The Role of Blockchain Technologies in Transforming Supply Chains Towards Social and Environmental Sustainability

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Keywords: blockchain technology, supply chains, social-environmental sustainability, digital transformation

Introduction

In today's economy, supply chain networks are the epitome of globalisation, connecting distant parts of the world in the extraction of raw materials, product design and development, manufacturing, and delivery – in short, the entire production process. Advances in the communication and information infrastructure have facilitated the spinning of intricate webs that build our supply chains (Min et al., 2019). This same infrastructure also enables access to and sharing of information about the origins of parts, the conditions of the involved workers, the environmental externalities and effects on local economies caused by the production of goods (OECD & KPMG, 2019). Reports of damaging practices and inhumane labour conditions in countries contributing to global supply chains raise public demands for disclosure of the networks (The Economist, 2020). At the moment, the European Union's (EU) legislative bodies discuss a directive to embed corporate due diligence in a legal framework (European Commission, 2022).

Central to due diligence reporting is the availability of trusted and traceable information. However, as supply chains grow increasingly complex and obscure, companies struggle to access information on the origin and circumstances of production at the intermediate steps (Härting et al., 2020), especially beyond the second-tier supplier (Free & Hecimovic, 2021; Ganeriwalla et al., 2018; Koberg & Longoni, 2019). As Hastig and Sodhi (2020, p. 15) phrase it "opacity in supply chains enables the exploitation of natural resources as well as human beings". For this purpose, a rising interest in blockchain-based technologies, a digital tool to store and share information, safeguarding the immutability and forgery-proof of data, can be noted (Francisco & Swanson, 2018; Gurtu & Johny, 2019; Min et al., 2019; Saberi et al., 2019).

The paper at hand contributes to the existing body of literature, approaching the intersection of blockchain technology, supply chains and sustainability, and is guided by the following question: *How can blockchain technology help to transform global supply chains and help contribute towards more environmentally and socially sustainable solutions?*

To address this question, the paper provides a descriptive overview of the state of the art of blockchain application in supply chains, giving special attention to sustainability effects. To identify current technological practices, both academic and grey literature sources were consulted. In a fast-paced environment the addition of grey literature provides insights into current application trends, although the potential underlying organisational agenda must be recognised (Juricek, 2009), as well as the lack of peer-reviewed scholarly rigour (Paez, 2017; Okoroma, 2012).

Two broad categories of relevance can be identified. Academically, the paper at hand adds to the fast-changing research area of blockchain technology applications. In this, constant updates are necessary to broaden the understanding, as rather young fields of research always require more breadth and depth. Societal relevance of this research is underlined by the public demand for supply chain transparency, and socially and environmentally sustainable production practices.

The paper is structured as follows. In a first section, the background and related works of research on supply chains, blockchain technology and the concept of sustainability are presented. Building on this, the discussion considers blockchain application in supply chains, and analyses the implications from a social and environmental sustainability perspective. This paper concludes with a short summary and an outlook for further investigation.

Core concepts

Supply chains as a source of vulnerability

A commonly accepted definition declares supply chains "as sets of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer" (Mentzer et al., 2001, p. 4). This definition entails four elements. Firstly, at the minimum, a supply chain involves a supplier, a focal organisation, and a customer. However, in most cases, reality is more complex and includes multiple suppliers, such as design and product development, manufacturing, transport, marketing and distribution, before a good arrives at its ultimate consumer (Rodrigues et al., 2021). The complexity of a supply chain is subject to variation depending on the type of industry and good. Secondly, both upstream and downstream activities are involved and highlight the bidirectional characteristic of a supply chain. Thirdly, multiple flow systems characterise the interaction and coordination of activities along a supply chain. Thus, a range of intermediate material, financial and informational transfers precede the successful delivery of a good or service. Fourthly, the consumer plays an active role in the development and manufacturing of a product according to demand. However, a holistic view of the entire supply chain goes beyond the final consumer to include waste management, recycling and upcycling options. This extension of the definition by Mentzer and colleagues (2001) then portrays the entire life cycle of a good and recognises the environmental strain of production and resource extraction.

The definition demonstrates the potentially complex characteristics of supply chain networks. This complexity is further promoted by larger market trends in the context of globalisation. On the one hand, customer expectations and demand patterns are subject to change. One important trend is the growing demand for mass customisation, as consumers call for individualised products (Min et al., 2019). Simultaneously, products are now often subject to 'planned obsolescence', meaning that they enjoy a shortened life cycle and are not made to last (Rivera & Lallmahomed, 2016; Christopher, 2000). Quick consumption and disposal are herein central to capitalism's success (cf. Martin et al., 2018). On the other hand, the supply side faces a stronger granularisation into single, highly specialised production steps. This development is facilitated by exploiting opportunities for economies of scale and varying regulatory frameworks with regards to labour, environmental and fiscal standards, and making use of advances in infrastructure and telecommunication (cf. Free & Hecimovic, 2021).

Considering their centrality in the globalised economy, supply chains face a range of problems, which severely complicate the work of their managers. These can be roughly broken down into two large categories. One considers internal problems within the supply chain in question, inhibiting in the very structure of the supply chain or the supporting network. The other considers external and environmental factors with an impact on the functioning and structure of supply chains. Table 1 summarises these problems as identified in the literature.

Table 1 Internal and external problems in supply chains

Internal problems	**Lack of upstream supplier visibility:** Companies rarely know the intermediate steps that precede their first-tier supplier; especially relevant in sectors where processed parts as used as input materials	Gardner et al., 2019 Härting et al., 2020 Free & Hecimovic, 2021 Gurzawska, 2020
	Difficulty to establish trust within network: Building trust requires time and effort, for which the fast-paced production is not set up; currently, trust is extended by costly third-party auditors	WEF, 2012 Batwa et al., 2021 Ganeriwalla et al., 2018 Casey & Wong, 2017 Min et al., 2019
	Insufficient information sharing: Companies are hesitant to share information due to protection of their competitive advantage; most information is shared in paper-format, which makes it difficult to analyse	Biswas & Sen, 2016 Hastig & Sodhi, 2020 Gurtu & Johny, 2019 Cabral et al., 2012 Gurzawska, 2020
	Bullwhip effect: Due to information asymmetry, intermediate suppliers often purchase or produce more than what is demanded; further downstream, the deviation from actual demand increases; inefficient and wasteful process	Christopher, 2000 Ghode et al., 2022 Biswas & Sen, 2016
	Liquidity gap: Due to time lag of transactions, companies may find themselves in the position where they delivered their product, but did not receive the corresponding payment, yet, which hinders their further operation	Jakob et al., 2018 Nelson et al., 2017
	Interoperability within supply chain network: Different tools and IT systems at various firms require legibility and translation to other systems	Cabral et al., 2012 Pawczuk, Nielsen et al., 2020
External problems	**Economic shocks:** Inflation, economic crises	Free & Hecimovic, 2021 Gurzawska, 2020
	Geopolitical shocks: Sanctions, (trade) wars, social disruptions, (sudden) limits to resource access	WEF, 2012 WFP, 2022 Free & Hecimovic, 2021
	Natural events: Disruption of routes, factories or raw material sources, (sudden) limits to resource availabilities	Ben-Daya et al., 2019 Auffhammer, 2018
	Changing demand patterns: Shift in consumer preference, change in current needs (potentially sudden, i.e., during the Covid-19 pandemic)	Min et al., 2019 Gurzawska, 2020 Kandil et al., 2020

This examination shows that supply chains pose a source of vulnerability. Therefore, resilience has become a central goal of supply chain managers. As such, regulatory changes impose requirements supply chain networks must follow. This is particularly difficult for supply chain regimes that stretch over the globe and must therefore respect legal frameworks in all affected regions. To fulfil this task, they must thus first gain an understanding of all intermediate steps and involved parties.

Basics of blockchain technology

As the name suggests, blockchain technology consists of individual digital items of data (blocks) that are linked together in a chronological chain. As a result, the entire blockchain generates a "database of records or a public ledger of all transactions or digital events that have been executed and shared among the participants" (Angelis & Ribeiro da Silva, 2019, p. 308). The individual blocks contain encrypted data, a timestamp, and a reference to the previous block on the chain (hash). The visible hash in the header, therefore, does not convey information of the contents, but a secure link to the related block. However, the stored information is only visible for users with the corresponding key (Francisco & Swanson, 2018). The immutability of added blocks underlines the secure character of the technology and the integrity of the stored data (Bender et al., 2019; Francisco & Swanson, 2018).

All network participants have access to a copy of the common blockchain, can view and, depending on the authorisation process, generate data blocks that are in turn validated by a consensus algorithm (Härting et al., 2020). This results in a peer-to-peer organisation without the need for a central authority (Batwa et al., 2021). Thus, among the network participants "[e]veryone can read and exchange information without a custom installation of software. This is valuable because it reduces integration needs exponentially" (MH&L, 2019, p. 4). Blockchain solutions are subsumed within the category of distributed ledger technologies (DLT), which suggest a decentralised framework of data storage. DLT forms the "umbrella term for technologies that store, distribute or exchange, publicly or privately, value between entities/users/peers based on shared transaction ledgers" (OECD & KPMG, 2019, p. 7).

Social and environmental sustainability in supply chains

To understand a potential transformation of supply chains towards sustainability, it is important to specify how this ambiguous term is understood. In the following, focus is set on social and environmental sustainability.

Social sustainability addresses the labour conditions in the intermediate production steps, such as the raw material extraction on farms or mines, in factories and assembly lines. Thus, adherence to minimum standards, with regards to wages, working hours and child protection, is considered a prerequisite to have a healthy and satisfied pool of workers, willing and able to continue to work in the future, contributing to societal well-being (Birkel & Müller, 2021). Therefore, social sustainability includes the safety of buildings and infrastructure, as well as the functioning of the health care sector. In short, everything that contributes to the continuation of the workforce and strengthens foundations of social and human capital. Additionally, social sustainability considers the physical integrity of consumers, and adherence of safety and health standards in final products. Social sustainability is evaluated on the basis of adherence to social and labour-related standards, as well as the production of safe consumer goods.

Environmental sustainability entails both the availability of natural resources and the effect of externalities on ecosystems (Saberi et al., 2019). Manufacturing requires the input of raw materials, some of which are non-renewable and depletable, others have a cycle of natural renewal, but this takes time. Subject to the environmentally-intense consumption behaviour and short product life cycles (Christopher, 2000), the speed of production often does not align with the speed of natural renewal of the resource. Moreover, all production processes have environmental externalities, which are additional effects that are not the main goal of a process. Thus, an environmental sustainability evaluation must consider both resource use and effects of externalities.

Despite these separate evaluations, there are considerable overlaps between both social and environmental sustainability concerns. As such, individuals and society are subsumed within the natural environment, and affected by it. For example, environmentally damaging externalities, such as contamination of groundwater is also detrimental to the safety of workers and the local population.

Discussion

Blockchain in supply chains

Upstream traceability of supply chains is particularly important to track provenance of products and facilitate recalling processes in case of shortcomings in the safety or quality of a good (Gambhir et al., 2018). Increased availability and use of information also allows to limit the scope of a recall, by tracing the quality impeachments directly to the affected products and consumers, without the need to recall the entire shipment. In this context the immutability of the stored data on the blockchain proves critical. Once data is added in the chain, it cannot be removed or forged with (Paliwal et al., 2020). This renders the shared information counterfeit-proof. Nevertheless, there still need to be mechanisms to ensure that the inputted data was correct in the first place. This is sometimes called the need for the "last mile connection" (Pai et al., 2018).

Being able to trace the product parts, the conditions of its sourcing and manufacturing, as well as the transportation routes, guarantees the authenticity of a product (Pai et al., 2018). This can have serious implications on customers' health, for example in the food or pharmaceutical sectors (Paliwal et al., 2020). Laaper et al. (2017, p. 6) find that "an estimated 10-30 percent of medicines sold in developing economies are counterfeits, leading to hundreds of thousands of deaths and billions of dollars in revenue losses globally". Thus, blockchain-based solutions could contribute to reduce the circulation of counterfeit goods. In other cases, this can have an effect on the ecological sourcing of goods, such as the authenticity of a wildly caught fish from a certain region (for example Provenance's Indonesian tuna pilot, cf. Leong et al., 2018). Additionally, high value luxury products carrying a certain prestige with the brand name can be authenticated (Bender et al., 2019; Saberi et al., 2019). This saves both time and resources and reduces potential reputational damage to the brand.

Intrinsically linked to the traceability aspect is the technology's inherent real-time transparency of transactions. Information can be shared easily with all network members without time lag and the blockchain network does not rely on a central authority to distribute information among the concerned stakeholders (Gurtu & Johny, 2019). Transparency is relevant for businesses, policymakers, and consumers alike (Bacchetta et al., 2021). Companies benefit from greater transparency to reduce information asymmetry and effectively disintermediate businesses benefiting from this asymmetry (Bender et al., 2019; Hughes et al., 2019; Roeck et al., 2020; van Engelenburg et al., 2018), and to better communicate the progress of the supply chain functions, inventory levels and demand data, but "keeping identities anonymized where possible" (Ghode et al., 2022, p. 100). This is necessary to protect potentially sensitive information of companies (Ganeriwalla et al., 2018).

For end consumers blockchain-enabled transparency assists to safeguard promises of a product's marketing, to increase product safety and to adhere to prevalent regulations. For policymakers, transparency is a means to assess the adherence to the governing rules, such as the forthcoming due diligence requirements. What is important to highlight here is that blockchain enables not just transparency, but continuous and real-time transparency, which improves the quality of the shared information (Gardner et al., 2019). Traceability and transparency thus constitute mechanisms to prevent fraudulent activities along the supply chain (Paliwal et al., 2020).

Additional opportunity related to the availability and timely sharing of information is mitigating the bullwhip effect (Helo & Hao, 2019). The bullwhip effect roots in information asymmetry that, due to greater distance to the final consumer, leads to deviation of supply from demand, and results in inefficiencies and wastes as more goods are produced than realistically sold. Enabled by blockchain-based solutions, and "by collaboration and sharing the end-customer demand with all parties in the chain, each party will be able to make a more realistic planning of the use of their capacity and the orders that will be produced" (van Engelenburg et al., 2018, p. 70). This enhances operational efficiency within the supply chain network (Gurtu & Johny, 2019; Min et al., 2019; Paliwal et al., 2020). The improved collaboration allows for lower inventories and less wastes, in line with the lean and green supply chain paradigms (Alicke et al., 2016). Moreover, "reduced information asymmetry could reduce the rent-seeking behaviour of any of the supply chain players" (Hastig & Sodhi, 2020, p. 17). However, it is necessary to note that businesses might not be willing to share the data, if it harms their competitive market position (van Engelenburg et al., 2018).

To exploit the full potential of blockchain applications, a combination with other (novel) technologies is suggested. Particularly tracking devices and Internet-of-Things (IoT) enhances the automated processes of smart contract execution, to drastically increase efficiency along the supply chain (Bacchetta et al., 2021; Gambhir et al., 2018; Saberi et al., 2019). Great potential also lies within artificial intelligence (AI) analyses of the vast amount of data collected (Min et al., 2019). As Ben-Daya et al. (2019, p. 4720) phrase it "What was lacking so far is not the availability of information but rather the technologies for collecting and processing big data and the lag between data collection and action". Thus, combining data collection of IoT tracking on a shared blockchain, and the data processing mechanisms of AI enable opportunities to adapt supply chain processes according to real circumstances of changing demand patterns (Gurzawska, 2020). These mechanisms can help identify potential weak links in the network, according to which management can redefine action plans. This improves operational efficiency and effectiveness of the supply chain (Gambhir et al., 2018; Laaper et al., 2017). Here it is crucial to highlight the potentials inhibiting in the instalment of self-executing smart contracts, which eliminate oversight authorities to approve standardised transactions and reduce accruing time lags (Saberi et al., 2019).

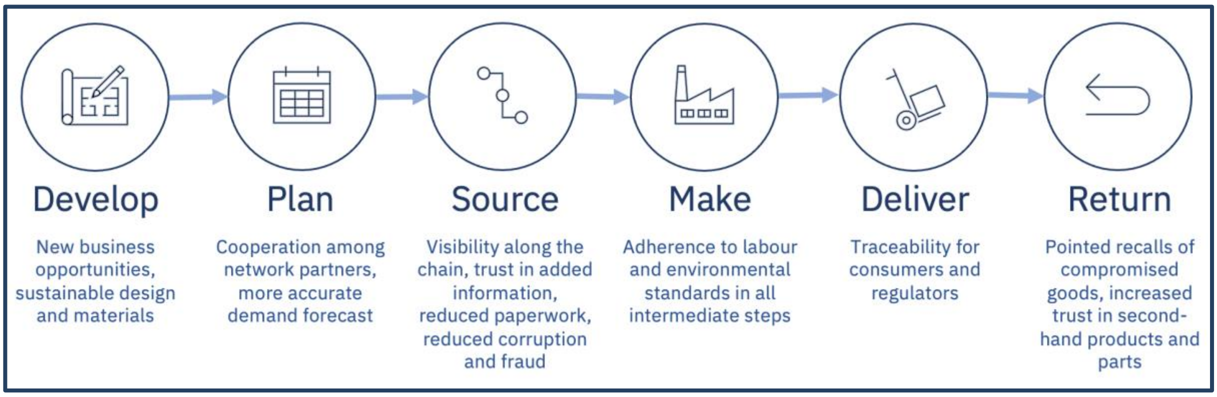

Figure 1: Blockchain's potential in supply chain management

(own illustration, based on Pai et al., 2018, p. 10)

To sum up, blockchain-based solutions have the ability to address inefficiencies in all steps of supply chain management, from the planning and development stages, through sourcing and manufacturing, to delivery and returns (see Figure 1 above). Critical is the availability and quality of the shared information, the ability to oversee supply chain processes in real-time and to share risks among members of the entire network.

Social Sustainability and Blockchain's Potential Contributions

Social sustainability encompasses actions and activities that affect human and community life. In the long term, social sustainability is concerned with the preservation of society across generations, ensuring liveability and livelihoods of communities. Thus, conditions to sustain life and to reproduce must be met. The social sustainability framework above, considers minimum requirements to meet basic needs and provide safe and just living conditions to safeguard social capital. In a supply chain context, social sustainability addresses two main subjects: workers along the chain and consumers of the final product.

In the functioning of a supply chain, many actors are involved. Especially in the early stages of the production cycle, such as the extraction of raw materials, initial processing and manufacturing, the adherence to working conditions according to international labour standards demonstrates deficiencies. By means of examples, investigative journalists have made public child labour involved in artisanal mining of metals, safety hazards of factories, and forced labour on farms (cf. Amnesty International, 2016; Burke, 2013; Chohan, 2018; The Economist, 2020). Although companies and countries are committed to the prevailing labour standards, these malpractices continue to exist. Blockchain technology-facilitated traceability can support the use of product inputs from certified and tested mines, factories, or farms, to support claims of social sustainability, and contribute to the fulfilment of SDG 8 on decent work, and SDG 3 on good health and wellbeing. This increases trustworthiness of responsibly sourced products and allows consumers to oversee practices involved in the production of the consumed good (Kühne, 2021). Moreover, this translates into increased accountability of companies (Chohan, 2018). Importantly, this "needs to be backed by an offline verification process that gives credibility to the information that is being shared" (European Parliament. Directorate General for Parliamentary Research Services., 2020, p. 49). Thus, certification and auditing continue to constitute necessary aspects of sustainability claims.

While blockchain technology can, in theory, track and trace all material inputs and intermediate production and distribution steps, complex supply chain networks face an operational problem. In order to impose a blockchain along all network participants, the instituting party first requires a complete, gapless overview starting at the first step. Yet, in reality, many supply chains are characterised by obscurity due to their complexity or mixing of material inputs. Hence, subsequent to melting metal ores it becomes nearly impossible to guarantee the origin of the raw material. Transparency and traceability of the supply chain should start at the earliest possible instance, i.e., the extraction of the natural resource, in order to truly safeguard claims of forced labour-free products. Hence, to enjoy the traceability of blockchain, traceability must already be available in the supply chain, which their managers currently lament. This is further complicated by the operationalisation of adding a digital token to a non-digital asset (Kshetri, 2022). It needs to be clarified, at which level of detail tokenisation takes place, and how tokens cope with changes of the material or part subject to later changes in the supply chain. For example, if a container of metal ores from a certified mine reaches the smelter, which processes multiple materials, the melted outcome cannot guarantee the same certification. Some industry experts have henceforth proposed a mass-balance approach, where minimum shares of certified inputs are guaranteed in mixes with non-certified resources, as is the case in fair trade cocoa (Batwa et al., 2021; Chohan, 2018).

Remaining on the production and supply side of social sustainability, blockchain technology entails opportunities for small suppliers in third countries, which would otherwise rarely have access to global markets (Jakob et al., 2018; Min et al., 2019). It has been discussed above that current supply chain structures have lengthy processes of receiving shipments which then trigger the payments of suppliers. This results in a liquidity gap, where suppliers advance their deliveries while not yet receiving financial compensation. Particularly small companies, with limited financial resources, struggle with this time lag. Blockchain-enabled smart contract execution can trigger immediate payments to suppliers, circumventing intermediaries and time lags (European Parliament. Directorate General for Parliamentary Research Services., 2020). Moreover, transparency and traceability of records allows companies to trace payments upstream to ensure that they arrive where intended. Thus, blockchain technology has the potential to reduce corruptibility in both directions. Yet, this also needs to consider the technological setup and necessary prerequisites to participate on the blockchain, usually the availability of a smartphone and stable internet connection (Bacchetta et al., 2021).

For consumers, social sustainability means that the product adheres to health standards and is safe to consume or use. In the above presentation, health considerations of food and pharmaceutical products have been mentioned. In these industry sectors, blockchain technology has found initial applications and exhibits great potential to safeguard the authenticity of the medicine, and the correct handling of the product in terms of temperature and transport (Leong et al., 2018). This reduces the need for costly recalls of faulty or damaged goods and the associated reparations claims and averts reputational damages of a brand. On a societal level, this increases consumer safety and reduces sickness-related costs. Further sectors and industries require considerations of social sustainability for consumers. For example, the supply chains forming the construction of a building must ensure that no potentially hazardous materials can be set free, such as asbestos. A permanent record of materials and tasks is herein important to facilitate later reparations and renovations. Digital solutions, possibly on a blockchain, can prove useful in this regard, also contributing to SDG 3 on health and wellbeing.

Environmental Sustainability Considerations of Blockchain Solutions

The second aspect of sustainability considers environmental effects of supply chain practices and exceeds consumption to include the entire life cycle of a product and its parts. A common argument against widespread blockchain adoption lays in the energy intensity of the technology (B. Biswas & Gupta, 2019; Cole et al., 2019; Hughes et al., 2019). The largest share of energy demand in blockchain technology originates in the

Proof-of-Work consensus mechanism (Paliwal et al., 2020), where computational 'work' allows the addition of new blocks to a chain. This is, thus, energy-intensive by design. However, newer generations of blockchain mostly rely on alternative consensus mechanisms, which allow the addition of new blocks without the corresponding computational effort (Sedlmeir et al., 2020).

Additional energy requirements are due to the inherent data redundancy, where each piece of (encrypted) information is shared and saved across all participants in the blockchain, the technology imposes a higher strain on data storage, thus energy, than non-blockchain centralised digital solutions (Schütte et al., 2017; Sedlmeir et al., 2020). Therefore, to consider blockchain-based solutions environmentally sustainable, enabled energy savings must offset energy requirements (Birkel & Müller, 2021). Energy savings can originate from "reduc[ing] the amount of paperwork and transport, including air-freight, or allow[ing] for more targeted recalls, leveraging many opportunities to reduce carbon emissions" (Sedlmeir et al., 2020, p. 607).

Under the assumption that knowledge and transparency about misdemeanour and damages is central to enable the mitigation of such unwanted effects, blockchain technology has the ability to "revolutionise life cycle assessments and carbon footprints" (Kühne, 2021, p. 92), therewith strengthening environmental sustainability. These assessments are crucial to evaluate the true costs of products and their preceding production processes. Moreover, they assist in the determination of damaging practices and provide more targeted mitigation. Indirectly, they can therefore assist in the protection of natural capital.

The examination of carbon footprints of products relies heavily on tracking of intermediate steps in the production process. Blockchain-enabled traceability and trust in the immutable, permanent records can hereby support the calculations with greater accuracy and transparency of the supply chain process, and inputs of i.e., recycled materials. Moreover, in line with the underpinnings of the IoT, information about the use and performance of products after consumption can support life cycle assessments in their entirety, thus, including (anonymised) data on the use of the product and re-use or recycling after its natural product cycle (Saberi et al., 2019). The availability of this information could significantly improve confidence in buying authentic, well-functioning second-hand products, such as machinery, technology, or luxury goods (Schwab, 2022). This also addresses the goals incorporated in SDG 12 on responsible consumption and production, and allows more targeted climate action (SDG 13) on mitigating adverse effects along the downstream supply chain.

In addition, information shared on the distributed ledger could contribute to a circular economy, where resources are used and re-used consciously (Saberi et al., 2019). This significantly limits wastes and reduces the need for raw materials. The circular economy is in stark contrast with the current economic setup, where enormous amounts of used goods end up in landfills, waste islands, or in waste incineration plants (cf. Brand & Wissen, 2011). In a circular economy, focus is set on reparation of products, reuse for different purposes or recycling of parts and materials. In this system, raw material extraction is limited, as is the consumption of new products. Yet, one must keep in mind that the extraction of recyclable parts and the reprocessing of used materials is also energy intensive. Blockchain technology could support the shift towards a circular economy by providing a permanent, immutable, and ideally complete record of the product cycle, including the use phase. In this, “valuable information could be gained for the downstream disposal phase or future product developments” (Kühne, 2021, p. 93).

To sum up, blockchain technology has the potential to assist in advancing environmental sustainability by providing transparent information on the circumstances of production, the negative externalities involved, and the raw or recycled material inputs. Yet, as with any digital technology solution, energy consumption with regards to data storage and dissemination needs to be considered as well.

Conclusion

This paper has set out to investigate the prevailing challenges supply chains continue to face, and the role blockchain technologies can play in addressing these issues. There are strong use cases where blockchain can seize additional benefits. However, the results also showed the limitations of the technology in some cases.

As characteristics such as complexity, length, industry, and geographic circumstances influence the need to reform current supply chain practices, it can be expected that the corresponding digital technology solution will vary. Additional research can therefore consider specific products and the respective characteristics and expectations of their supply chains, rather than supply chain management as a general field. Additionally, more research focused on the implementation phase of blockchain applications is needed. Despite the vast theoretical and technical interest in blockchain technology, there is still limited availability of applied cases. Research on initial applications could advance solutions and address the specific challenges that arise during implementation, to better understand the learning process involved in blockchain adoption.

Bibliography:

Amnesty International. (2016). *Democratic Republic of Congo: 'This is what we die for': Human rights abuses in the DRC power the global trade in Cobalt*. https://www.amnesty.org/en/documents/afr62/3183/2016/en/

Angelis, J., & Ribeiro da Silva, E. (2019). Blockchain adoption: A value driver perspective. *Business Horizons*, *62*(3), 307–314. https://doi.org/10.1016/j.bushor.2018.12.001

Auffhammer, M. (2018). Quantifying Economic Damages from Climate Change. *Journal of Economic Perspectives*, *32*(4), 33–52. https://doi.org/10.1257/jep.32.4.33

Bacchetta, A. v. B., Krümpel, V., & Cullen, E. (2021). Transparency with Blockchain and Physical Tracking Technologies: Enabling Traceability in Raw Material Supply Chains. *International Conference on Raw Materials and Circular Economy*, 1. https://doi.org/10.3390/materproc2021005001

Batwa, A., Norrman, A., & Arvidsson, A. (2021). *How Blockchain interrelates with trust in the supply chain context: Insights from tracing sustainability in the metal industry*. *31*, 329–351.

Ben-Daya, M., Hassini, E., & Bahroun, Z. (2019). Internet of things and supply chain management: A literature review. *International Journal of Production Research*, *57*(15–16), 4719–4742. https://doi.org/10.1080/00207543.2017.1402140

Bender, J. P., Burchardi, K., & Shepherd, N. (2019). *Capturing the Value of Blockchain*. The Boston Consulting Group.

Birkel, H., & Müller, J. M. (2021). Potentials of industry 4.0 for supply chain management within the triple bottom line of sustainability – A systematic literature review. *Journal of Cleaner Production*, *289*, 125612. https://doi.org/10.1016/j.jclepro.2020.125612

Biswas, B., & Gupta, R. (2019). Analysis of barriers to implement blockchain in industry and service sectors. *Computers & Industrial Engineering*, *136*, 225–241. https://doi.org/10.1016/j.cie.2019.07.005

Biswas, S., & Sen, J. (2016). A Proposed Architecture for Big Data Driven Supply Chain Analytics. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.2795906

Brand, U., Wissen, M. (2011). Die Regulation der ökologischen Krise. *Österreichische Zeitschrift für Soziologie*, 36, 12-34. https://doi.org/10.1007/s11614-011-0031-1

Cabral, I., Grilo, A., & Cruz-Machado, V. (2012). A decision-making model for Lean, Agile, Resilient and Green supply chain management. *International Journal of Production Research*, *50*(17), 4830–4845. https://doi.org/10.1080/00207543.2012.657970

Casey, M. J., & Wong, P. (2017, March 13). Global Supply Chains Are About to Get Better, Thanks to Blockchain. *Harvard Business Review*. https://hbr.org/2017/03/global-supply-chains-are-about-to-get-better-thanks-to-blockchain

Chohan, U. (2018). Blockchain and the Extractive Industries: Cobalt Case Study. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3138271

Christopher, M. (2000). The Agile Supply Chain. *Industrial Marketing Management*, *29*(1), 37–44. https://doi.org/10.1016/S0019-8501(99)00110-8

Cole, R., Stevenson, M., & Aitken, J. (2019). Blockchain technology: Implications for operations and supply chain management. *Supply Chain Management*, *24*(4), 469–483. https://doi.org/10.1108/SCM-09-2018-0309

European Commission. (2022). *Proposal for a Directive of the European Parliament and of the Council on Corporate Sustainability Due Diligence and amending Directive (EU) 2019/1937*. COM/2022/71 final.

European Parliament. Directorate General for Parliamentary Research Services. (2020). *Blockchain for supply chains and international trade*. Publications Office. https://data.europa.eu/doi/10.2861/957600

Francisco, K., & Swanson, D. (2018). The Supply Chain Has No Clothes: Technology Adoption of Blockchain for Supply Chain Transparency. *Logistics*, *2*(1), 2. https://doi.org/10.3390/logistics2010002

Free, C., & Hecimovic, A. (2021). Global supply chains after COVID-19: The end of the road for neoliberal globalisation? *Accounting, Auditing & Accountability Journal*, *34*(1), 58–84. https://doi.org/10.1108/AAAJ-06-2020-4634

Gambhir, P., Bevan, P., & Davenport, F. (2018). *Unlocking supply chain benefits through blockchain technology* (Digital Disruption). KPMG LLP. https://assets.kpmg/content/dam/kpmg/ca/pdf/2018/09/digital-disruption-blockchain.pdf

Ganeriwalla, A., Casey, M., Shrikrishna, P., Bender, J. P., & Gstettner, S. (2018). *Does your supply chain need a blockchain?* (pp. 1–6). The Boston Consulting Group & MIT Media Lab.

Gardner, T. A., Benzie, M., Börner, J., Dawkins, E., Fick, S., Garrett, R., Godar, J., Grimard, A., Lake, S., Larsen, R. K., Mardas, N., McDermott, C. L., Meyfroidt, P., Osbeck, M., Persson, M., Sembres, T., Suavet, C., Strassburg, B., Trevisan, A., … Wolvekamp, P. (2019). Transparency and sustainability in global commodity s upply chains. *World Development*, *121*, 163–177. https://doi.org/10.1016/j.worlddev.2018.05.025

Ghode, D. J., Yadav, V., Jain, R., & Soni, G. (2022). Lassoing the bullwhip effect by applying blockchain to supply chains. *Journal of Global Operations and Strategic Sourcing*, *15*(1), 96–114. https://doi.org/10.1108/JGOSS-06-2021-0045

Gurtu, A., & Johny, J. (2019). Potential of blockchain technology in supply chain management: A literature review. *International Journal of Physical Distribution & Logistics Management*, *49*(9), 881–900. https://doi.org/10.1108/IJPDLM-11-2018-0371

Gurzawska, A. (2020). Towards Responsible and Sustainable Supply Chains – Innovation, Multi-stakeholder Approach and Governance. *Philosophy of Management*, *19*(3), 267–295. https://doi.org/10.1007/s40926-019-00114-z

Härting, R.-C., Sprengel, A., Wottle, K., & Rettenmaier, J. (2020). Potentials of Blockchain Technologies in Supply Chain Management—A Conceptual Model. *Procedia Computer Science*, *176*, 1950–1959. https://doi.org/10.1016/j.procs.2020.09.334

Hastig, G. M., & Sodhi, M. S. (2020). Blockchain for Supply Chain Traceability: Business Requirements and Critical Success Factors. *Production and Operations Management*, *29*(4), 935–954. https://doi.org/10.1111/poms.13147

Helo, P., & Hao, Y. (2019). Blockchains in operations and supply chains: A model and reference implementation. *Computers & Industrial Engineering*, *136*, 242–251. https://doi.org/10.1016/j.cie.2019.07.023

Hughes, L., Dwivedi, Y. K., Misra, S. K., Rana, N. P., Raghavan, V., & Akella, V. (2019). Blockchain research, practice and policy: Applications, benefits, limitations, emerging research themes and research agenda. *International Journal of Information Management*, *49*, 114–129. https://doi.org/10.1016/j.ijinfomgt.2019.02.005

Jakob, S., Schulte, A. T., Sparer, D., Koller, R., & Henke, M. (2018). *Blockchain und Smart Contracts: Effiziente und sichere Wertschöpfungsnetzwerke* [White Paper]. Fraunhofer IML.

Juricek, J. E. (2009). Access to Grey Literature in Business: An Exploration of Commercial White Papers. *Journal of Business & Finance Librarianship*, *14*(4), 318–332. https://doi.org/10.1080/08963560802365388

Kandil, N., Battaïa, O., & Hammami, R. (2020). Globalisation vs. Slowbalisation: A literature review of analytical models for sourcing decisions in supply chain management. *Annual Reviews in Control*, *49*, 277–287. https://doi.org/10.1016/j.arcontrol.2020.04.004

Koberg, E., & Longoni, A. (2019). A systematic review of sustainable supply chain management in global supply chains. *Journal of Cleaner Production*, *207*, 1084–1098. https://doi.org/10.1016/j.jclepro.2018.10.033

Kshetri, N. (2022). Blockchain systems and ethical sourcing in the mineral and metal industry: A multiple case study. *The International Journal of Logistics Management*, *33*(1), 1–27. https://doi.org/10.1108/IJLM-02-2021-0108

Kühne, C. (2021). *Blockchain Technology for Industrial Production and the Digital Circular Economy* [Informational Brochure]. Think Tank for Industrial Resource Strategies at KIT.

Laaper, S., Yeh, W., Fitzgerald, J., Basir, M., & Quasney, E. (2017). *Using blockchain to drive supply chain innovation*. Deloitte Development LLC.

Leong, C., Viskin, T., & Stewart, R. (2018). *Tracing the Supply Chain: How blockchain can enable traceability in the food industry* (No. 181091). Accenture.

Martin, R., Tyler, P., Storper, M., Evenhuis, E., & Glasmeier, A. (2018). Globalisation at a critical conjuncture? *Cambridge Journal of Regions, Economy and Society*, *11*(1), 3–16. https://doi.org/10.1093/cjres/rsy002

Mentzer, J. T., DeWitt, W., Keebler, J. S., Min, S., Nix, N. W., Smith, C. D., & Zacharia, Z. G. (2001). Defining Supply Chain Management. *Journal of Business Logistics*, *22*(2), 1–25. https://doi.org/10.1002/j.2158-1592.2001.tb00001.x

MH&L (Ed.). (2019). *Blockchain in the supply chain*. MH&L Library. https://www.mhlnews.com/white-papers/whitepaper/22055564/blockchain-in-the-supply-chain

Min, S., Zacharia, Z. G., & Smith, C. D. (2019). Defining Supply Chain Management: In the Past, Present, and Future. *Journal of Business Logistics*, *40*(1), 44–55. https://doi.org/10.1111/jbl.12201

Nelson, J. S., Henderson, D., Jones, G., Roon, M., Zargham, M., Bulkin, A., Brukhman, J., & Rowe, K. (2017). *A blockchain-based protocol stack for global commerce and supply chains* [White Paper]. Sweetbridge.

OECD, & KPMG. (2019). *Is there a role for blockchain in responsible supply chains?* (Responsible Business Conduct). OECD. https://mneguidelines.oecd.org/Is-there-a-role-for-blockchain-in-responsible-supply-chains.pdf

Okoroma, F. N. (2012). *Grey Literature Management at SIUE Library, USA: A Macarthur Foundation Grant Research Project*. *706*. https://digitalcommons.unl.edu/libphilprac/706

Paez, A. (2017). Gray literature: An important resource in systematic reviews: PAEZ. *Journal of Evidence-Based Medicine*, *10*(3), 233–240. https://doi.org/10.1111/jebm.12266

Pai, S., Sevilla, M., Buvat, J., Schneider-Maul, R., Lise, O., Calvayrac, A., Karanam, T., & Puttur, R. (2018). *Does blockchain hold the key to a new age of supply chain transparency and trust?* Capgemini Research Institute.

Paliwal, V., Chandra, S., & Sharma, S. (2020). Blockchain Technology for Sustainable Supply Chain Management: A Systematic Literature Review and a Classification Framework. *Sustainability*, *12*(18), 7638. https://doi.org/10.3390/su12187638

Pawczuk, L., Nielsen, J. M., HangSin, P. K., & Hewett, N. (2020). *Inclusive Deployment of Blockchain for Supply Chain: Part 6—A Framework for Blockchain Interoperability* [White Paper]. World Economic Forum & Deloitte.

Rivera, J. L., & Lallmahomed, A. (2016). Environmental implications of planned obsolescence and product lifetime: A literature review. *International Journal of Sustainable Engineering*, *9*(2), 119–129. https://doi.org/10.1080/19397038.2015.1099757

Rodrigues, E. B., Lourenzani, W. L., Satolo, E. G., Braga Júnior, S. S., Anholon, R., & Rampasso, I. S. (2021). Blockchain in supply chain management: A grounded theory-based analysis. *Kybernetes*. https://doi.org/10.1108/K-05-2021-0384

Roeck, D., Sternberg, H., & Hofmann, E. (2020). Distributed ledger technology in supply chains: A transaction cost perspective. *International Journal of Production Research*, *58*(7), 2124–2141. https://doi.org/10.1080/00207543.2019.1657247

Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. *International Journal of Production Research*, *57*(7), 2117–2135. https://doi.org/10.1080/00207543.2018.1533261

Schütte, J., Fridgen, G., Prinz, W., Rose, T., Urbach, N., Hoeren, T., Guggenberger, N., Welzel, C., Holly, S., Schulte, A. T., Sprenger, P., Schwede, C., Weimert, B., Otto, B., Dalheimer, M., Wenzel, M., Kreutzer, M., Fritz, M., Leiner, U., & Nouak, A. (2017). *Blockchain und Smart Contracts: Technologien, Forschungsfragen und Anwendungen*. Fraunhofer-Gesellschaft.

Schwab, J. (2022). *Blockchain in the manufacturing industry—Key use cases* [FSBC Working Paper].

Sedlmeir, J., Buhl, H. U., Fridgen, G., & Keller, R. (2020). The Energy Consumption of Blockchain Technology: Beyond Myth. *Business & Information Systems Engineering*, *62*(6), 599–608. https://doi.org/10.1007/s12599-020-00656-x

The Economist. (2020, August 20). Forced labour in China presents dilemmas for fashion brands. *The Economist Group Limited*. https://www.economist.com/business/2020/08/20/forced-labour-in-china-presents-dilemmas-for-fashion-brands

van Engelenburg, S., Janssen, M., & Klievink, B. (2018). A Blockchain Architecture for Reducing the Bullwhip Effect. In B. Shishkov (Ed.), *Business Modeling and Software Design* (Vol. 319, pp. 69–82). Springer International Publishing. https://doi.org/10.1007/978-3-319-94214-8_5

WEF (Ed.). (2012). *New Models for Addressing Supply Chain and Transport Risk*. World Economic Forum. https://www3.weforum.org/docs/WEF_SCT_RRN_NewModelsAddressingSupplyChainTransportRisk_IndustryAgenda_2012.pdf

World Food Programme. (2022). *Projected increase in acute food insecurity due to war in Ukraine*. World Food Programme. https://www.wfp.org/publications/projected-increase-acute-food-insecurity-due-war-ukraine