is continually increasing, there is still a lack of research exploring the application of the technology for supply chain sustainability. Most academics who studied blockchain in the context of supply chain management and logistics majorly focused on the economic implications of the technology while barely discussing the non-quantifiable benefits (e.g., social values, human and environmental sustainability) resulting from the incorporation of blockchain into supply chain networks. To fill this knowledge gap, this paper aims to examine and synthesize the landscape of current literature on blockchain and sustainable supply chain practices. The research is designed to answer the following research question:

"How can blockchain technology facilitate supply chain sustainability?"

In order to uncover this important interlink of key trends, we conducted a systematic literature review [SLR] to identify and analyze relevant publications. To our best knowledge, no other researchers have investigated and synthesized the existing body of knowledge from the lens of sustainability, making this study one of the earliest attempts to explore the sustainability-induced changes generated by the leveraging of blockchain in supply chains and logistics. The remainder of this paper is organized as follows. Section 2 describes the review methodology used for the SLR. Section 3 provides a detailed discussion of the possibilities of blockchain technology based on the findings of the review. The last section concludes the paper and presents the research contributions and limitations.

METHODOLOGY

To investigate how blockchain technology influences supply chain sustainability, we employed a systematic literature methodology following the guidelines proposed by Denyer & Tranfield [2009]. An SLR is a helpful tool for learning more about new topics, resolving uncertainties, providing a synthesis of previous studies, discovering research gaps, and highlighting the boundaries of knowledge. Similarly, this approach is useful to identify, select, and evaluate existing contributions. The SLR is also suitable for establishing rigor, completeness, and reporting quality.

Table 1. Research protocol

Research protocol	Details description
Research online databases	Searches were carried out in 5 leading databases which were Scopus, ScienceDirect [Elsevier], Web of Science, EmeraldInsight, and Taylor and Francis.
Publication types	Only peer-reviewed literature was considered. The search was limited to journal articles in order to ensure the academic nature of the sources. Book chapters, books, white papers, editorial notes, and doctoral theses were excluded.
Language	Only publications in English were considered to expand the coverage of literature.
Date range	No specific date range
Search fields	Title, abstract and keywords
Search keywords	["blockchain*" AND ["supply chain*" OR logistic*]] AND [sustainable OR sustainability OR green OR environment* OR social OR ethic*]
Inclusion criteria	Only articles that studied blockchain in the supply chain management and logistics context were selected.
Exclusion criteria	Publications treating blockchain technology with a deep and pure technical focus were considered beyond the scope of the study.

The authors undertook an iterative cycle identifying appropriate search keywords, surveying the relevant literature, and carrying out the analysis of the findings. A review protocol has been developed to determine procedures of the review conducting stage and necessary rules to follow. Table 1 presents in detail the selection of online search databases, the collection of articles, and the filtering criteria.

Data Collection

According to the surveyed online databases, the initial search queries resulted in a total number of 133 articles. To filter the results further, we eliminated the redundant publications that appeared in different databases. The articles were analyzed using the inclusion and exclusion criteria already mentioned in Table 1. The authors screened the titles and abstracts for relevance retaining only 90 publications for full-text review. A total number of 79 studies were eventually considered relevant for the scope of research. Out of those we will only cite the ones that we regarded to be the most useful. Figures 1 presents the process of data collection.

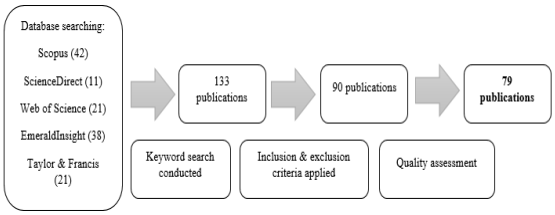

Fig. 1. Schematic presentation of data collection

REVIEW FINDINGS

Elkington [1998] coins the concept of the "triple bottom line" (TBL), indicating that organizations have to emphasize the importance of economic, social, and environmental performance. Carter & Rogers [2008] suggest that firms who pursue the three foundational dimensions of the TBL would be able to achieve better economic performance. In the context of the supply chain, the organization's vision of sustainability implies that these dimensions are equally important. In this review, we relied on the TBL framework to investigate how blockchain technologies could potentially influence the different facets of supply chain sustainability.

Economic Sustainability

Market Disintermediation

Disintermediation is a crucial advantage of applying blockchain technologies to supply chain management. As such, blockchain technologies offer disintermediation [Zamani & Giaglis, 2018], which can support several business transactions by connecting buyers and sellers without the need for intermediaries [Betti et al., 2019]. The flows of products and materials that are monopolized by fewer intermediaries may result in additional costs, increased system complexity, and product rejection by customers [Kouhizadeh et al., 2019]. However, blockchain technology could help to overcome these issues by eliminating these intermediaries serving as a central authority whose primary function is to validate transactions [Hald, Kinra 2019, Kamble et al., 2019]. For example, The Bitcoin Blockchain system removes the third party that is concerned with monitoring the authenticity of cryptocurrency transactions using asymmetric encryption [Rahmanzadeh et al., 2019]. The combination of smart contracts and blockchain is a viable and workable solution to substitute intermediaries or trusted third parties in the case of transshipment operations in a global supply chain setting [Hasan et al., 2019].

Operational Efficiencies

Blockchains can dramatically streamline entire business processes and make the whole supply chain more responsive and efficient [Faria 2019]. Through a blockchain-enabled supply chain, firms can benefit from increased levels of verification efficiencies and automation [Cole et al., 2019]. For example, blockchain facilitates the digital traceability and authentication of food products throughout the entire supply chain from suppliers to store shelves and finally to end consumers [Tijan et al., 2019]. Blockchain technology ensures end-to-end product tracking and enables multiparty authentication of the possession of goods [Treiblmaier 2018] and information sharing in real time. With such enhanced visibility,

supply chain partners can eliminate several non-value adding activities as they will be able to see the progress of goods and their movements along the supply chain [Hald, Kinra 2019]. The traceback capability of blockchain allows companies to quickly identify the inventory level of their products and raw materials and to make more integrated and well-informed decisions across all stages of the supply chain. As a result, blockchain technology has a time-saving advantage and can simplify many business tasks and eliminate inefficiencies resulted from archaic processes, trade-related paperwork, complex bureaucratic procedures, and stringent institutional requirements. As noted by Wong et al. [2019], familiarity with blockchain can lead to short task completion time, more simplicity, and enhanced job performance.

Blockchain leads to the formation of strong integration links between supply chain partners and allows rapid verification of outsourcing chain partners' documents such certificates, licenses, proofs of records, transactions, processes, and events [Pankowska 2019]. In trade finance, blockchain technology can ensure real-time approval and payments of transactions [Kamble et al. 2019]. A system for efficient supply chain management was developed by Hasan et al. [2019] using the features of smart contracts in Ethereum blockchain to manage items shipped via smart containers, govern and orchestrate interactions between the sender and receiver. Therefore, blockchain can substantially enhance operational efficiency, optimize resource allocation, and free up resources that can be used to soften the variability of supply chain demand and supply [Schmidt, Wagner 2019].

Cost Efficiency

The effective application of blockchain technology to supply chains can reduce several costs associated with the verification of product quality, the distortion of business processes, and the transfer of ownership among supply chain partners. The disintermediated approach of blockchains can dramatically reduce the costs of transactions that were economically unfeasible [Ashley, Johnson 2018]. Moreover, the pressure to reduce the costs of products and services constitutes an impetus for firms to use the technology for removing the overhead costs which are required for the exchange of assets. For example, Ko et al. [2018] note that blockchain technology can decrease manufacturing firms' networking costs and usher in the construction of new market platforms in the manufacturing industry. Results of before and after blockchain adoption have also shown that firms could improve their profits through the transparency and cost-saving nature of blockchain [Ko et al., 2018]. Because of these key characteristics, companies can be profitable and produce at smaller marginal and competitive costs when they incorporate blockchain technology into their business processes. The costless verification enabled by blockchain can benefit all the actors in the supply chain through eliminating or reducing the costs related to the certification of products and their ingredients [dos Santos et al., 2019]. As a result, supply chain partners would have the opportunity to generate significant savings on costs associated with enforcement, such as labor expenses, legal fees, taxes, and court costs. Moreover, companies may realize cost savings from the reduction of waste and all adverse outcomes. Information on the blockchain can then be used to take proactive actions, mitigate process frictions, and shorten the time-to-market.

Value Creation Opportunities

A promising application of blockchain is its potential to allocate resources among supply chain partners efficiently. As such, sharing models powered by blockchain technology allow businesses to have visibility into the availability of all underutilized logistics assets (e.g., trucks, vehicles, machinery and equipment, warehouse capacity, etc.). Likewise, blockchain has the appropriate digital capabilities to create a new world of collaborative and decentralized logistics [Meyer et al., 2019], which hosts a vast network of supply chain actors, matches firms on-demand, and delivers improved availability and better utilization of logistics resources. Blockchain helps to create a fair economic business model and preserve the benefits of the sharing economy because companies that are based on resource sharing will be under strict monitoring and scrutiny [Sicilia, Visvizi 2019].

This approach prepares the fertile ground for entrepreneurship and the development of new business ventures and companies. Unlike traditional IT platforms, blockchain can significantly contribute to the simplification of crowdfunding [Veuger 2018] and the reduction of entry barriers and costs. This implies that both small and small and medium enterprises would be able to attract cheaper capital and funding from investors all over the world. Regardless of their size, businesses also can majorly benefit from the economic incentives provided by the application of blockchain. For instance, it is highly likely that the enforcement of intellectual property rights will increase the incentives to invest, create wealth and growth, and to generate competitive resources. Clear property rights would allow companies to add new business values and allow potential investors to increase their access to capital [Kshetri 2017]. Furthermore, firms have incentives to adopt blockchain technology because, if not, they risk to be outperformed by their competitors [Ko et al., 2018], not live up to the expectations of their customers, and to lose the preferential financing, subsidies, and tax incentives that can be otherwise obtained as a result of increased transparency and disclosure of sustainability claims. The extent to which blockchain can ensure transparency unlocks other economic advantages such as branding benefits and positive signaling to consumers. Therefore, blockchain discerns a branding narrative that communicates several corporate values to all supply chain partners, and particularly to customers, and this unfolding can result in a high willingness to pay and high-value perception of service or product quality [Keyser et al., 2019].

Social Sustainability

Empowering Trust

In a review study by Wang et al. [2018], trust is considered the most influential factor for awaking the interest in the blockchain within supply chain management. Blockchain technology offers a universally trusted computing platform [Ramkumar 2018] where untrusted parties can reach agreement on a secured, distributed, and transparent ledger [Rahmanzadeh et al. 2019]. Blockchains place more trust and authority in decentralized networks, representing a total shift away from the conventional ways of orchestrating and managing supply chains. With the blockchain-enabled trust, supply chain risks and contingencies can be significantly reduced among exchange partners. The completeness and transparency of information and transactions on the blockchain constitute the necessary ingredients for establishing mutual trustful relationships between supply chain stakeholders [Veuger 2018]. Moreover, blockchain technology creates an atmosphere of trust, continued ethical behavior, fairness, and honesty. This trust is often a necessary antecedent of information and resource sharing in supply chains. For instance, Lemieux [2016] noted that blockchain technology ensures trustworthiness of records, which is a necessity in a range of different contexts where record systems provide the critical underlying infrastructure necessary to achieve development objectives. In business relations, blockchain solves the problem of missing trust between a large number of untrusted stakeholders [Wang et al. 2018]. The technology acts as a foundation for cooperative and collaborative supply chain connections. Trust is gained through blockchain-enabled data integrity, security, and protection against fraud, infringements, and cybercrime [Modic et al., 2019]. Therefore, blockchain promotes a new ecosystem where shared values on goals and policies, strong regulations and control mechanisms, reputation, and healthy relationships all enhance the firm's social capital, namely, trust.

Food Safety

Food safety is an increasingly important public health issue [Aung, Chang 2014]. Considering the potential of increased transparency, efficiency, and accountability that blockchain-enabled traceability can provide, it is expected that there would be a significant reduction in healthcare costs and improvements in public perception of the food industry [Astill et al., 2019]. Wang et al. [2018] argue further that blockchain-based tracking enables food retailers and manufacturers to respond quickly to recalls and other safety issues, thus reducing the spread of foodborne illnesses. The use of blockchain

technology in the development of agri-food supply chain traceability can secure all data entries regarding food products and allow end-to-end traceability of any food item that reaches the consumer in a quick time [Keyser et al., 2019]. For example, Walmart and nine other firms (e.g., Nestle, Dole, Tyson Foods, Unilever, etc.) have established business partnerships to leverage blockchain technology in order to track and trace provenance so that they guarantee food safety and more responsiveness to food recalls. By increasing traceability, the source of any contaminations during foodborne crises can be quickly identified, resulting in a low number of affected people and causing less anxiety and panic for consumers. Therefore, the societal implications of blockchain are rooted in its ability to respond to the increasing demands of consumers for more food safety, to support the expansion of global food chains while at the same meeting the quality requirements and standards of food products.

Humanitarian Causes & Social Empowerment

Beyond the economic considerations, organizations are also recognizing the importance of social responsibilities and the need to sustain humanitarian supply chain operations. There is tremendous potential for blockchain technology to make humanitarian aids more productive and agile. During times of crises and disasters, the technology can be used to streamline the process of financial aids (e.g., medications) and eliminate delays caused by bureaucracy, paperwork, or political barriers [Al-Saqaf, Seidler 2017]. To encounter supply chain disasters and support humanitarian activities, blockchain technology creates an adequate information infrastructure that can manage all humanitarian eventualities at the field level, reduce the delivery time of required goods or services to the beneficiaries, and optimize the accuracy in terms of the quality and quantity of the most important items. For example, the application of smart contract-enabled blockchain can facilitate the transfer of remittances automatically and in a pre-programmed fashion [Al-Saqaf, Seidler 2017]. In their study, Wang et al. [2018] indicate that blockchain was piloted at the Azraq Refugee Camp for Syrian refugees. In critical emergencies, the technology can improve trust and promote more solidarity among people, helping to encourage mutual communications and to transparently track donations. More important is also the fact that blockchain enhances the transparency of supply chains, which is useful to counteract human rights abuses, child labor, and corruption. Blockchain also promotes more financial inclusion by supporting the integration of the unbanked population and the smallholding farmers and businesses [Kamble et al., 2019].

Environmental Sustainability

In many aspects, the adoption of blockchain technology can strengthen the ecological dimension of sustainability by reducing the environmental logistic footprint [Wong et al., 2019]. By leveraging blockchain and smart contracts, it would be possible to incorporate several environmental protection and control initiatives through the careful monitoring of production parameters such as energy consumption, raw materials processing, and emissions. In this regard, Ashley & Johnson [2018] note that blockchain can simplify the participation of stakeholders in low-carbon energy initiatives, facilitate the implementation of environmental protection programs, and increase consumer access to clean energy. Blockchain technology has the potential to unlock environmentally sustainable manufacturing. To specify, the use of the technology, according to Kouhizadeh et al. [2019], helps firms determine the materials and products that use non-renewable resources and remove them or invest in alternative renewable and green resources to benefit the circularity of energy.

Blockchain drives the transition towards the efficient and sustainable use of energy and the delivery of sustainable products. The transparency enabled by blockchain could be used to ensure that purportedly green products are environmentally friendly [Saberi et al., 2019]. Similarly, the engagement in the blockchain network emphasizes the commitment of businesses to several environmental issues such as climate change, pollution, and depletion of energy resources. Blockchain could foster sustainability by building close environmental cooperation with

supply chain partners and allow the firm to efficiently allocate resources based on precise scheduling and real-time data collection from the production processes. Unnecessary transportation processes can be avoided by the collaborative capabilities of blockchain. As such, supply chain partners would be able to effectively collaborate and coordinate several actions related to the shipment and transportation of products. According to Saberi et al. [2019], blockchain technology enables to trace the carbon footprint of products and gives organizations the opportunity to cooperate and trade their carbon assets efficiently in the green-asset markets. Through mapping the journey of the product across the supply chain, blockchain can precisely identify the carbon tax that should be charged on the company. As a result, blockchain technology can significantly contribute to the reduction of carbon emissions and air pollution through accurate and easily traceable greenhouse footprint analyses.

CONCLUSIONS

In this paper, we have comprehensively analyzed the possibilities for blockchain technology in supply chain sustainability. The aim of the study was to synthesize the current academic literature on the topic of blockchain and its relationships to sustainable supply chains by performing an SLR on selected publications. The findings of the review indicate that blockchain technology is a promising paradigm for sustaining supply chain operations. Academic research on blockchain technology is continuously progressing in terms of the number of studies published in leading journals over the last recent years. The possibilities of the technology for sustainability identified from the review and classified according to the TBL approach are a valuable contribution to the growing literature on the applications of blockchains for improving the economic performance of organizations, empowering the social aspects of supply chains, and sustaining the environmental practices among the stakeholders of the ecosystem. The majority of studies focused on the economic implications of blockchains on supply chains. The sustainable economic aspects of the technology identified in the reviewed literature are mostly the transformational potentials of blockchains and their capabilities to drive new disintermediated business models, higher operational efficiencies, cost advantages, and additional sources of value creation. The social empowerment of supply chains is found through the ability of blockchain to create trustful relationships among supply chain partners, increase food safety, support humanitarian logistics, and promote social equity. Moreover, firms attempting to move forward in their environmental policies and strategies can use blockchain to extend their efforts to improve their environmental practices across the supply chain, reduce the strain on energy and natural resources, and offer environmentally friendly products.

Although this paper, to the authors' best knowledge, is among the first attempts to synthesize the literature published in leading journals and contribute to the existing and increasing body of knowledge regarding the role of blockchain in leveraging sustainable supply chains, there remain several limitations. The selection of search databases might omit articles that might be relevant to the scope of this study. In addition, we have only focused on reviewing journal articles neglecting other equally important sources of knowledge such as conference papers and book chapters. Therefore, review studies in the future may consider synthesizing the different types of literature and rely on databases with extensive coverage such as Google Scholar. The findings of this study and the conclusions drawn here should be validated with other methodologies such as quantitative research and expert interviews.

ACKNOWLEDGMENTS AND FUNDING SOURCE DECLARATION

Abderahman Rejeb is grateful to Professor László Imre Komlósi, Dr. Katalin Czakó and Ms. Tihana Vasic for their valuable support. This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

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BLOCKCHAIN I ZRÓWNOWAŻONOŚĆ ŁAŃCUCHA DOSTAW

STRESZCZENIE. **Wstęp:** Zrównoważoność łańcucha dostaw leży w centrum zainteresowania większości organizacji. Głównym celem zrównoważonych łańcuchów dostaw jest stworzenie i utrzymanie długoterminowych ekonomicznych, socjalnych i ekologicznych zysków dla wszystkich akcjonariuszy w trakcie dostaw produktów i usług na rynek. Rozwój zrównoważony wydaje się być jednym z krytycznych czynników innowacyjności, ostatnio pojawiające się technologie blockchain mają istotny wpływ na zrównoważoność łańcuchów dostaw. Blockchain jest technologią, która może istotnie przyczynić się do rozwoju zrównoważonego łańcucha dostaw.
Metody: Pomimo rosnącego zainteresowania znaczenie blockchainu dla poprawy efektywności łańcuchów dostaw, istnieje bardzo mało badań I publikacji na ten temat. Dlatego ten celem tej pracy było wypełnienie istniejącej luki i stworzeni syntezy literatury naukowej na blockchain oraz jego relacji ze zrównoważonym łańcuchem dostaw. Prace badawcze były uzyskane z różnych baz publikacyjnych i poddane wnikliwej analizie. Możliwości wynikające ze stosowania blockchain zostały zidentyfikowane i sklasyfikowane w odniesienie do wymiaru ekonomicznego, socjalnego, środowiskowego oraz rozwoju zrównoważonego.
Wyniki i wnioski: Większość prac badawczych skupia się na ekonomicznych wpływach blockchainu na łańcuch dostaw. Zrównoważone ekonomiczne aspekty technologii zidentyfikowane w badanej literaturze głównie dotyczą możliwości transformacji przez blockchain oraz możliwości zmiany modelu biznesowego, zwiększenie efektywności operacyjne, korzyści kosztowych oraz dodatkowych źródeł finansowania. Zalety socjalne łańcuchów dostaw są widziane głównie w możliwości stworzenie zaufanych relacji między partnerami biznesowymi, wzroście bezpieczeństwa żywności, wspomożeniu logistyki humanitarnej oraz promocji równości socjalnej. Jednocześnie firmy starają się zmienić swoją politykę środowiskową używając blockchainu dla zwiększenie swoich praktyk ekologicznych w obrębie łańcuchów dostaw, redukcję zużycia energii i zasobów naturalnych oraz wprowadzenie produktów przyjaznych środowisku.

Słowa kluczowe: technologia blockchain, łańcuch dostaw, rozwój zrównoważony, ekonomiczny, socjalny, środowiskowy

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